Prospecting the Physicochemical Past

Three dimensional geochemical investigation into the use of space in Viking Age sites in southern Norway using portable XRF

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Abbreviations and definitions

Within this research, abbreviations are occasionally used for frequently repeated words and phrases, which are listed below. The abbreviations for elements are used throughout, and the reader is guided to the periodic table provided in chapter 3 (figure 3.2).

F.A.O: Food and Agriculture Organization for the United Nations.

GOREV: Gokstad Revitalised Project.

GPR: Ground penetrating radar

GPS: Global positioning system

ICP-MS/OES/AES: Inductively coupled plasma mass spectroscopy/optical emission spectroscopy/atomic emission spectroscopy.

Kilden: NIBIO's online database for soil and geomorphological information in Norway.

LiDAR: Light detection and ranging

LOD: Limits of detection.

LOI: loss on ignition

m a.s.l.: metres above sea level

MCH: Museum of Cultural History, part of the University of Oslo.

NIBIO: Norwegian Institute for Bio-economy, formerly known as Skog og Landskap (Norwegian Forestry and Landscape Institute).

PCA: Principal Component Analysis

PPM/ppm: parts per million

pXRF: portable X-ray fluorescence.

RMP: Royal Manor Project.

SD: standard deviation

SRM: Standard Reference Material.

UiO: University of Oslo

WRB: World reference base, a soil classification system used in Norway, and increasingly used internationally, devised by the F.A.O.

List of publications directly resulting from this research

CANNELL, R. J. S., WELHAM, K. & CHEETHAM, P. *in press*. Geochemical analysis using portable X-Ray Fluorescence at Avaldsnes. *In:* SKRE, D. (ed.) *Avaldsnes: A Sea-King's Seat at the Island of Kormt.* Berlin, New York: De Gruyter.

Conferences

Presentations relating to this research were given at the following conferences:

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Abstract

This research centres on the use of portable X-Ray fluorescence (XRF) as a tool for archaeological geochemistry. The instrument was used as part of varied contextual, vertical and horizontal sampling strategies on three Viking Age sites in southern Norway in order to investigate archaeological geochemistry as a method of better understanding spatial and temporal variation in occupation deposits. Archaeological deposits are often truncated, redeposited or otherwise disturbed, which limits the application of more established methods for geochemical sampling by means of a static, horizontal grid. Instead, flexible sampling strategies were developed that included coring as a prospection method combined with high-resolution GPR data. The combination of portable XRF and coring, both within excavation contexts and as prospection, allowed high resolution analysis directly onto the core. The minimal sample preparation allowed a greater data volume to be gathered, and the data provided a geochemical chronological sequence for the deposits. Thus, both spatial and temporal planes were accessible where the archaeological material was suitable.

The validity of this method, as well as the use of portable XRF for geochemical analysis in archaeology, was assessed critically throughout this research. The results suggest that there is a loss of accuracy and resolution by using portable XRF on unprepared samples; here this is deemed offset by the benefits. The method of coring, and thus preserving the stratigraphy for sampling and analysis, allows not only the continuity and change within the archaeological deposits to be assessed, but also details soil processes to a greater extent than established, extraction based methods such as ICP-MS. XRF analyses the whole sample, and whilst this can mute certain trends in the anthropological inputs, it means that interpretation can include the impact soil processes have had on these inputs by stratigraphic phase. Moreover, on sites where preservation is limited, deposits that would previously be disregarded for geochemistry can be used to form some understanding of past occupation from the little that remains.

This approach is developed though the course of the three case studies, and the data statistically treated using principal component analysis, and interpreted from a geoarchaeological perspective. The research also attempts to embrace theoretical perspectives that enhance insight into past social and cultural practices. As archaeological geochemistry aims to understand space, it is also fundamental to understand the social meaning of space within the contexts investigated.

Personal Introduction and Acknowledgements

I distinctly remember sitting in the grey, breeze block office in the warren-like Archaeology Department of Bradford University. The view out of the window cast the eye directly onto spindly, wet tree trunks and bare shrubs, all appearing ready to give up and turn to decay in the low winter light. I was in the final throws of completing my Master's dissertation, and across the cluttered desk sat Carl Heron, my then supervisor. He was patient, candid and supportive, supplying praise and academic criticism to encourage and improve the over-lengthy project I had designed. This will sound familiar to my more recent supervisors. I clearly recall expressing that I had enjoyed creating and researching the project so much, I didn't see why I should stop. He replied something along the lines of, 'you mean do a Ph.D.?' He spoke neutrally, without positive or negative connotation, and the utterance of the letters Ph.D. slowly cemented into my head and refused to relent.

Later, at home, I had suggested this to my father, who promptly said something like, 'haven't you got enough qualifications now to get a proper job?' Of course, within a couple of days he had arranged for a friend, who worked at Leeds University, to contact me about how Ph.D. funding worked.

It was also Carl Heron, in a passing comment eighteen months previously during a seminar on archaeological soil chemistry, who inspired my choice of subject area. Whilst discussing an early but key paper in multi-elemental approaches, he had suggested the method had too many problems to be successful, or indeed be a good idea. In my stubbornness, it could be that I either wished to prove him wrong, which is entirely plausible in my naivety, or that I wanted to know why he thought that. I think it was both. It was not my first direct experience of the method. Some years earlier, in 2004, after months of scrubbing hotel rooms, I finally got my first job in Norwegian archaeology. I had moved from the United Kingdom to Norway in autumn 2003, leaving my employment in field archaeology, something I had willed to define me, all year round, since graduating in Archaeology from York University in 2001. Many things struck me as strange in Norwegian field archaeology, and to be honest still do, although you learn to accept the system and its apparent and real logic as you go. What was clear, though, was that they spent their resources very differently, they had different priorities in response to the challenges and conditions. The project leader I worked with, Vibeke Vandrup Martens, introduced me to the idea of doing multi-elemental analysis on an archaeological site. The introduction was practical, i.e. we spend days digging little holes in massive grids over areas of the site where evidence suggested Iron Age houses had been. Vibeke did, and has on many occasions since, shared results and discussed opinions on the subject. With hindsight, I would say this gave me the idea that such a method could be practically done in Norwegian archaeology, but at the time I did not realise the facets and complexities involved in the technique. That realisation occurred in Bradford during my masters (2008-2010). It fascinated me, mainly because, despite its mosaic and almost mysterious complexities, I always thought it was a diamond in the rough. Imagine the potential to directly measure what had happened somewhere, a method that took archaeology beyond objects, especially for a country like Norway where revealing objects are sadly rare. I also found it egalitarian. Objects of status, and indeed the remains of structures of status, dominate. They probably always have done, but to understand the past we need to comprehend every segment of life; mental, cultural, physical, and practical. Whilst archaeological geochemistry cannot evidence or answer all of these facets of the past, I have always been intrigued by the potential, if only the complexities of medium and method were better understood….

I left the path for a while after my Masters, although in the three years hunting for PhD funding, there was never any intention to focus on anything but archaeological geochemistry. By immense fortune, I became involved in projects that provided room to research soils in archaeological contexts, via coring. These projects introduced me to a host of great minded archaeologists with varied interests and specialisations, and I am indebted to each and every one. To all the people involved in the Avaldsnes Royal Manor Project and Gokstad Revitalised, I owe heartfelt thanks.

The project leader for the Avaldsnes Project, Prof. Dagfinn Skre, together with Mari A. Østmo and Egil Lindhart Bauer, not only provided some of the equipment, but let me take an extraordinary 364 cores on the site over two years. Many of the fieldwork staff suffered sore muscles and immense frustration with me and equipment over the two field campaigns, but I will say now every core taught me something invaluable about soil process, site formation, sampling and the archaeology. Thank you, all of you. Similar suffering was later inflicted on the Gokstad Revitalised staff.

Another moment deeply imprinted upon me came on hearing that Prof. Jan Bill was going to use coring in his project, heard via the dense, intertwined and rapid archaeological grapevine. Whilst sitting in the rotten-cabbage scented house the Avaldsnes Project used as a field office, Anja Nordvik Sætre and others encouraged me to send him an email. I was still just as excited and full of trepidation when, a few weeks later, I was let loose on the monumental Gokstad mound with a coring rig, thankfully under the expert guidance and acumen of Richard Macphail and Jan Bill, and with Marianne Hem Eriksen providing much needed wisdom and practical support. Once again, through the long, intense days, I could feel my brain expanding exponentially with transferred and observed knowledge with every new core. The project continued in subsequent years, introducing me to Johan Linderholm, Chrisitan L. Rødsrud, Christer Tonning, and many other talented archaeologists, as well the geophysicists from the Ludwig Boltzmann Institute (LBI) at the University of Vienna, whom all helped and inspired. I would like to add a special thanks to Petra Schneidhofer, also from the LBI project. Working with Petra at Gokstad was like finally finding one of your own in a vast crowd; a fellow geoarchaeologist who had as many questions in their head as I did, and was looking for answers by coring, and never tired of discussing everything they saw. Thank you, Petra.

Weaving in and out of personal and professional situations were many people who have offered critical discussion of academic points and life in general, and friendship over (sometimes plentiful) wine or alternatively, a muddy field. These include Vegard Vike, Arne Anderson Stamnes, Daniella Vos, Emily Norton and Sarah Franklin. Iain Green kindly offered time and advice on soil chemistry, as has Richard Macphail on many occasions, which is warmly appreciated. Jessica L. McGraw, thank you for your unreserved friendship and intrinsic enthusiasm for archaeology, and always being open to everything life brings. And for inviting me to take cores at your rescue excavation at Kaupangveien (led by the Museum of Cultural History, University of Oslo), it could not have been more fortuitous in timing and location.

After a lengthy email exchange with Paul Cheetham and a formal application, on a hot (for northern Europe) July day I travelled from Avaldsnes and the remote island of Karmøy to Bournemouth and back in a day for an interview. On my return journey, I was in Gatwick, talking to my patient partner Lars Gustavsen over the phone, when I found out I had been offered the PhD position. This was not unproblematic, nothing ever is. Despite the thrill, it was a wage cut and a move to another, albeit very familiar, country. When I was young, my mother had a fridge magnet. It wasn't on the fridge, but at the bottom of the stairs to the cellar kitchen, so I passed it several times a day. On it, a silhouetted bird flew against a stormy sunset, beside these words; 'if you love something, set it free, if it comes back to you, it is yours. If it doesn't, it never was.' It was the very typical trite you find on a fridge magnet, and I always balked at the thought you could possess a person. But you can, and Lars, you do.

So it was to another university, two excellent supervisors, Paul Cheetham and Kate Welham and many colleagues, and then further complications. I owe a great debt of gratitude to the University of Oslo, who after I returned from maternity leave, allowed me to sit in their department to finish my PhD. I was warmly welcomed, and have benefited daily from the fraternity and immense, diverse intellect I found there. Everyone has put up with my questions, offered books and ideas, especially Julie Lund. Thank you all, and to Unn Pedersen for generously providing an early copy of her publication. Marianne Hem Eriksen, you will see your inspiration (and the extensive borrowing of books) in this, thank you, for your faith in me, your friendship and support. Similar sentiments are owed to Jan Bill, who became a third supervisor to this project, and has always gone way beyond obligation and duty to provide academic support and practical, insightful and honest advice. Thank you, to Kate Welham, Paul Cheetham and Jan Bill, for having faith in me, putting me up and putting up with me, and seeing me through every stumble.

No one, of course, is ever an island. I have an extensive, diverse and fantastic family, who are always behind and with me, and on many occasions ahead of me too. To my family in Norway and abroad, thank you. There are many that have helped me along the way, family, friends, colleagues, too many to mention here, but thank you.

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1. Introduction

1.1 Chapter Introduction

Archaeology is never whole. The record of the past is fragmentary, and increasingly at risk of becoming ever more so due to modern land use (Papworth et al., 2016). The informal archaeological mandate, if you will, is to adapt to and learn from what we have; maximising and developing the tools available to us in order to understand the evidence of the past. Archaeologists are becoming increasingly adept at adapting technological innovations to suit its purpose, and the advances in near surface geophysics and archaeological geochemistry are no exception. Through developing new means of increasing the information we can retrieve from even heavily truncated or damaged sites, and becoming better able to detect archaeology beneath the ground, we are able to retrieve a more nuanced and complete picture from what we have.

Scales in archaeology are changing with technological innovation. Whole, interconnected, multi-phase landscapes can now be investigated via LiDAR, satellite imagery and geophysical prospection (Bennett, 2011, Bennett et al., 2012, Gaffney et al., 2012, Lasaponara and Masini, 2012, Schneidhofer et al., 2016). On the other extreme, we have micromorphology coupled with µXRF detailing micro contexts (Wouters et al., 2017), and DNA and isotope analysis on human remains diverging genetic history (e.g. Hagelberg, 2006, Naumann et al., 2014, Beaumont and Montgomery, 2016). Detail is ever increasing, at ever increasing speed via developments that allow impressive understanding of the fabric of the past. However, archaeology is not renowned for its wealth. In the commercial/rescue sector, where the majority of practical archaeology occurs, time is often precious as well. In this context, it is understandable that one instrument, has been eagerly seized as a rapid, affordable tool for multi-elemental analysis. The instrument is portable XRF (hereafter pXRF). It is this instrument that forms the connecting path throughout this research into archaeological geochemistry.

Scepticism toward pXRF from the established archaeological science academic community met the wave of enthusiasm with a counter-force, levelling just academic criticism concerning its lack of precision, accuracy and comparability to more established instrumental methods, and the fact that user ease may cause poor quality science (Heginbotham et al., 2011, Goodale et al., 2012, Frahm and Doonan, 2013, Speakman and Shackley, 2013). Just the criticism may have been, however, the perspective of the established versus the new is often contentious (e.g. in geophysics, Stamnes and Gustavsen, 2014). It also assumes that every possible application of the new technology has already been tested, which is certainly not the case. Researchers need to judge suitability for themselves on their own terms, in response to their own research needs. Time, technology and evidence are the best forms of persuasion. Many archaeologists have since begun to evaluate the potentials and weaknesses of the instrument within various branches of archaeological sciences. Particularly in lithic sourcing, pXRF has proven to deserve the title of revolutionary (e.g. Frahm et al., 2014). What is exceptional about the instrument is its flexibility. It cannot compare to established methods for multi-elemental analysis in terms of precision (see chapters 2 and 4) but it is transportable, adaptable and non-destructive. Some would also claim it to be a viable alternative to more established multi-elemental instruments such as ICP (Schneider et al., 2015).

Research relating the use of pXRF to soils in archaeology is sparse. This research aims to partly fill this void, and to address wider questions in archaeological geochemistry in combination with other methods, including coring and geophysical data. Archaeological geochemistry measures major and minor inorganic trace elements in the soil that can be informative of past human activity. In simple terms, it is an attempt to measure what happened somewhere by the traces the activity left in the soil from deliberate or accidental discard. The question, 'why is it important to attempt to find out how past settlements were structured and developed, from the elemental traces different activities leave?' can be posed. If archaeological geochemistry can shed light on past settlement, what does that mean, and how can it be connected to greater archaeological questions? More crudely, who cares if they used the right side of their house for antler working, what does that reveal about past peoples? It could be argued that the method is a means to itself, and the data created and interpreted is sufficient. However, without acknowledging the wider archaeological relevance and implications to past societies, how can the data be correctly interpreted? For example; within a small, heavily truncated building, geochemical analysis finds a pattern, which implies middening took place in the small area on the left side of the house as you entered. Stopping at the point of saying the rubbish was deposited on the left side of the house, is essentially useless. It answers no questions. Now, we could elaborate and say that the rubbish was composed of predominantly burnt bone, perhaps revealed from high calcium and strontium values, from which some economic implications may be imparted. However it still does not explain why the rubbish was on the left side of the house, or why that is important. Perhaps it was the aspect of the house, the drainage, access, or perhaps it was because of a local superstition, of local cultural norms, or none of the above. Why is it important? It is important because this is perhaps as revealing of the mind set of those that made the sampled deposit as it is their economy. Surely, it is the people we ultimately wish to reach, in all the complexities of their society and culture, and not simply stop at where they put their rubbish.

Therefore, within this thesis is a brief consideration of these theoretical factors, such as how space is used, the physical and mental processes that create the patterns we can measure, and how data sets generated from what are termed 'hard' scientific approaches, need to be integrated with wider archaeological questions, not only to improve interpretation, but to create greater relevance of application to archaeological research (chapter 2). The division between the natural sciences in archaeology is both overtly and subtly present on many levels, and is inherently counter-productive to a subject area that aims to study the human past, in every detail and dimension. Not to acknowledge the unpredictable, cultural and socially motivated peculiarities of human nature is to create a falsely confident picture of comprehension.

1.2 Aims and objectives

1.2.1 Aims

The overall aim is to assess the potential of integrated geochemical sampling and data using pXRF within archaeological excavation and prospection to better interpret use of space and the range of activities in Viking Age settlements.

1.2.2 Objectives

- Assess whether coring can be a solution to determining phases within multi-period sites, combined with geochemical analysis.
- Investigate the application of pXRF and coring together as an effective means of producing three dimensional geochemical data sets from secondary contexts.
- Assess whether the combination of geophysical data, coring and geochemistry using pXRF is a viable prospection method for understanding phases/site chronology by vertical sampling.
- Apply the developed approach to differing environmental conditions within the context of Norwegian late Iron Age/Viking Age sites in order to meet the aim.
- Investigate the use of space in Viking Age settlements, with a focus upon evidence for metalworking within settlements.

1.3 Terminology and definitions

1.3.1 Chronological divisions

For clarity, certain terms are here defined that are repeatedly used throughout this thesis. The Viking Age in Norway is considered to be the final phase of the Iron Age, generally lasting from AD 800 to AD 1030, although opinions of the dates do differ. This date range is used here, in light of it being the definition adhered to by the Royal Manor Project, directed by Dagfinn Skre, and therefore used in Cannell et al. (in press).

The period classifications for southern Norway used in this thesis are given in table 1.1. In addition, the Late Iron Age is a term that bridges AD 550-1030, and the Early Iron Age refers to the period AD 500 BC- 550.

Table 1. 1. The period classifications used in this thesis for southern Norway.

Period	Date range	Abbreviation
Bronze Age	1800-500 BC	BA
Pre-Roman Iron Age	500-0 BC	PRIA
Roman Iron Age	0-400 AD	RIA
Migration Period	400-550 AD	MIP
Merovingian Period	550-800 AD	MP
Viking Age	800-1030 AD	VA
Early Medieval Period	1030-1200 AD	EMP

1.3.2 Place names

The second and main case study in this research is on the site of Heimdalsjordet. This Viking Age trading site is located 500 m from the better known Gokstad burial mound. Articles have been published using the site name of Heimdalsjordet (Bill, 2013, Bill and Rødsrud, 2013, Macphail et al., 2013, Macphail, 2013, Macphail et al., 2016b, Schneidhofer et al., 2016, Bill and Rødsrud, in press,), and therefore the name is kept. The term 'Gokstad' is used to refer to the landscape surrounding the burial mound *and* Heimdalsjordet, whilst the term 'the Gokstad Mound' refers to the burial monument only. Despite the variety of names, the sites are seen as culturally, economically and chronologically connected, as part of one and the same landscape and settlement.

The final case study is located at the modern day address of Kaupangveien 224, indeed, it is part of the garden. It is also within the area of a larger Viking Age trading site, known from previous excavation work. The trading site is Kaupang, and therefore to distinguish between the case study in this research and the larger trading site, the case study is referred to as Kaupangveien, and the term Kaupang used to refer to the larger trading site.

1.3.3 Proto-urbanism

The term proto-urban is used in the contexts of Heimdalsjordet and Kaupang(veien). These are both trading sites from the early Viking Age. The reader is referred to Skre (2007a:44-47), Gansum (2009) and Croix (2015) for a discussion on the definition of early urbanism in Scandinavia. The definition of a town or urban space, as Skre discusses, is complex in the case of early settlements. The relationship between trading posts and early urban centres, and where the defining boundary between them lies, is often difficult to specify. Most definitions of urbanism are characterised by certain economic functions unconnected to subsistence, including specialist production, a relatively dense settlement pattern, urban planning, and permanent occupation. As discussed further in chapter 8, it is clear that the first settlement of Heimdalsjordet was intermittent, before potentially becoming permanent, or year round. Similar questions of seasonality have been posed for the first phase of the Kaupang site (chapter 7). Skre (2007a) extensively discusses the development of Kaupang into a permanent settlement, and similar but briefer evidence is presented for Heimdalsjordet. Therefore, to reflect the fact that the period studied here encompasses that change, the term proto-urban has been selected as an umbrella term to describe all evidenced phases.

1.4 The selection of case studies

The selection of case studies was directed by many factors, including access, time and geographical scale and the availability of collaborative data. Testing pXRF as a tool for archaeological geochemistry is a research project in itself, if the pure technicalities are to be exhaustively evaluated. However, the concept was to test the method within the constraints of archaeology, not purely within a laboratory, as the goal with any technique is to provide data and information that can answer real and relevant archaeological questions, not purely technical ones. Therefore case studies were selected to create common threads running from one study, to the next. To narrow the focus, they all are dated from the same archaeological time period, and located in Norway. The sites became available prior to and during the course of the PhD through connections to rescue and research archaeology conducted by the Museum of Cultural History (MCH), part of the University of Oslo. All are connected to larger research projects in one capacity or another, and therefore essential collaborative data is available as well as a reciprocal platform upon which to evaluate the benefits of applying archaeological geochemistry using pXRF. This is evaluated as a prospection method guided by geophysical data and within excavated areas, and also where constrained by the practical and financial realities of commercial and research archaeology. Simultaneously the connected projects provided relevant archaeological research questions unique to each project that could be addressed, thus testing the validity and applicability of the approach to wider archaeological research.

All three case studies are located in Southern Norway, and the period in focus is the Viking Age. Whilst this does narrow the archaeological possibilities, it must be noted that both the Viking Age and Norway are culturally and geologically varied, therefore each site must be considered in its own right before any tentative comparisons can be made.

1.4.1. Avaldsnes

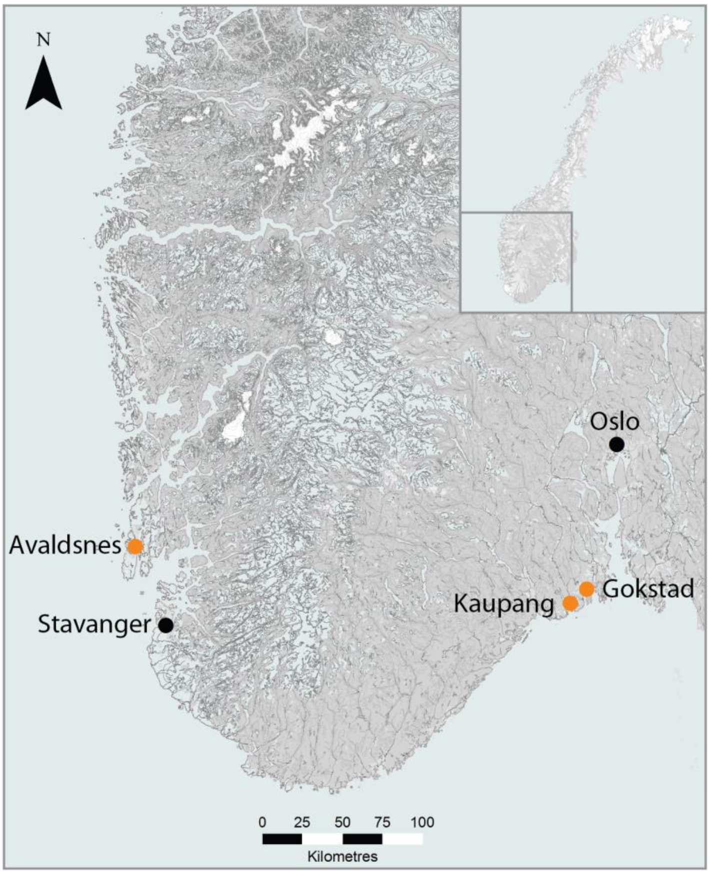


Figure 1. 1. Map of case study locations. Map source: Author/Norwegian Mapping Authority 2016.

The first case study is Avaldsnes, located on the pluvial, mountainous west coast of Norway, on the island of Karmøy, split from the mainland by the relatively narrow Karmesund. Early textural sources lay status upon the site as the seat of local, and then later, the first King who could call himself the King of Norway, Harald Fairhair (Skre, 2015). High status, and already set in the modern conscious as a tourist destination, the research project managed by the Museum of Cultural History, University of Oslo, therefore had high expectations and pressures to deepen knowledge of the status and development of the site by excavation and research. The opportunity to be part of the project came before this Ph.D thesis was conceptualised and funded. However, due to the immense support from the Royal Manor Project, led by Prof. Dagfinn Skre, extensive and at times highly experimental sampling involving coring and geophysics were undertaken by the author and others on the project throughout the two seasons of excavation, some of which were analysed for inclusion in this thesis. These samples were also used to test the parameters of pXRF as a tool for archaeological geochemistry (Chapter 4).

1.4.2. Heimdalsjordet and Kaupangveien

The other two case studies are located on the South-Eastern coast of Norway, and at first glance have much in common. Kaupang and Heimdalsjordet are both of early to mid-Viking Age, situated on the coast of the Oslo fjord, defined as planned settlements connected to trade, with implied reliance on imported resources rather than being self-sufficient. The finds material from the partial excavations at both sites firmly established far flung international connections, from as far away as Iran, or closer to 'home' in Northern Europe, such as Hedeby (Skre, 2007b, Skre, 2008b, Skre, 2011, Bill and Rødsrud, 2013, Bill and Rødsrud, in press). They also have physical traits associated with early urbanism, such as the parcelling of land and divided plots, buildings that in the case of Kaupangveien can be confidently said to have different dimensions to those of contemporary rural Norway.

The site of Heimdalsjordet is the main focus of this thesis, and represents the considered implementation of a sampling strategy for geochemistry, integrated with excavation. High-resolution GPR (ground penetrating radar) data provided both a focus for excavation, and coring for geochemistry and site formation processes as a prospection method. Excavated under the auspices of the Gokstad Revitalised Project, managed by Prof. Jan Bill at the Cultural Historical Museum, University of Oslo, the opportunity to become part of this project also predated funding for this research. As many of the initial ideas connected to the Ph.D funding could be investigated at the site as part of the ongoing project, it was selected as a case study. The integration of this research into a wider research project has provided insight into wider aspects of the settlement and landscape in a depth that published material alone cannot provide, and allowed the integration of research ideas and the application of methods to have a wider significance than just the research aims and objectives stated above.

The inclusion of Kaupangveien as a case study was opportune. Time and practical constraints limited the scale of a final case study, however as the site of Heimdalsjordet was and would inevitably be compared to the only other potentially proto-urban Viking Age site in Norway, namely Kaupang, the potential for testing the methodology in theoretically comparable contexts was taken. The wider area had twice been excavated in limited areas previously, first by Charlotte Blindheim in campaigns between 1950 and 1974 and again by the Kaupang Excavation Project headed by Dagfinn Skre from 1998 to 2003 (Skre, 2007a). A rescue excavation close to the now protected area was undertaken in summer 2015 by the Museum of Cultural History, and during this excavation the author was able to partake and take core samples on what proved to be a near intact house and metalworking area, dated by artefacts and radiocarbon dating to the mid to late Viking Age, with similarities to other houses excavated in the Kaupang area by the Kaupang Excavation Project. Chapter 7 briefly introduces the results from the Kaupang

Excavation Project, and the sampling and results for geochemical analysis sourced from the 2015 excavation.

1.5 Contribution to knowledge

It is the design that this research will contribute toward the understanding of the potential and problems that the use of pXRF on archaeological soils offers. As a by-product of this, it aims to demonstrate that sampling can and should become more source critical, more contextually and pedologically aware, and more inventive. By viewing archaeological geochemistry as a method well suited to better understanding how past cultures viewed, constructed and inhabited spaces, archaeological science can and should acknowledge that it needs to consider theoretical issues and be better integrated into archaeological practice. Archaeological science is growing exponentially, on its own terms in some instances. Instrumentation such as pXRF allow all to partake, and the result must be a better dialogue to maintain standards of analysis, and work with theoretical developments.

On a more practical note, all of the sites used as case studies are under-threat from modern encroachment and land use. If the data offered here in some way forwards our understanding of this finite resource, then this research has fulfilled some of its purpose.

Temporal and spatial changes provide archaeologists with the evidence for continuity and change within past cultural contexts. The means of interpretation are all too often illusive, or ambiguous. Geochemistry, as a method to analyse what was happening where, can be used more fully to breach this gap in evidence created by the paucity of the other sources. This research aims to contribute toward demonstrating and evidence the various potential applications geochemistry has within settlement archaeology.

1.6 Thesis construction

This thesis is composed of two introductory chapters, one focussing on the research agenda which, as the thesis developed, increasingly lay behind the research aims, methods and ultimate goals. In chapter 2, a consideration of how an understanding of space, by implementing social theoretical approaches, provides an important tool for interpreting past human activities, cultural and social structures. This primarily focusses upon the house and similarly structured spaces of upstanding architecture, as the case studies presented here are focused upon this type of settlement evidence. Do note, however, that many ideas of space can equally be applied to wider landscapes as well as the settlement area. The chapter then offers a critical history of geochemical analysis, focussing on how the technique can be used to more directly evidence the use of space in past cultural contexts.

Chapter 3 continues the research background by outlining previous applications of XRF technology in archaeology, and a multi-disciplinary consideration of the use of the technology on soils and sediments.

Chapter 4 outlines the field and laboratory methods used on a general and site specific level, including an evaluation of sampling methods, including coring. Within this chapter are also parameters tested for the use of pXRF on soils, such as precision and accuracy, moisture content and repeatability of the data.

The first of the three case studies is presented in chapter 5. This chapter contains both the background to the Avaldsnes site, the site specific aims and objectives, and where necessary any deviation from the standard methods stated in chapter 4. The results are then visually and textually presented and discussed. A similar format follows in chapters 6 and 7 for the Heimdalsjordet and Kaupangveien sites respectively. The second case study, Heimdalsjordet, was used to test experimental methodology to a greater degree than the other case studies, and therefore the resulting written volume for this case study is more substantial.

The discussion continues into chapter 8, where the case studies are compared where possible, in terms of sampling methodology, temporality in geochemical data sets, and the combination of methods (including archaeological geophysics and coring) in prospection and excavation contexts, the use of pXRF and the validity of the data in technical and archaeological terms. This is then furthered, as specified in the aims and objectives, to discuss the Viking Age house in proto-urban contexts, as relevant for the sites of Heimdalsjordet and Kaupangveien, briefly drawing on comparable excavated sites from North-Western Europe.

The thesis ends with the overall conclusions presented in chapter 9.

2. Archaeological geochemistry and the concept of space

2.1 Introduction

Whilst the primary aim of this research is to investigate the use of pXRF as an analytical tool for archaeological geochemistry on broadly comparable archaeological sites, the motivation behind testing this methodology is to advance the use of geochemical data sets as a means of understanding the past use of internal and external space. The concept of space as something that has a reciprocal physical and cognitive effect in creating and bounding social norms, can be a window into past mentalities and customs that, theoretically at least, geochemistry is uniquely placed to explore. Before this can become a practical possibility, geochemistry has to become better able to effectively and affordably deal with challenging contexts and connect results with past human actions. In setting out these aims, it becomes apparent that ingrained thresholds have to be crossed, namely the divide between archaeological sciences and humanities. This step is not unproblematic, and the first section of this chapter contains a brief review of the challenges (section 2.2). The chapter progresses, becoming more focussed on this research by providing a short summary of the use of geoarchaeological approaches in combination with theoretical issues (section 2.3), before the focus narrows to concepts of space in social theoretical approaches (section 2.4). This is intended to create a theoretical background for this research, and introduce the potential role geochemistry can take (section 2.5). The chapter finishes with review of the development of archaeological geochemistry, outlining previous research into the connection between measured elemental enhancement and depletion and past human activity, as well as the different sampling and analytical strategies and interpretative methods that have advanced the technique (sections 2.6-2.7).

2.2 Science and theory in archaeology: polarised perspectives?

'One camp deems the sciences accurate only when they have been purged of any contamination by subjectivity, politics or passion; the other camp, spread out much more widely, deems humanity, morality, subjectivity, or rights worthwhile only when they have been protected from any contact with science, technology and objectivity.' (Latour, 1999: 18)

2.2.1 Introduction

The past is not separate from the present. It is not series of events, detached and floating free from our own culture and concepts simply waiting to be measured and defined. There is a continual line, a cord that connects past events and actions with our present (Evans, 2003). Archaeology, and history, aim to deepen our understanding of the past to give the present context. How we view the past is as crucial as how we choose to explain it. As the saying goes in literature and recent western culture, *'the past is a foreign country'* (Hartley, 1953). To the historian it is societies' fragmented collective memory (Tosh, 2010:1-2). How we, as archaeologists, perceive the past and piece together the fragments is the choice of the researcher. Our agency within the field allows us to direct and select the tools and approaches we feel most relevant and those we can sufficiently master to make a coherent discussion. It is no secret that there is no utopian neutrality in any selection, and whether the approach selected is using what are traditionally categorised as 'natural science' or 'social theory' does not alter the aim, simply how we design to achieve it. Human society is, and has always been, an intricate web of tangible evidence and cognitive actions. Whether we choose to objectively quantify one particular aspect or explore the mental perceptions of the past, our goal is to elucidate past behaviours and events. Each approach contributes toward our understanding of our human past, and the separation of them is detrimental to the whole.

2.2.2 The poles

An extensive discussion of the history of the overlaps and divisions between the approaches of the natural sciences and humanities in archaeology will not be offered here, but as Lidén and Eriksson (2013) and Shennan (2013) note, the susceptible relationship and inter-reliance is nothing new (for a breif overveiw see Hodder, 1999, Kristiansen, 2014). However, as Lidén and Eriksson also note, there are fundamental differences which are rarely navigated or even acknowledged. The academic methods of deciphering the world are polarising into the objective and subjective approaches, the scientific and social theories. These poles have conflicted and progressed to meet new challenges before (Jones, 2002), such as during the radiocarbon revolution (Kristiansen, 2014), and the purpose of this research is not to evaluate the entire history or perpetual reinforcement or reconstruction of this division.

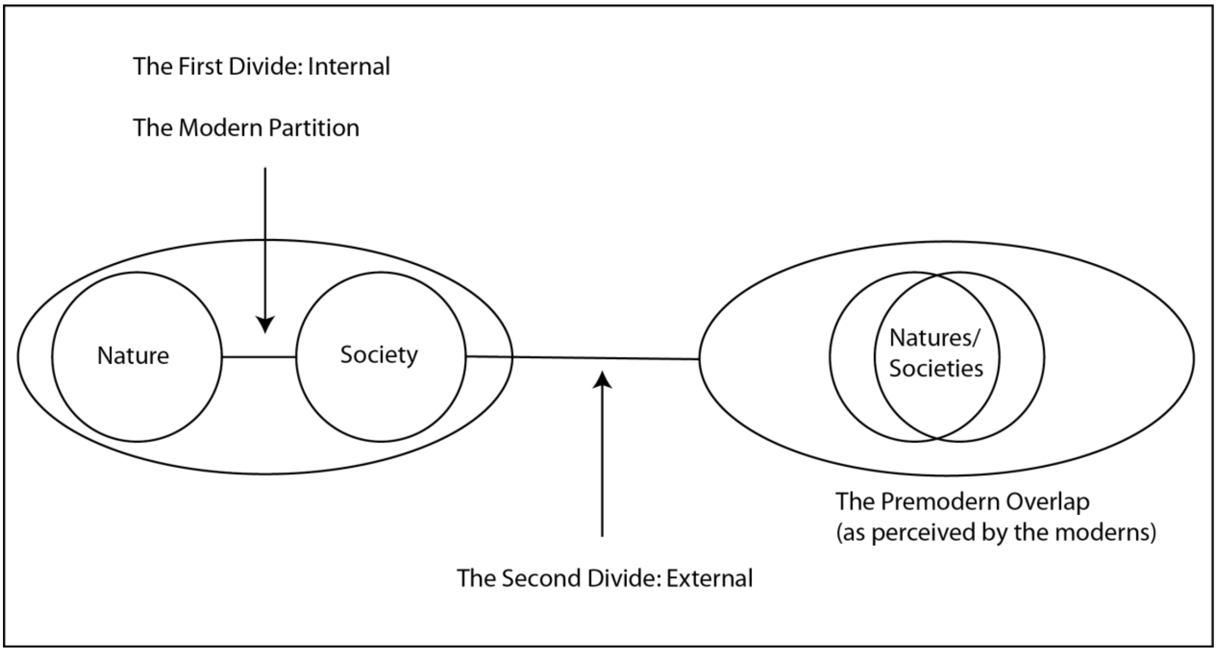


Figure 2. 1. The Great Divide as seen by Latour, illustrating that modern society has both divided nature and society within its structure, and believes itself separate from pre-modern societies who do not maintain the divide between society and nature. Therefore, there are two divisions, neither of them real or productive. Adapted from Latour (1993:99, figure 4.2).

Just as claiming there are two clear cut camps is too simplistic to represent reality, a call saying both should aim to dissolve the divide ignores the incompatibility of aspects of the founding philosophies. One employs repeatable measurements to observe a phenomenon, the interpretations of a static world often grounded in uniformitarian principles. Meanwhile, the other uses multiple sources of highly subjective and fragmentary information to understand a shifting world through the limitations of our own culture, in order to form the basis of interpretation by analogy in conjunction with developing social theoretical approaches. However, the notion that we can objectively measure anything, without cultural bias, is demonstrably flawed (Latour, 1999). The juxtaposition between the polarised states of reason exists as an enduring construction designed to keep them apart, held and defined within arenas they can dictate the boundaries for, to maintain their present, workable positions (Latour, 1993). They are only superficially workable, in the sense that blinkers and belief adhered to, the rules create a path to be followed offering reduced risk. However, as Latour (1993) discusses, the boundaries have always been flexed to incorporate countless hybrids. This polarisation, seen by Latour (1993) as encapsulated within western thought, purposively separates us from primitives or pre-moderns, and is illustrated in figure 2.1. If, as he suggests, in some respects we are no different from that which we, steeped in western thought, label pre-moderns, then we can cast off any illusion that Nature and Society are separable. By extension, we can discard the ideas that one can only be measured by neutral, repeated observation and the other only understood via our own subjective theories and opinions. These divisions are deeply entrenched within our definitions of knowledge. Can removal of the idea that Nature is neutral, governed by immutable laws, out there to be objectively measured, and Society exists entirely separate and subjectively understood, be achieved? Perhaps in the heartland of academic practice, however even that is constrained by those who are governed by the division. The individuals and institutions such as funding bodies and Universities, who adhere to what Latour defines as those clinging to the notions of modernity, and the segregation of spheres. The danger is, even in the attempt to explore Society and Nature as a seamless whole, because of the fundamental divisions in how knowledge is constructed and validated, two parallel tracks are created even within the single aim. These are imperfectly merged at the end under the guise of originality without truly dissecting the problem. How modern.

2.2.3 Between the poles

Moreover, this simplification of seeing two poles ignores more common realities. Relevant to many situations, and to the reality of Norwegian archaeology, there is a grey, middle ground that archaeology has occupied for some time in its processual, empiricist stance, a position that has endured the throes of post-processual rejections and new theoretical landscapes. This stance is often able to produce workable, relatable narratives that are easily disseminated and debated. It follows a well-defined hybrid path. It is able to utilise scientific data without the rigorous evaluative criteria the scientist who produced the data adheres to, and touch upon social theory without embracing the subjective critique of theory or of the production of 'hard' scientific knowledge. The grey is the reality of commercial archaeology in a pressured environment, and the need for research to produce something that can be disseminated, and funded. This is the epitome of attempting to break down the divisions between Society and Nature by starting half way, without really acknowledging how much deconstruction has to be first achieved.

However undeniably productive this stance, it is avoiding the fundamental incompatibilities in both means of knowledge production. This begs the question, is it possible to have a foot in both camps, and adhere to two, incompatible principles *and* be productive within our current constraints? Henderson (2000a) suggests the distinction between scientific and archaeological theory should be a false one, that instead there should be a continuum without breach. The question becomes, is this possible, or even desirable?

The status quo; a scale with a well-trodden middle ground, is as problematic as the solution. As it fails to grapple the incompatibilities, what it is in danger of representing is un-dissected data, accepted without critique as 'fact', then arranged to fit a selected social theory (Bintliff, 2011). This extreme, whilst it no doubt exists, does little service to the countless researchers who do acknowledge these issues, and do attempt to address them within the confines of their position (e.g. Hjulström et al., 2008, Codding and Bird, 2015). A discussion of attempts at hybrid approaches, acknowledging the tenants of objective, political and subjective approaches within archaeology were themselves beset by the rather processual idea that some form of universal answer was to be found (e.g. Wylie, 1994). Hodder (1999) suggests that the answer to incorporating both sides could only be found in practice, a subject which is returned to in section 2.2.6.

2.2.4 Integration and communication

Perhaps, in the meantime, integration would be a more promising and productive aim, in order to interconnect the two poles and create a productive dialogue that can, over time, address the foundations of the divide and develop the middle ground. Often, when integration is discussed, the implication is that the archaeologist should be capable in both fields. This is unproductive, as whilst it is possible for one to be well versed in both fields, in practical terms to ensure the best, most thoroughly considered results that draw on a wealth of experience from both approaches, better collaboration should be the aim. The requirement is mutual understanding and respect for the limitations and knowledge on both sides (Henderson, 2000b). This is not to say there should be no knowledge overlap, there has to be. Without any acknowledgement or understanding of archaeological/ theoretical frameworks, the scientist may well fail to frame archaeologically relevant research questions, or in conveying data, focus upon their own, subject orientated interests (Lidén and Eriksson, 2013). This is equally applicable of the theoretical archaeologist using scientific data without questioning how it was created, or what paths have been chosen before it became the statistics presented as dependable. Integration is achieved through communication. The indecipherable nature of social theory and ‘pure’ archaeological science research does not aid collaboration, however this should not be used as an accusative generalisation. There are many works on both sides of the divide that manage to convey ideas without drowning the subject in jargon (e.g. Evans, 2003).

Subjects have their language. Textbooks may be produced in with an explanatory, amenable tone (e.g. Dincauze, 2000), however when one aims to publish in peer reviewed journals, the language emulates the peer group. This becomes a means of joining, belonging to the group, and excludes those who don’t. The desire to emulate to succeed is powerful, and can hark back to power relations in social interactions (Evans, 2003: 44). While precise contextual language is necessary to relate the rigorous standards required in archaeological science, and complex terminology is necessary to precisely relay the myriad of subtle distinctions of cognitive and symbolic concepts in social theory, the requirement for it to be exclusive is not. When new research material is continually presented as a challenge to the reader, it encourages the divide, a division that has been seen by many as counter-productive (Prescott, 2014). If the aim truly is collaboration, then inaccessibility must be the first obstacle to fall. This may occur through practice, as Hodder suggested, prompted by technological advancement. If, or rather when, the steadily increasing range and affordability of scientific instrumentation and analysis becomes more apparent, the increased access and affordability will make quantitative analysis more common place, more familiar and better understood, creating a closer dialogue. Alternatively, the increasing availability of technology, created for non-experts to operate, may create a middle ground of quasi-science, chaotically blooming without rigour or guidance, and subsequently derided by those sitting high on the peaks of pure subject matter.

This result could be, as Speakman and Shackley (2013) prophesise and label 'silo science', the lack of rigour in archaeometry as new instrumentation allows all to partake. This demeans the development and cumulative knowledge of the subject, and will potentially result in inferior data being used for archaeological interpretation. Cracks are easily found, and criticism can justly or unjustly undermine interpretations built on unsound premises (or data). This goes both ways, and is particularly relevant to the use of portable XRF (see chapter 3).

As outlined above, what archaeological scientists often fail to address, is that as perceptions stand, there exists a fundamental division within archaeology. This line is vague, repeatedly crossed, but rarely discussed. Archaeology is far from unique in drawing on information (or data) gleaned from 'hard' scientific enquiry, and humanistic approaches, however it rarely acknowledges the fundamental differences in the construction of knowledge, and the means used for the most basic steps of interpretation. The objective and subjective, repeated, controlled measurements and analogy, are incompatible philosophies. The middle ground, as it currently stands, does not glean the best from both worlds.

2.2.5 Where to?

Where does this leave us? It is not a necessarily an apocalyptic vision. If we acknowledge that all knowledge is constructed and culturally dependent, and exists only by internal reinforcement, this is not a catastrophe (Latour and Woolgar, 1986, Jones, 2002). It does not sink the scientific ship, just as our own shifting cultural limitations do not prevent social theory contributing to our knowledge of past societies (Latour, 2005, Jones, 2002). In essence, the past is a foreign country, which we can only understand on our own, not their terms. But how else are we to understand the past, if not in our own terms in forms that we can accept and interpret?

Latour (1993) sees the 'human' as belonging nowhere but between, neither a subject or object, nature or society, perfectly placed to delve in any direction, using any means. The constructions we have created are the only things that let the apparent divisions in how we understand our past endure. We have created our own cage by repetition. If society and nature are one and the same, and all knowledge subjective and constructed, then as long as this is acknowledged, what does it matter how we approach it? Archaeology then, in its attempt to understand the natural/social past in all its complexities, should seek to gather more in the subjective, eclectic middle, no matter how the information is gleaned and interpreted. And there are, after all, real physical objects and materials that can be weighed and tested, and those measurements can be repeated in a structured fashion. The control of parameters for analysis, the collection and isolation of a selected material for repeated and repeatable measurement is necessary. Without it, nothing is comparable. The parameters controlled in the production of scientific data allow us to set objects and phenomenon side by side to contrast and compare, knowing that certain aspects of the data are similar enough to be used as a foundation for interpretation. We can be what could be termed 'selectively objective', but we first and last, we choose which objects are of value, and what measurements are informative (figure 2.2).

Figure 2. 2. A highly simplified view of research starting in the subjective and passing through the selectively objective.

As Hodder (1999) debates, all approaches are valid, as long as the extremities of the poles are rejected. Then the developing middle ground can be defined by communication, transparency and acknowledgement of the multiple flaws, because if we only attempt to cross the perceived line between society and nature at the end, armed with 'rigorous' scientific data, we are failing to admit if that line exists, it was crossed long, long before.

Post-processualism, to some, near signed its own death warrant by becoming so esoteric that it could perform no practical function (Kristiansen, 2014). By declaring everything so steeped in subjective, intangible chaos, its application became limited to the few niches that created it. That does not warrant its outright dismissal, nor is the solution to step back, into the comfort and security of what the non-theoretical world would unquestionably except as objective and scientific. The application of the natural sciences in archaeology is growing exponentially (Torrence et al., 2015), and this trend should be embraced and scrutinised. And it is progressing. We are no longer *only* divided into the hard science, empirical, and culture-theoretical. Those divisions endure, and examples are easily found to emulate it, however archaeological science is engaging in social theory (ibid). The application of archaeological science has to be rigorous, the methods tested by repeated observation and standardised, comparable methodologies. But at the same time, we have to acknowledge, as post-processualism tried to teach us, that every step of the analytical process is a subjective choice of objective methods. This paradox has long since existed, nowhere more so than in the field.

2.2.6 The Source

Thus far, we have remained in the domain of academia, where acceptable forms of knowledge are tested, constructed, and challenged. To stop here would to be ignore the very foundation of archaeological thought and subject material. The creation of archaeology begins, ultimately, in the field, where the physical remains of the past are exposed, directed, recorded and interpreted. It is the source of all material used for this thesis.

The notion that excavation is scientific has been challenged ever since the days of Petrie and Pitt-Rivers (Hodder, 1999:22). The current, but certainly not universally adhered to, practices of matrix-led, stratigraphical excavation came to the fore with the combination of New or Processual Archaeology and the concurrent expansion of rescue archaeology. Excavation was a science; an objective procedure, and a skill of meticulous observation and recording (see for example, Barker, 1982, Harris, 1989, Carver, 1995, Roskams, 2001). Roskams 2001 book *Excavation,* arriving at a time when the paradigm shift to post-processualism was too apparent to ignore, is ultimately dismissive. He implies, as others have, that theory had little impact on excavation (Roskams, 2001, Shott, 2002), and the view that excavation is a scientific, empirical exercise persists (Carver et al., 2014).

As excavation is necessarily destructive, it can never be repeated. This limits its ability to be defined as truly objective and scientific (Carver, 2004), a limitation that can equally be placed on geological events such as volcanic eruptions, although most accept these can be scientifically studied because they do not attempt to combine a human dimension. They are held in the confines of Nature. Remote sensing, is some respects is repeatable, in that the same methods can be applied to the same area, however as conditions under our feet are in constant flux, two data sets will never be identical (Conyers, 2016: 27). This may be perceived as a matter of scale and governing parameters, but past and present human agency cannot be removed from the equation.

Taking a further step back, to how and why we excavate and prospect rather than what we measure and how we record stratigraphy, certainly in Nordic countries where the law is archaeology-friendly, the act of excavation has become a routine, or even a ritual (Nilsson, 2011). It becomes an archaeological identity and self-perpetuating necessity, and a powerful means of tacitly connecting 'us' to the past (Edgeworth, 2011). Edgeworth (2012) goes further. Bringing forth the aspect of discovery in field archaeology, we are physically confronted and linked to the past in a unique way. What we uncover has a material as well as cognitive component, which when faced with it, can challenge our ideas and assumptions. As Wylie (1994) also insinuates, we do have the ability to move outside our cultural constraints when faced with something that changes or undermines them. Therefore excavation, despite being superficially objective, encircled with subjective opinions, theories and assumptions, is a dynamic, individual, collective and institutionalised process that has many forms. In the process of selective discovery, where the past emerges into our cultural world as variations within sediments and soils or as objects, they are products of interlaced past and present agency, and the result of cultural and natural processes. They can be categorised and labelled, but they cannot truly be separated (Edgeworth, 2012).

Therefore, within this study into archaeological geochemistry, there is no preconception that the samples or actions taken to select and retrieve them, are within the realms of a disconnected, neutral 'nature'. A Nature that can be objectively measured, producing data that only when, having completed on objective study, can be moved into the realms of the Social. It was always there. However, that is not to say that no objectivity will be attempted. Selective objectivity is the aim. Data has to be compared, validated, standardised and processed through peer accepted channels in order to be accepted as knowledge, and to stand up to any kind of test. However, it makes no pretence of hopping from one field to the other; it is an attempt to integrate the conjoined halves.

The issue of integration will be discussed further with specific reference to the broad field of geoarchaeology and the narrower range of archaeological geochemistry as a means of understanding space in archaeological contexts.

2.3 Geoarchaeology and social theory

'approaches that fail to integrate social dimensions with the geological world undoubtedly run the risk of constructing internalist histories, where change is described (and not explained) within rigidly disciplinary categories' (Jusseret, 2010:676)

In 2010, Jusseret argued that geoarchaeology, as it wasn't a sub-discipline in archaeology but an essential integral part of archaeology, could no longer be excused from the tendency to take a clinical method based approach and ignore social theory. Geoarchaeology, defined as archaeological research using the methods and concepts of the earth sciences (Butzer, 1982:35, Cannell, 2012b), should indeed be seen as an essential means of connecting environmental and landscape continuality and change with past human activity. Alternative definitions often build upon similar foundations, expanding or refining the definition as the subject grows, such as Engel and Brückner (2014), defining geoarchaeology as a *'science that studies geo-bio-archives in an archaeological context.'* An article by Kluiving (2015), drawing on niche construction theory and geoarchaeology, contains similar calls to Engel and Brückner for geoarchaeology to be an inclusive, multi-disciplinary approach stepping between geosciences and cultural sciences.

The idea that geoarchaeology without social theory is incapable of explaining change, as Leach (1992) also insinuated, misses the point. It is perfectly capable of explaining change, but risks missing the complexities of social and cultural dimensions in the change without also applying or integrating humanistic approaches. This potentially depletes the relevance of the data and interpretation. This arises from the understandable tendency for like minds to flock together and discuss their own data in terms they comprehend (Kluiving, 2015). But this is not purely communication at fault. It is how we educate, structure knowledge and employment within academia, and manage archaeology from the field to the museum, which incorporates many ingrained legacies (Carver, 2011).

As geoarchaeology has its home in excavation and fieldwork, where primary data is gathered and combined with collected or external, more regional data sets to understand site formation processes, the resources and 'tools' are reciprocal to the notion that excavation is 'scientific', as is the data collected. Operating via earth science theory (Goldberg and Macphail, 2006), studying geomorphology, hydrology and geology (for example), the foundation of interpretation lay upon repeatable measurements and observations, becoming fact through uniformitarian principles. However, as noted above, geoarchaeology is essential branch of archaeology (Renfrew, 1976), interconnected with so many other sub-branches we choose to label to indicate specialisation, it cannot exist without reference to the developments in the subject as a whole. The increasingly holistic, truly multi-disciplinary approach is becoming more apparent (e.g. Milek, 2006, Kluiving and Guttmann, 2012a), however is certainly far from universal.

Once again we are at the two poles. It should not be insisted that all embrace theory as the only means to approach archaeological questions, as it would be making the case for one being superior, which is not the best means of persuasion. Time and advancement within the great variegated palimpsest of archaeology is proving that both can take and learn from one another, and try to understand the world on the same terms it exists. One part can be extracted from another to be measured, but for it to mean anything it has to be inserted back into the complex, multi-layered Nature/Society (e.g. Boivin, 2008).

2.4 The social meaning of space and the role of geochemistry

2.4.1 Space itself

The use of space, as a social and physical construct, is fundamental to our understanding of, and how we relate to, the world around us. How we conceive and divide that space, be it the rural landscape, the urban street, or the place we live in and call home, is created by the things we are surrounded by and how we choose to use them. The objects, both 'natural' and man-made, are not in themselves creators of the meaning we associate with them, although their form has undeniable influence. The current theoretical focus on objects and materiality has an important role to play, but can be seen as a symptom of our limitations and inability to see beyond the materialistic world we live in, and to other ways of thinking. This becomes ever more complex in archaeology by the necessary assumption that the objects that have survived and end up in our hands, often the durable, high status objects, can in anyway provide us with a complete representation of past cultural perceptions. As an example, without becoming mired in the debate over the specific uses of them, early medieval texts such as the saga's are source material for the Viking Age and Medieval period, and demonstrate that the ontology and belief system of the Viking Age was far more nuanced and complex than objects archaeologists happen to have obtained can represent (Price, 2002:44-47). In the same sense, western values are firmly grounded in our concept of time. Temporality ascribes impact and relevance on lives, which is typified in education by teaching the most recent events last, to the older child.

Neil Price, in his seminal thesis, *The Viking Way,* discussed the belief and customs of Viking Age society as revealed from written sources and archaeological evidence (Price, 2002). What is striking is the plurality of Viking Age beliefs, how embodied they were in everyday lives and practice, diverse in time and space, and incomparable to any modern western notion of religion.

They encompassed every aspect of *being*, without any concept of subservient worship. In Severin M. Fowles *Archaeology of Doings,* a study of Pueblo customs and beliefs in the Hopi culture, he concludes that spatiality constructed and defined their world, composed of a customs, *a way of being* incomparable to modern western religion. Time is viewed as secondary to space, and in spatial terms. It is not when, but *where* something happened that connects it to the living world (Fowles, 2013). This is not a direct suggestion that Viking Age society was entirely composed on spatial planes, but that our obsession with temporality, with our typologies, radiocarbon dates, historical successions and manner of ordering and valuing, can distort our ability to see other ways of being. Indeed, Fowles suggests, much in the same manner Price infers, that because the written sources that we have for both the Viking Age and Pueblo societies were from Christian sources, they became religions, organised after Christian thinking, and we are still in the process of deconstructing that concept from the few sources we have (Fowles, 2013, Price, 2002). In the same sense, the notion of objective science, which is entirely a modern western construct, being able to define or infer meaning on societies structured around paradoxically different concepts, appears naive. A more holistic, reflective approach is needed, that allows for both our concepts of knowledge, and theirs. We need to consider how space was inhabited, as well as the objects placed within, through the constraints the paucity of physical remains of the past places on us.

When studying such a loose term as space, which in western society has differing and nuanced definitions, it is necessary to set constraints. In doing this, we are creating boundaries and definitions by convenience, and not in response to the material of study. Literature is often divided into the house and settlement (e.g. Giles and Kristiansen, 2014, Webley, 2008) and the landscape (e.g. Kluiving and Guttmann, 2012b). Theories and texts exist that breach this division (e.g. Ingold, 2000), however it is challenging to incorporate every dimension of internal and external space within a material based study. Therefore, although this research is primarily concerned with the settlement and house, many of the concepts of spatial construction and theory are not seen to start or end at the threshold.

Objects form part of this understanding – objects are in themselves a medium to focus cognitive responses in time and space – but they are not the sole means of interpreting the social and cultural constructs people divide the world by. Actions, as in learning by doing, are also fundamental to the way people mentally and physically divide space (Bourdieu, 1977:89). Seeing things in binary opposites, as Bourdieu does in his structuralist study of Kabyle houses, he himself saw lacked temporal depth, and any concept of agency. However repetition and reciprocal reinforcement cement how space is comprehended. The social rules embodied in the house were taught through repeated actions and associations from an early age (Bourdieu, 1977, Hem Eriksen, 2015).

Space is not just something we label, culturally specifically and elaborately, it is something that is created as it simultaneously creates social constructions (Lefebvre, 1991, Kühtreiber, 2014). We are immersed in a world which we decipher as we experience it (Thomas, 2012). The creation, language and concept cannot be completely drawn from one another, however the perception of space is fluid and dynamic; dependent upon the perceiver, and infinitely changeable. Space also can accrue individual and collective meanings over time, it can become laden with evolving past identities and meaning, which can relate to one or many observers. The experience of space can differ from the perspective of the creator, the architect or builder, to the user. Where the builder, individually or collectively defines a space physically or through action, the user occupying the space can be seen as more passive to the form of the space, but not necessarily the symbolic meanings within it, where the user can create reciprocal and/or conflicting associations within a space compared to the creator, and indeed other users (Lefebvre, 1991:43).

2.4.2 Engaging in space

In this thesis, instead of seeing objects as steeping in meaning and architecture as static (Schmid, 2014), space will be viewed as a manifestation of socially constructed and accepted behaviours that are environmentally responsive (Løvschal and Holst, 2014). Drawing from Løvschal and Holst work on Iron Age landscape and settlement, how people engage and live within spatial divisions will be seen as the incremental accumulation of behavioural responses to cultural and environmental factors. Over time, certain behaviours and responses become more prominent as they, consciously or unconsciously, are seen as more acceptable responses. What Løvschal and Holst term a ‘spatial repertoire’, is a set of choices within a range of possibilities applied to socially communicate, coordinate and regulate. To this can be added the need to identify and define. Temporarily and the explanation of change is added by shared references and retrospect within the cultural and environmental context, which can be implemented, modified or ignored by a person or group. This creates a dynamic between past and present, the individual and society.

This allows study of the manifestations we have before us, such as postholes or ditches, to be both unique and comparable within similar or contrasting cultural and environmental constraints. For example, a ditch may be a boundary created to drain a plot of land for settlement, however it may evolve as a physical boundary into a political and social one. Thus comparable ditches may appear on land that requires no drainage, as the ditch becomes an economic and social division, a statement of cultural identity, or a symbol that colludes to another.

2.5 The means of interpretation: objects are not enough

Our means of interpreting the past use of space is often limited to fragments of material culture and truncated negative features in the sub-soil. Materials are rarely found by the archaeologist exactly where they were lost, abandoned or discarded (Fernández et al., 2002), they have potentially been subject to bioturbation, cryoturbation, truncation, re-deposition and weathering. What is more, the vast majority of objects utilised in the past were made of organic materials, which under most environmental conditions, do not survive to the present day. As testified by the Coppergate excavations in York, with its wealth of organic objects and biological evidence, interpretation of site activities from just the durable, inorganic artefacts will result in a fragmentary picture (Kenward and Hall, 1995, Hall et al., 2014). In the same sense, just using the organic remains would not give the complete picture. What is also clear from the Coppergate evidence is that our idea of domestic versus 'work' or economic activity has little relevance to the past, and therefore we are confronted with interwoven remains of 'industry' and 'domestic' in close proximity as perhaps one and the same mental perception, but with differing physical remains. We need to look at all aspects of settlement in order to understand the range and social organisation of activities within it, without labelling space first. For this we need 'access' to the inorganic and organic remains.

As people live, they produce waste on all scales. Humans manipulate environmental resources, and in especially in sedentary economies, have the effect of introducing 'foreign' material to an area. The surface we live on is ultimately almost always soil or sediment. Soil is essential for life, and humans have long since learned to work with soils to produce the food and fuel required. In addition, soils and sediments are utilised for vessels, decoration, building material, and frequently are symbolic and meaningful, socially and spiritually, to past societies (Boivin, 2004). Soils are therefore enhanced by occupation with deliberately and accidentally added materials by human occupation. This enhancement over the natural or background conditions can be measured.

Capturing long since degraded organic waste by using inorganic chemistry is in fact a common occurrence in archaeology. Phosphate analysis seeks to do just that, measuring the once organic inputs by determining the inorganic traces (Bethell and Smith, 1989). Phosphate analysis fills out the picture somewhat, but phosphate alone does not 'access' the variety of organic inputs into the soil from past anthropogenic activity, merely one product of it. Measuring the inorganic and organic by looking at the elemental traces within the soil has the potential to measure all types of anthropogenic inputs, from the plethora of activities humans that have occurred in the past. This method is usually termed either geochemistry in more recent publications (e.g. Vyncke et al., 2011), but is also called multi-elemental analysis by some authors (e.g. Entwistle et al., 1998, Abrahams et al., 2010). The development of the method is discussed in more detail below (section 2.6.1-2).

2.6 Geochemistry and space

2.6.1 The development of archaeological geochemistry

The first systematic study of the relationship between enhanced soil phosphate and past human settlement was by Olaf Arrhenius in Sweden (Arrhenius, 1931, Arrhenius, 1934), although apparently the connection between phosphate and past settlement had been noted as early as 1911 by Hughes whilst working in Eygpt (Bethell and Máté, 1989). Arrhenius conducted systematic surveys in Skåne, southern Sweden, whilst working for a sugar beet company, and published his results relating to archaeology from the late 1920’s and on into the 1960’s. The method was employed and adapted elsewhere, for example by Walter Lorch in Germany, and although initial uptake was slow, by the 1960’s published studies from Europe and the U.S.A. began appear thick and fast (Cook and Heizer, 1965). It is misleading to think that phosphate analysis at this time was the only chemical analysis employed on soils by archaeologists. As Cornwall (1958) details in *Soils for the Archaeologist,* there were a wide range of available wet chemistry techniques available to identify single element concentrations, however many were either qualitative, laborious, or both. In a short article by Lutz (1951), the enhancement of P, N, Ca and K over old settlements in Alaska was noted, however the sample number was small and the spacing between samples 50 feet (15.24 m), presumably to limit the time and cost of the analysis, but perhaps also as the research question was simply to measure the properties of the observed enhanced soil. Whilst phosphate analysis was also primarily qualitative, it was quick and affordable, and unlike other elements connected to human activity, offered a single element that could capture a wide range of activities with repeated success (Holliday and Gartner, 2007).

Methods improved, as well as the understanding of the factors that influence phosphate retention in soils. In an extensive and thorough article by Cook and Heizer (1965), based on numerous sites in the U.S.A. and Mexico, sampling was employed on different scales, on highly varied soils, and both vertical and horizontal retention of phosphate in the soils was related to archaeological evidence. In many of the case studies, several elements were quantified (Ca, P, C, N) as well as organic content. The interconnection between these factors, the different elements and the soil properties was stressed, suggesting that measuring just one variable, such as phosphate, could lead to misinterpretation. Entwistle et al. (1998) also found P alone an unreliable source for human settlement patterns. Phosphate, as the elements is present in a wide range of organic and inorganic materials utilised by humans, often cannot distinguish between past activities.

Published in 1973, Eidt's short article on phosphate spot testing is widely referred to. The method is a rapid, qualitative test for soils using inexpensive reagents (hydrochloric acid, ammonium molybdate) and an ascorbic acid reducing agent in a two-step process (Eidt, 1973). This method was an alternative to the previously widespread use of ammonium sulphate as a reagent, or the method used by Provan (1971) (see next section), which was also developed primarily for agriculture. Published in *Science*, in 1977, Eidt's improved method offered both qualitative and quantitative methods for enhanced results, and specifically refers to the use of phosphate testing in archaeology (Eidt, 1977). The paper outlines extracting phosphate fractions retained by differing mechanisms within the soil, and also the alternative, qualitative, quick spot test that became widely used in archaeology as a means of understanding the past use of space on micro and macro scales.

Not all published studies undertook spot testing alone. Conway's analysis of a Romano-British settlement used a complicated analysis to determine the proportions of extractable phosphates compared to total phosphates in occupation deposits, the results determined by colourimetry (Conway, 1983), and more recently, likewise Hutson et al. (2009) employed fractionated phosphate to determine potential sources.

Phosphate analysis, by the 1980's, had decades of research and refinement, and as a result, a plethora of extraction and analytical methods had been applied to archaeological sites. The widely divergent approaches, from quick, in situ spot tests (Bakkevig, 1980), to Conway's quantitative total extraction, mainly stems from the uncertainty in our knowledge of the phosphate cycle and its relation to archaeological samples in varied environmental conditions (Conway, 1983). Published in 1989, Bethell and Máté's thorough dissection of the topic is still very much relevant in the subject of archeologically geochemistry, and is still widely referred to (Linderholm, 2007, Oonk et al., 2009a). The problems identified in the critique are many, such as the lack of temporality in phosphate mapping results, particularly when used as a topsoil prospection technique. Multi-phase aspects of a site are lost or blurred, although attempts have been made to relate relative proportion of available and unavailable phosphate to chronological changes (Beach, 1998), and equally post occupation land use can affect results (Gjerpe and Samdal, 2005). In addition, despite the theory that organic phosphates added to the soil quickly mineralise and become ‘fixed’, there is a volume of evidence that suggests mobility is a problem in certain environmental conditions (Crowther, 1997, Craddock, 1989, Cannell, 2013). The paper by Bethell and Máté (1989) is now perhaps a little outdated, if, and only if, one considers multi-element analysis to have superseded single element analysis. Clearly, not all deem this to be the case, as phosphate analysis continues in archaeology in commercial and research projects, which has ever expanded the number of applied analytical methods, which were thoroughly considered by Holliday and Gartner (2007). However, Bethell and Máté (1989) do state, that without multi-elemental approaches in the future, the development of feature specific geochemical interpretations are potentially limited. Unsurprisingly, therefore, Bethell and Smith (1989), published a multi-elemental approach the same year, based upon work on burials at Sutton Hoo in 1987.

Although Bethell and Smith (1989) was not the first multi-elemental application using a single instrument in archaeology, (e.g. Keeley et al., 1977), is remains an excellent example for integrated, planned sampling within an archaeological excavation strategy. The paper does not shy away from some of the key questions in archaeological geochemistry, such as the use of background sampling, sampling methods, elemental mobility, the effect of local environmental conditions, and inter-site comparability. In addition, because of its early use of ICP-AES, it inevitably had to include the discussion of appropriate extraction techniques for sample preparation. In the intervening years since Bethell and Smith (1989) published their Sutton Hoo study, the use of ICP, particularly ICP-MS, has increased, becoming most commonly used instrument for multi-elemental approaches. In the 1990’s, the number of published studies began to grow (Linderholm and Lundberg, 1994, Entwistle and Abrahams, 1997, Entwistle et al., 1998, Wells et al., 2000, Middleton, 1996, Rimmington, 1998, Aston et al., 1998a, 1998b), and the expansion continues to this day.

In tandem with the small, but growing number of published studies, the understanding of the differential retention mechanisms within soil improved. Certain elements seemed to be repeatedly enhanced in archaeological contexts, such as calcium (Ca), potassium (K), magnesium (Mg), and of course P (Middleton, 1996, Entwistle et al., 2000). In addition, strontium (Sr) was particularly associated with food preparation, alongside P and Ca (Middleton, 1996, Milek and Roberts, 2013), whilst hearths were associated with these elements and zinc (Zn), K, Mg. Copper (Cu), lead (Pb), barium (Ba), iron (Fe), aluminium (Al), and sodium (Na) appear to be less universal and more site specific indicators (Knudson et al., 2004, Wilson et al., 2007, Vyncke et al., 2011 Milek and Roberts, 2013). Rather than wade through what each element has been associated with by whom, it is more fruitful to consider that whilst a handful of elements (Ca, P, K, Sr) have more universal application, most sites need to be seen as unique. Figure 2.3 shows the complex relationship between input, retention and exchange within the soil, the dominance of the different systems, and the environmental dependence of retention mechanisms. Nor is it solely enhancement that is measured, relative depletion of certain elements has also been observed. For example, Oonk et al. (2009b) and Vyncke et al. (2011) highlight that relative depletion due to organic loading of the soil or high trafficked areas is also a factor that applies to archaeological contexts.

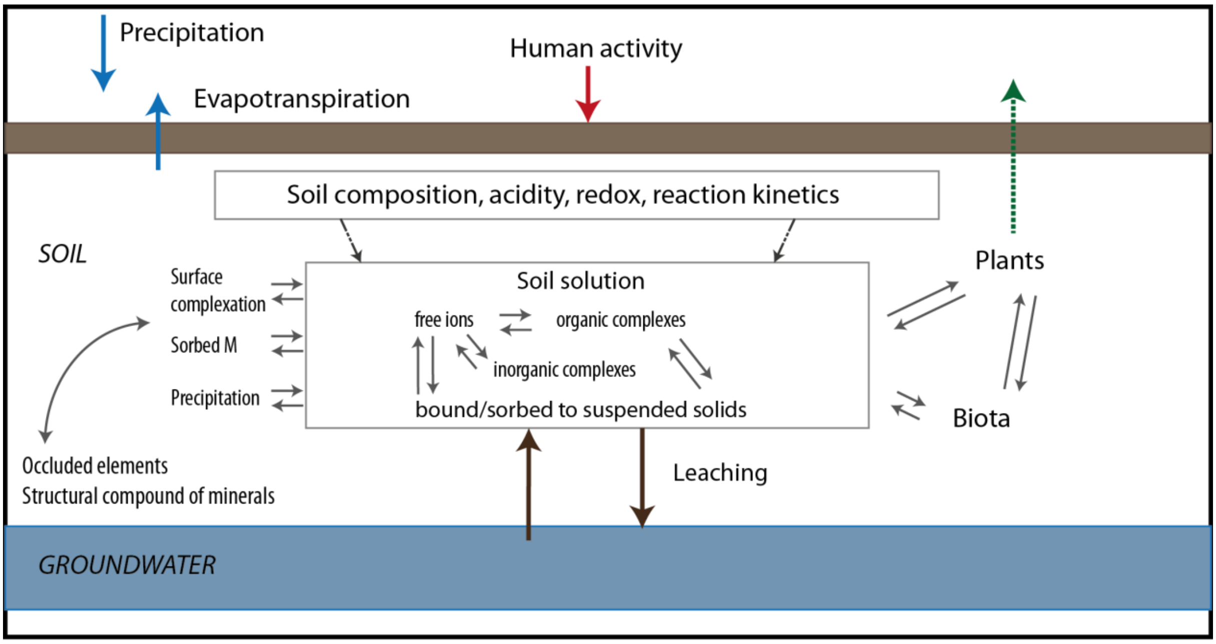


Figure 2. 3. Diagram of the various pathways and pools of trace elements within a soil, with the soil solution as the dominant means of various forms of elements entering and interacting within the soil. Modified from Tack (2010), figure 2.1.

In summary, in the many decades since archaeological geochemistry was instigated as a tool in archaeology for prospection and understanding settlement morphology, a plethora of extraction and instrumentation approaches have been tried. Starting with wet chemical extraction of available phosphate through to the use of ICP to simultaneous detect up to seventy elements, the method has been applied on a wide range of archaeological sites. That said, there are still gaps in our knowledge, technological issues and challenges facing the use of major and minor elemental concentrations' in the soil as a window into past human activity. Further past and present challenges are considered in the next section and chapter 3.

2.6.2 Past to present challenges in geochemistry

The history of this tiny niche in archaeological methods still weights upon the choices the researcher makes. The idea that past human occupation leaves chemical traces in the soil, which we can today measure and interpret with the technology available to us, remains the tenant of the method. The development and acceptance of geochemistry can, at best, be described as staggered and gradual, the main limitations being the technology available, the cost, and the limited understanding of the connections between specific activities, and the data we can produce. These issues have been present for decades, but still are a challenge to address with the relatively limited number of published studies available. It becomes a self-fulfilling circle, in that the data is discouraging costly to produce, and difficult to interpret due to the lack of published studies available for comparison. Like many other methods, it is also profoundly influenced by trends, both positive and negative, and access to expertise. For example, when phosphate spot testing (discussed above) was introduced in Norway in the 1970's, there was a flurry of attempts to use the method on site being excavated (e.g: Provan, 1971, Provan, 1973, Bakkevig, 1980). The eventual limited success, in some cases, resulted in an attitude that it was not worth the considerable time and expense, without first questioning whether the method had been correctly applied to suitable sites (Bakkevig, 1980). As late as 1991, phosphate analysis was used as a prospection tool in combination with field walking by the Åker project, Hedmark, Norway, to locate farmsteads in arable terrain. The results are dismissed in a few sentences by the project leader, saying the local phosphate levels were too high for the method to be useful (Pilø, 1992). The perceived failure of the method on various sites led to a phase of critique for phosphates analysis in the 1980's and 1990's, which was both caused by the poor results in certain circumstances, and advancement of technology. Its role as a prospection tool changed with the adaption of new excavation methods within rescue and research archaeology. In the early 1990's, open area archaeology using machine topsoil stripping (strip and map archaeology), was becoming increasingly widespread in Norway (Løken et al., 1996). Prior to this advent and adaption, locating sites existing purely as negative features below topsoil. Locating sites was time consuming and often inaccurate, reliant on topographical evidence, place name etymology, previous stray finds and field walking. Geochemical prospection, using phosphate analysis, was embraced as an addition to this tool set, sometimes with success (Prøsch-Danielsen, 1996, Prøsch-Danielsen, 2005), however challenges such as soil conditions, land use and drainage, and the application of inappropriate sample scaling (e.g. Forsberg and Haavaldsen, 1990, Höglin, 1984) meant not all results could contribute toward research aims.

Above it was suggested that, with increasing scepticism and changing methods of excavation, geochemistry perhaps declined slightly in Norway and further afield, especially as a prospection method. However the application of phosphate mapping didn't vanish entirely, in Norway or internationally. The decline in prospection was met by an increase in smaller scale sampling within excavation contexts as strip and map archaeology grew. Internationally, the sampling focus turned to internal spaces and intra-site relationships rather than prospection and large scale settlement morphology, using both multi element and P alone (e.g. Middleton, 1996, Wells et al., 2000, Terry et al., 2004, Wells, 2004). In Norway, however, currently the application of single element geochemistry is on the rise. For example, large scale sampling was undertaken over a Viking Age mound cemetery and associated features, however the data over two of the three areas appeared to illustrate local soil conditions, drainage and modern land use rather than aiding archaeological interpretation (Gjerpe and Samdal, 2005). Multi-element approaches using ICP-MS have also been applied to commercial sites with mixed success (Martens, 2007). More recently, fractionated phosphate analysis was applied to two of the three case studies presented in this thesis, and sites in southern Scandinavia (Macphail et al., 2013, Rødsrud, 2014, Grabowski, 2014, Macphail et al., 2016b, Macphail and Linderholm, in press).

The issues outlined here are not alleviated by the application of multi-elemental methods, they are heightened. Oonk et al. (2009c) outlined three issues with archaeologically geochemistry that were unsatisfactorily resolved. Firstly, for P (and arguably other elements), it remained unclear which soil phases retained P in differing environmental conditions. Secondly, determining background or a natural baseline was problematic. Thirdly, the connection between the elemental enhancement/depletion measured and the past activity remains undefined. As these issues are central to the current state of the art, rather than a relic of past development in the method, they are addressed in chapter 3.

2.6.3 Geochemistry defining space, space defining geochemistry

In the past three decades, multi-elemental geochemistry has been applied to vastly different environmental conditions, from tropical Guatemala (Terry et al., 2004) to Iceland (Milek and Roberts, 2013), on sites dating from the Neolithic (e.g. Jones et al., 2010) to post reformation (Entwistle et al., 1998) or even recently abandoned sites (e.g. Wilson et al., 2009). Ethnographic studies have also been conducted in an attempt to connect observed activities to elemental enhancement (Middleton, 1996, Beck, 2007, Coronel et al., 2014, Vos, 2016), as have experimental approaches (Carey et al., 2014). The majority of published work centres on the use of space on various scales, however certain tendencies can be extracted. A house or defined structure is often internally sampled (Middleton, 2004, Oonk et al., 2009b, Jones et al., 2010, Middleton et al., 2010, Vyncke et al., 2011) in order to understand how the structure was used. Middleton (1996) notes, activities directly related to those within the house also would have occurred outside the house, especially waste disposal. The sampling area becomes an issue of convenience, access and motivation. As archaeological sites are often multi-phase and challenging, the contextual relationships inside a house are often possible to ascertain, thus it becomes a manageable unit. It also then exists in isolation, as a studied space divorced from its surroundings.

Houses are not the only focus of study. Open areas, courtyards, plazas and field systems have been the focus of single and multi-elemental approaches (Entwistle and Abrahams, 1997, Wells et al., 2000, Dahlin et al., 2007, Fleisher and Sulas, 2015). Often applied in conjunction with artefact distribution, geophysical prospection or test pitting, these approaches can suggest both the focus and range of activities, often connected to production, processing and trade, in otherwise featureless areas. Whilst some areas can be arguably archaeologically defined by the space being enclosed by contemporary features (Dahlin et al., 2007), others are more arbitrary (Wells et al., 2000), or constrained by budget and/or modern topography (Fleisher and Sulas, 2015). There are studies that attempt to combine internal and external spaces, however the scale often results in single element analysis (Hutson et al., 2009, Grabowski, 2014) and/or few samples representing potentially diverse areas (Luzzadder-Beach et al., 2011). Therefore, whilst geochemistry has successfully been applied to understanding the use of space internally and externally, and on varied scales, how we define what can and should be measured and defined as a unit of space means we are always interpreting space through our definitions and limitations.

2.6.4 Adding dimensions

Sampling for archaeological geochemistry does vary, and it not to suggest that inventive and reflective methods have never been attempted, but there is a strong tendency for methods to fall into one of two categories: sampling specific features only (Cook et al., 2005, Cook et al., 2009, Wilson et al., 2007, Wilson et al., 2009, Luzzadder-Beach et al., 2011,), or using a horizontal grid within an archaeologically defined area (Middleton, 2004, Oonk et al., 2009b, Jones et al., 2010, Vyncke et al., 2011, Middleton et al., 2010). The first approach, sampling a feature, lays weight on the function and activity, and not the significance of why and how it happened. It ignores the significance of motion, reference and relationships in human-created spaces, focusing solely on the what. The second achieves more by way of spatial patterning and social relations, but often occurs on one horizontal plane. Time, in effect, ceases to matter, and it assumes all is comparable, culturally and pedologically. In addition, the analytical space is not always defined by the past population, but ourselves (section 2.6.3). There have been published studies that include down section sampling, for single or multiple elements, however these are often limited to one or two sections, and then time becomes the only thing that matters (Ottaway and Matthews, 1988, Crowther, 1997, Salisbury, 2013).

There are alternatives, or at least addition methods that can be used with the more established methods. Coring (as opposed to augering) as a sample method has not received extensive discussion in archaeology, however capturing stratigraphy in this manner has potential. Cores can access unexcavated areas, provide a record of the site development with minimal instruction, and provide valuable sample material. In archaeology, coring is predominantly used for shallow submerged sites (e.g. Horlings, 2013), pollen sampling (Ghilardi and O'Connell, 2013), lake sediments for environmental reconstruction (Støren et al., 2008), and, above all, in alluvial landscapes (Passmore et al., 2002, Brown, 2009). The method has a longer history of application in archaeology in the U.S. than in Europe, but has become more common globally in recent years (Canti and Meddens, 1998). There are many examples of augers used for soil sampling without mention of the specifics (e.g. Salisbury, 2012), but as noted by Gauss et al. (2013), augers frequently lose soil as they are drawn up, sample sizes can be very small, and fine stratigraphy can be blurred or lost. A great deal of information regarding soil- and site-formation processes is held in the layer interfaces, which are obviously lost in the strip-and-map method of excavation. Maintained sections can be far apart and therefore unrepresentative of the site as a whole. Taking undisturbed cores prior to excavation has the dual benefit of providing prospection information as well as full soil profiles and sample material, which, if the core locations are surveyed precisely, can be related to subsequent excavation results.

The disadvantages inherent in this method are primarily the time it requires to achieve significant depths and the disturbance it potentially causes – for instance, creating an oxidising area in anaerobic soils, which can be detrimental to preservation in the area around the core. Another disadvantage to coring is the potential for hitting and damaging an archaeologically significant object, deposit, or feature. Similar damage occurs, however, when excavation is conducted with mechanical excavators, shovels, and spades; damage is a risk regularly taken when balancing the time constraints against the information potential. Whilst not suitable for every site and situation, coring captures fine vertical stratigraphical detail that is otherwise lost during excavation, and offers a middle ground between micro-scale approaches such as micromorphology and the macro approach of excavation. By the laws of superposition, it also adds chronology.

2.7 Conclusions of chapter

2.7.1 And there we cease

Once again it is unproductive to generalise and finger-point, however the majority published studies, after a thorough divulgence of background, methods, analysis and results, offer conclusions constrained to the empirical. Economic and social interpretations are outlined, with little reference to what that means beyond ‘this happened there.’ This approach, to define ‘what happened here,’ often fails to address the issues arising from the possible interpretations, regarding the correlation between past event and chemical signature, and the inbuilt assumptions the archaeologists/scientist has when defining the space to be sampled, then moving from the raw data, to interpretation.

These issues become far more acute when methods move from phosphate analysis to multi-elemental approaches. In essence, single element analysis cannot define single activities, without overwhelming complimentary data, therefore single element data cannot be as specific. Multi-elemental analysis explicitly aims to relate measured chemical values in the soil to past activities, beyond broad categories such as people lived here, to people did something specific here, such as prepared food (Hjulström et al., 2008), butchered (Coronel et al., 2014), worked semi-precious metals (Cook et al., 2009), traded and socialised (Dahlin et al., 2007), buried their dead (Bethell and Smith, 1989) and even trampled (Vyncke et al., 2011).

This cessation at the practical can be seen as a symptom of the specific criteria expected from the scientific journals these studies are published in, and the fact that even within larger projects, research and publication is still within the two parallels. The scientist produces the data, and the humanist interprets. The division is maintained, and reaffirmed.

Whilst not all of these challenges and considerations can and will be satisfactorily addressed in this research, these factors do impact on the interpretation of the case studies presented in chapters 5 to 7.

2.7.2 Looking forward

This brief summary of the development of geochemical analysis in archaeology is far from exhaustive, and is aimed to provide a background for this research rather than deconstruct every aspect of the subject. A key feature of the vast majority of geochemical research in archaeology, is that it is aimed to provide information from the most universal medium in archaeology, the soil, on past use of space. This aim is usually achieved with spatial statics, distribution maps or other graphic forms, often in relation to excavated or known archaeological phenomena. This is often, but not always, where the interpretation stops. Functional areas are identified and explained, where possible, in practical, structuralised terms. This leaves a gap; a void between people in the past, and our data. We can surmise where people processed food in their house, the economy and resources they grew and traded, perhaps even deduce what was typical or atypical for a period and culture. We should strive for more. We should aim to explain why people chose to conform or renounce traditions, why space was used in the way it was, beyond pure functionality, and what it symbolised to those who constructed and dwelt in the created spaces.

This is the subject of many theoretical published works, however there are few cases of integration between archaeological geochemistry and social theory of space, with Karen Milek's integrated study of Icelandic houses being the exception, rather than the rule (Milek, 2006, Milek and Roberts, 2013). Studies of artefacts have made significant collaborative advances between human and natural sciences (Torrence et al., 2015), geochemistry must do the same. Understanding space in settlements, especially on sites truncated by ploughing, with very few artefactual remains in situ, or at all, is challenging to archaeology. Geochemistry offers the potential to greatly enhance our understanding of this fundamental aspect of people's lives, from the highest echelons of the society to the lowest. The cause of the slow uptake of the method, and more complete integration with established and new archaeological methods and theory, stem perhaps from the expense and scepticism over the value of geochemical data sets. More research is needed, without doubt, into the connection between major and trace elements held in the soil and specific past activities for the method to reach its critical mass. I also argue that more reflexive and experimental sampling strategies are needed, encompassing more than the single horizon. Methodological developments can be seen as an essential part of the archaeological process, to improve the relevance and reliability of interpretation of geochemical data sets for archaeological research, research that encompasses all aspects of current archaeological thought, including scientific methodologies and theoretical interpretations. The use of portable XRF, offers that ability.

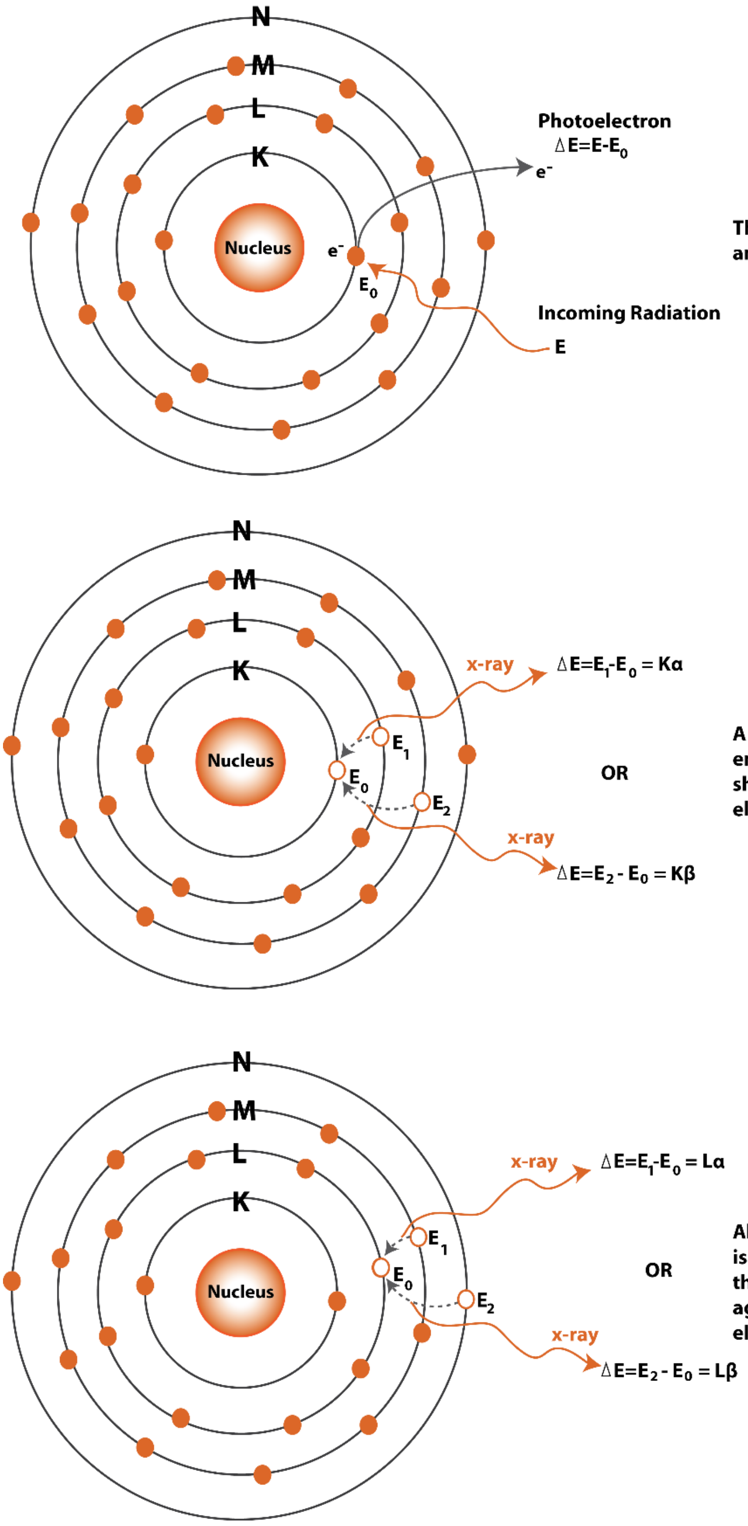
3. The use of portable XRF in archaeology and its application to archaeological geochemistry

3.1 Introduction

This chapter first reviews the ever increasing application of pXRF in archaeology, and the technological advances that allowed this handheld ‘revolution’ to occur. To set the scene, the current focus on portable objects is outlined in section 3.2. The trend for artefact studies to preferably select pXRF is set to continue, and the possible motivations for this are considered. Section 3.3 turns to the published studies that combine XRF in all forms with soil and sediment analysis, in order to outline the potential pXRF has for archaeological geochemistry, a subject that directs much of this chapter. The technical obstacles are undeniable, and reviewed here through published studies from archaeology and environmental science. Acceptance of new technology is almost always achieved through comparison to more established means, and this subject is considered in section 3.5. As pXRF has a lower resolution, accuracy and precision to instruments such as ICP, the decision to use pXRF has to be reasoned in a contextually relevant manner, as is attempted in this and subsequent chapters. Secondary contexts are a theme that reoccurs throughout the case studies, and therefore the definition and issues relating to these archaeological deposits are included in section 3.6. In the final section of this chapter, geophysical prospection is also included, as this research utilises and integrates geophysical data as a prospection tool for archaeological and environmental conditions.

3.1.1 X-Ray fluorescence

X-ray fluorescence works, in short, by using high energy X-ray photons to excite an electron in the K or L shell of an atom. By using an excitation source with energy slightly greater than the binding energy of the inner K (or L) shell electron, this electron is ejected from the atom. Electrons shift down shells within the atom, so that an L (or M) shell electron replaces the lost K (or L) shell electron. As outer shell electrons have higher potential energy states than inner shell electrons, as they replace the lost electron they release secondary energy; x-ray fluorescence (see figure 3.1). The energy released is element specific and known. X-ray fluorescence has been applied to archaeological research for over 50 years, but a complete review will not be attempted here as there are many published works available. The general application of pXRF in archaeology has been covered by, for example, Shackley (2011b), Frahm and Doonan (2013), and Charlton (2013).



The external excitation x-ray source ejects an electron from the atoms K shell

A vacancy is created. To maintain an optimal energy state, and electron from the L or M shell moves to fill the vacancy, emitting a element specific x-ray

Alternativly, in heavier elements, the vacancy is created in the L shell. An electron from the M or N shell moves to fill the vacancy, again emitting a
element specific x-ray

Figure 3. 1. The principles of X-ray fluorescence. Adapted from Tykot (2014).

Also easily found in published literature are studies comparing pXRF with laboratory based instruments or comparative techniques such as PIXE (Particle-induced X-ray emission), NAA (Neutron activation analysis), AAS (Atomic absorption spectroscopy), and Raman spectroscopy (such as Craig et al., 2010, Bonizzoni et al., 2011, Kocsonya et al., 2011, Martinón-Torres et al., 2012, Mitchell et al., 2012), which has helped establish its suitability to certain research objectives.

3.2 Portable XRF in archaeology

3.2.1 XRF goes portable

The first truly portable, hand-held instrument on the market was produced in 1994 by Thermo Scientific/Niton[1]. The downsizing of instruments from bench-top to hand-held was thanks to the development of smaller components, such as the Peltier cooled Si-PiN X-ray detector (Pantazis et al., 2010). Early instruments contained a radioactive source, which has the advantage of being highly compact, but the obvious disadvantage of being radioactive and therefore needing periodic replacement and special licensing (Liritzis and Zacharias, 2011). The development of miniature X-ray tubes resolved this issue, as well as increasing the potential kV, thus improving the accuracy of results and range of elements that could be measured. Alongside this advancement, the improvement in detectors (e.g. the silicon drift detector, SDD), automatic filter selection, and fundamental parameters (FP) software, have transformed the size, ease of use and accuracy of XRF technology (Liritzis and Zacharias, 2011). Ease of use and better software calibration does not eliminate the need for empirical calibration and the use of recognised international standards (Shackley, 2011a), but takes away the exclusivity of the technology from highly specialised laboratories (Frahm and Doonan, 2013). Essentially, without empirical calibration the analysis is qualitative and incomparable, although the results may be internally consistent (Speakman and Shackley, 2013, Frahm, 2013). For some studies this may, of course, be more than acceptable and suitable to the research goal (Frahm, 2013). The idea of using the manufacturer’s settings and the suitability of using internally consistent results only, in order to answer archaeological research questions, is tested in regard to the data sets presented within this thesis. The definition of portable in this chapter is not in the purist sense of the word, and some instruments in papers cited require a power supply, whilst others are handheld. This theme is discussed further below.

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[1] See http://www.niton.com/en/portable-xrf-technology.

3.2.2 Obsidian

The use of pXRF in archaeology has grown exponentially in the past decade or so, as have the variety of applications. The focus has been predominantly on lithic provenance, initially through the vocal support and expertise of M. Steven Shackley, Robert Speakman and colleagues who have all been part of the Geoarchaeological XRF laboratory in, Berkley, U.S.A at some point in time. New specialist laboratories have also appeared over the last decades, such as at the University of Missouri Research Reactor (MURR), and at The Center for Applied Isotope Studies at the University of Georgia, amongst others. For published examples see Phillips and Speakman (2009), Craig et al. (2010) Shackley (2010), Speakman et al. (2011), Shackley (2011a), Speakman and Shackley (2013). This has now an echo on this side of the Atlantic from Sheffield University through the works of Frahm (2013), Frahm et al. (2013), Frahm and Doonan (2013) and Frahm and Feinberg (2013). Similar studies increasingly abound worldwide, and although some do not adhere strictly to purely portable instrumentation, they can be considered similar in aim and scientific method (Jia et al., 2010, Nazaroff et al., 2010, Burley et al., 2011, Millhauser et al., 2011, Sheppard et al., 2011, Forster and Grave, 2012, McCoy et al., 2011, Kellett et al., 2013, Neri et al., 2015). These all are concerned with obsidian, which lends itself especially well to the technique. Obsidian is a geological sample which is not subject to the plethora of taphonomic processes that would otherwise be detrimental to non-destructive analysis, and in some senses the focus on obsidian by the most vocal, has stifled the critical debate over the method and application of pXRF in archaeology. The success of pXRF with lithic sourcing is due to it being potentially accurate to ppm (mg/kg) for mid-weight elements (from Ti, Z=22 to Au, Z=79, although few studies use elements heavier than Z=58 as the signal to noise ratio declines) for the majority of recent (i.e. since 2008) pXRF instruments. The combination of a proportion of a small group of elements present as major and minor traces within the artefact, which are statistically treated and compared to likely sources, thus providing a potential provenance. This plays to the strengths of the instrument, which is non-destructive and allows rapid analysis without complex sample preparation, therefore allowing a large quantity of artefacts to be analysed, giving a statistically viable and relevant data set. In a more recent article in this obsidian trend, Frahm et al. (2014) demonstrate that by teaching the portable XRF the chemical 'fingerprint' of selected obsidian types, the analytical time required to provenance the artefact is minimised. They suggest identification can be achieved in ten seconds using pXRF allowing hundreds of artefacts to be analysed and sourced, per day. Again, obsidian is ideal, as the chemical signature can often be constrained to a singular volcanic event or geographic area.

There are issues with the application of pXRF that can, generally speaking, be safely ignored in obsidian sourcing. These are the elemental range required, moisture content, the surface of the sample, the corrosion/contaminate layers on artefacts from burial or conservation, the homogeneity and therefore representativeness of the sample area and the detector resolution (overlap between emitted wavelength/energies). These issues are discussed below.

3.2.3 Beyond obsidian

Aside from obsidian, pXRF is also readily applied to ceramics, glass, paints and metal artefacts, and a range of lithics types. The appeal of the instrument, with its flexibility and ease of use, means it is rapidly becoming a feature in research and conservation of a wide range of materials. For example, pXRF has been applied to carbonate rocks, more specifically limestone in Sicily, to source the materials used for construction materials and sculpture (Barbera et al., 2013). Away from geology, Uda et al. (2002) and Abe et al. (2012) considered the composition of pigments and paints on Egyptian glass and ceramics, and Bonizzoni et al. (2011) looked at pigments in a sarcophagus. Glass from the far-east have also been studied using pXRF (Liu et al., 2011, 2012, Tantrakarn et al., 2012) and Europe (Oikonomou et al., 2008), and the study of ceramics (Forster et al., 2011, Frankel and Webb, 2012) and glazes (Pappalardo et al., 2004) is also becoming frequent. In common for many studies is the purpose, which is generally provenance. This can be the provenance of the raw material itself, or that of the pigments, dyes or paints used. This is not to say other aspects are not considered, such as the manufacture techniques of the objects or issues connected to preservation and conservation. XRF and pXRF are also an established technique for testing the alloy composition of artefacts, although it is not always sensitive enough for more than coarse compositional analysis of objects (Gliozzo et al., 2011, Heginbotham et al., 2011, Martinón-Torres et al., 2012, Karydas et al., 2004), however, it is often more than sufficient for historic and prehistoric artefacts where the manufactured composition contains considerable variation.

Once away from the dominant field of provenance, the amount of published studies relating to archaeology falls dramatically. Indeed, few studies have been published in the field of archaeology using truly portable XRF (i.e. hand held) that do not relate to the provenance and/or composition of an artefact in a museum or laboratory. Few studies use the instrument on site, and of those that do, many are in a stable field station rather than outside exposed to the elements. For example Carter (2009) used the hand-held Bruker Tracer III-V at Catalhöyük, although the analysis of pigments on skulls was done at the local museum rather than in situ. As Phillips and Speakman (2009) point out, the portability of the instrument alleviates the need to export artefacts to a foreign laboratory, something that can be problematic, and in some cases impossible. In addition, analysis on artefacts in situ, i.e. outdoors on-site is rather pointless. The only cases where this is perhaps more relevant is when considering phenomena on upstanding monuments and buildings, and soils and sediments. There is huge range and potential in using pXRF on archaeological and historical sites for the purposes of in situ conservation, researching past activities that do not leave clear artefact or other physical evidence, or refining the understanding of those that do, such as the function of oven constructions (Cook et al., 2009).

The debate over what defines ‘portable’ is well covered by Frahm et al. (2014), who chooses to divide instruments in the portable category into hand-held (HH), field-portable and lab-based. The first division is useful, as it differentiates between instruments that in theory can be moved to locations and those that can be easily carried and used without mains electricity. The second is vague and less useful, as many field-portable instruments are light and flexible but require a power supply and stand to operate (e.g. Outstex used by Liu et al. (2012)) and many are portable in the sense that can be moved but weigh 8 kilos (see Frahm 2013). As many prospective surveys are carried out over large areas and/or in remote locations, the division in this sense is between those instruments that allow on site, in situ results without extensive resources, and those that do not. A reassessment of the definition is not offered here as to choose which instruments fit into which category, and what is suitable for in situ analysis varies with the physical constraints and resources of the fieldwork. In addition, with a rapid technological development in this area, the range of lightweight, battery powered instruments is moving steadily forward, meaning soon the debate over what qualifies as portable, will soon be redundant.

Lack of published studies using in situ pXRF and pXRF on archaeological sediments does not reflect the potential. Portable technology is demand-led innovation from industry, such as mining/mineral extraction, metal sorting and quality control, and environmental monitoring. In common for these industries is the need for robust, weatherproof design and flexibility, which the major manufactures have long since provided[2]. Robustness is not the only advantage to pXRF design. They allow for non-specialist spaces to be utilised, and the instrument to be applied in a more reflexive, intuitive manner. Perhaps the lack of published studies is the traditional divide between laboratory science in archaeology and fieldwork, and specialists in instrumental techniques in archaeology have a tendency to focus upon portable objects rather than the constraints or application of portable instruments. There are limitations to pXRF in terms of specialist calibration and accuracy over a wide elemental range, however, the question is whether these are offset by the flexibility and more fundamentally, what is the level of precision

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[2] Major manufacturers referred to are: Olympus (http://www.olympus-ims.com/en/xrf-xrd/delta-handheld/), Themo Scientific/Niton (http://www.niton.com/en/portable-xrf-technology),
Bruker (http://www.bruker.com/products/x-ray-diffraction-and-elemental-analysis/handheld-xrf.html),
Oxford Instruments (http://www.oxford-instruments.com/products/analysers/handheld-xrf-analyser-x-met7000-series),
and Spectro/Ametek (http://www.spectro.com/pages/e/p010602_spectro_xsort_overview.htm).

required in archaeology to provide reliable, applicable data? These issues will be addressed through the application to geochemistry in archaeology.

3.3 Archaeological geochemistry and XRF

A review of the development of archaeological geochemistry is provided in chapter 2. Here the focus is on analytical methods rather than the broader development of the method. The use of laboratory based XRF (lab XRF) in archaeological geochemistry is not unheard of, nor unsuccessful. For example Cook et al. used XRF on samples from Silchester (Cook et al., 2005, Cook et al., 2009). The study was highly successful in combining XRF results with archaeological data to identify the differing uses of hearths and ovens over time. Oonk et al. (2009b) used ICP-OES and HCl digestion to extract available elements from excavated surfaces, and used XRF for totals of all elements of interest. Lubos et al. (2013) used XRF on samples taken from exposed sections, whereas Abrahams et al. (2010) also used XRF alone on topsoil. Their earlier work used ICP-AES in semi-quantitative mode, uncalibrated, which would not be any better in terms of comparability and accuracy, as the data is not comparable beyond that day and that sample run. So, whilst ICP-MS/OES/AS is the overwhelmingly dominant choice of analytical instrument in archaeological geochemistry, viable results are produced with XRF.

One of the central questions in archaeological geochemistry is 'what are we actually measuring?' This is rarely satisfactorily addressed in research articles, as the answer is dependent on a plethora of factors, some of which are uncertain. This spans a number of methodological debates, such as extraction and digestion methods for ICP, sample depth on site, pedological processes over time, variation in elemental retention over space and time, geological input, and issues of interpretation such as how universal elements/groups of elements are for a specific activity in differing conditions. These will not all be covered here, but these are covered to some degree in recent review papers (Wilson et al., 2008, Oonk et al., 2009a, 2009b, Wilson et al., 2009, Walkington, 2010) and other good published case studies (e.g. Jones et al., 2010, Luzzadder-Beach et al., 2011, Vyncke et al., 2011), as well as chapter 8 of this research.

The intention is to measure anthropogenic enhancement in soils and sediments, which can be used to define past activity and occupation areas. As illustrated by the predecessor to multi-elemental analysis, phosphate mapping (as outlined in chapter 2), there are a vast array of extraction or digestion procedures that can be used to extract the elements of interest from the soil or sediment, but what is deemed suitable varies with the background of the researcher, the project research questions, the soil type and the resources available (Bethell and Mate, 1989, Holliday and Gartner, 2007). To complicate things further, the pathways within the soil for elemental retention vary according to the pH, particle size and type (e.g. type of clay, proportion of sesquioxides) and organic content of the soil, and are not completely understood for all elements. With digestion or extraction for ICP, regardless of the method used, unless total digestion using HF is employed, only a selection of the sample is actually analysed. And as this sample is usually about 0.1 g, how representative can it be? The inhibitive cost of ICP, although reducing, does still limit the amount of samples that can reasonably be taken, and therefore many sites have coarse sampling resolutions of 5 or more metres (Entwistle et al., 2000, Salisbury, 2013,). The potential to miss features, especially if the site is essentially an 'unknown' i.e. without any evaluation data available, is rather great.

Returning to the sample itself, there are many that argue that the extraction of elements from the soils using, for example, 2-3% HNO_3 , as opposed to digestion, is more representative of anthropogenic inputs (Wells et al., 2000, Middleton, 2004, Wells, 2004, Salisbury, 2013), as with 'available' phosphate extraction. New methods such as mobile metal ion extraction are also being introduced to target a specific element group and phase (Sylvester et al., 2015). The principle is that added elements to the soil, from metalworking debris and corrosion products to rotten organic waste, will be held in labile, soluble form as they are adsorbed primarily onto charged clay surfaces, amorphous phyllosilicates and organic compounds. These are then oxidised and released by the extraction procedure. This ignores the fact that this mechanism is an over simplification, as elements are constantly exchanged and leached through interaction with the soil solution. Elements that are retained through anion rather than cation exchange can rapidly become mineralised and thus more 'fixed' in the soil matrix. Soil processes are highly dependent on pH, and not invulnerable to change from environmental and human pressures over archaeological time frames. It therefore depends upon the prevalent soil conditions over time, part of which is an unknown. However, weak extractions do work as there will be a proportion of the anthropogenic elements that can be drawn into solution. Whilst often described as the fraction of interest, it also contains everything else that has worked its way into the soil since the archaeological occupation in question. Thus, it is never the actual values that are of interest, but the proportional enhancement and the correlation between elements. Therefore, how accurate do we need to be?

More aggressive extractions are common, such as *aqua regia,* HCl or $HClO_4$, which can extract more complex ions into solution, and this middle ground is potentially more representative of the inputs of interest than weak extraction. A second alternative to weak extraction is HF or total digestions, which are not ideal either. Firstly, it requires specialised safety standards and equipment, which not all labs have. Secondly, the silicate structure, including all the elements in the clay lattice, either in large sheets such as K in Illite, or as isomorphic substitutions, will be measured. This can have the effect of 'drowning' the anthropogenic inputs. However, it is absolute in that everything is measured. XRF has the advantage and disadvantage of also being a total method, in which the whole sample is analysed (Gauss et al., 2013). Admittedly, pXRF is not as accurate as ICP-MS using HF digestion, but is which is also without the dangerous, lengthy and costly extraction.

As insisted frequently by Speakman and Shackley (2013), and again in Hunt and Speakman (2015), and also the theme of this chapter, pXRF should not be seen as point and shoot, therefore some factors affecting the use of pXRF on archaeological soils and sediments must be addressed. These are first considered below, and are illustrated in later chapters through case studies.

3.4 pXRF on soils and sediments

3.4.1 Methodological limitations

Soils and sediments provide their own set of challenges for using pXRF, either in or ex situ. This section considers the major known limitations; water or moisture content, sample heterogeneity, sample geometry and in situ analysis before considering instrumental elemental range.

Water content

This is a major inhibitor for analysis. Water attenuates the radiation both from the x-ray source, and the emitted radiation by a factor which varies according to the elements of interest. Bastos et al. (2012) found moisture content attenuated the signal by up to 20% compared to dried and ground samples when measuring Mn, Ni, Zn, Br, Y, Nb, Ti, Fe, Zr and Pb. Berger et al. (2009) demonstrated that when measuring the lighter elements, S, Al, Ca, P, Si, Fe, in sediment samples using a helium purge, water content was negatively correlated with element count. The difference in measured values between a dry sample and samples with 50% water was over 50% in some cases, but the degree varied by sample and element. The difference of 30% in findings for the degree of attenuation is probably due to using the helium purge and a focus upon lighter elements. A further study by Coronel et al. (2014) used pXRF on four samples with differing properties (sand, clay loam, high organic matter, low organic matter) with varying degrees of moisture saturation. For the elements Cu, Zn, Sr and Zr, the results were significantly lower in the saturated soil in all cases. The effects were greater in the high organic soil for all elements except Fe, due to the soil's ability to retain a large water volume. However, on the other soil types, Mn and Fe increased with moisture content, attributed to finer particles being held in solution closer to the instrument than in dry samples. They conclude that Cu, Fe, Mn, Sr and Zn levels in soils with low organic content could be measured in situ or without drying. This partly contradicts Berger et al. (2009), and Bastos et al. (2012), and as the study is based upon four samples, definitive conclusions cannot be drawn. A further example is provided by Crooks et al. (2006), who conclude that moisture content, if known, can be corrected for, although they found a direct correlation between moisture content and lower readings in samples when measuring heavy metal concentrations. Therefore, there is a degree of attenuation with both lighter and heavier elements in moist samples.

In a larger study by Schneider et al. (2015), 215 samples from differing environmental conditions tested both the correlation between elemental results from *aqua regia* digestion using ICP-AES and pXRF. Going further, the samples were then tested using pXRF dry, recently wetted, and two days after wetting, in which time the samples had been left in ambient air conditions. The results strongly suggest that all elements were affected by moisture content, although in differing degrees. The attenuation by moisture content could be fixed using the Lambert-Beer equation, that is to say the attenuation is to some degree predictable based upon known moisture content for all elements measured in their study.

These published studies also clearly demonstrate the link between moisture content, particle size and signal diffraction, meaning wet, coarse samples are poor representatives of actual content (Berger et al., 2009). Ge et al. (2005) suggest this can be corrected using a formula based upon the direct correlation between the back-scattered radiation and the water content of the sample. This formula can be applied to samples with up to 20% moisture. Schneider et al. (2015) also concluded it was feasible to apply moisture corrections to elemental concentrations from samples. However for this to be possible, for in situ analysis, the soil water content has to be known for later data correction. It is also questionable whether one formula can correct for the effects of water in varied soil conditions, given that other mentioned studies found that the soil type strongly affected the elemental results when moist.

Sample heterogeneity

To return to the study mentioned above, Coronel et al. (2014) also studied the effect of grain size on pXRF readings. They conclude that sample heterogeneity, especially in situ, is a large source of error. However, their study concludes that sieving to 2 mm and grinding the samples in a porcelain mortar is adequate to compensate for this effect with the majority of elements. Harking back to the previous section on representative sampling, how representative is 1 g or even 0.1 g of dried and crushed soil? This issue is not avoided by any other method employed in archaeological geochemistry, and the best solution is to increase sample density and be consistent in sampling method. An alternative solution can be to grind, homogenise and pelletize the samples prior to analysis to create a more uniform sample in terms of surface and texture; it also removes the air spaces within the samples to improve light element detection with or without helium purge when using pXRF. Obviously, this can significantly increase the sample processing time and cost, and does not remove the issue of soil heterogeneity over a site or archaeological surface.

Using XRF, the penetration for the analysis of heavier elements can be up to 2 millimetres in highly porous samples, whereas for the lighter elements only the surface is excited due to the lower KeV required (Berger et al., 2009). Davis et al. (2011) analysed obsidian samples using a lab XRF to examine the effect of sample dimensions. The minimum width of the sample in their study is 10-25 mm, however, this is dictated by the sample window, which ideally should be covered by the sample and the elements to be analysed. The thickness, they suggest, should be over 1.2 mm, but they note this is dependent upon the excitation energy used and the composition of the sample. This is based on ideal conditions, when results are to be as precise as possible, and the study does note that less than ideal sample sizes can produce viable results.

Surface geometry

The instrument assumes an infinitely thick, homogenous sample with a smooth surface (Charlton, 2013), which of course many archaeological samples are not, and cannot be without very undesirable damage or lengthy processing. Newer instruments also have modes or settings which automatically select the filter and elemental range suitable for the material, which can also have inbuilt assumptions over the sample texture. For example, the Niton XL3t GOLDD used in this research has a soils mode, which is designed for environmental monitoring. This mode assumes the sample is not ideal, but porous with an uneven surface geometry, whereas the metals mode assumes a homogenous and flat surface. Therefore the results are not purely a measure of sample processing, but of instrument setting and assumptions with the newer portable instruments. Additionally, Hunt and Speakman (2015) note that for ED-XRF instruments such as portable XRF instruments, the effect of surface geometry on sediment and clay samples is often small.

This stands opposed to studies by Crooks et al. (2006) and Coronel et al. (2014) who both suggest that increasing particle size is negatively correlated with elemental count for the studied elements. Technological developments have advanced since 2006, and the recommendation by Crooks et al. (2006) that sampled should be sieved to 125 µm is a reflection of this. In Coronel et al. (2014), 2 mm was deemed sufficient for dried samples analysed in a field laboratory. This change is perhaps a reflection of both the purposes of the study (land contamination and ethnographical geochemical survey), and the improvements in fundamental parameter calibration algorithms.

In the previously mentioned study, Davis et al. (2011) analysed the effect of surface angle on samples, and concluded this had a minimal effect for all but one of the elements they selected (Fe). This experiment, as they note, was on modern samples that have not been subject to weathering etc. as archaeological samples are. This experiment was also on obsidian, which as stated previously, is close to ideal. When considering soil and sediments, surface geometry is closely linked to sample heterogeneity, and can be partly mitigated by sample preparation methods such as sieving.

Trace element accuracy on site

There is a general consensus that pXRF instruments are internally stable and fairly precise (Nazaroff et al., 2010, Shackley, 2010). The accuracy has been questioned, which will be discussed further below and in chapter 4. Instrument precision and accuracy is easily measured and reconciled with the correct use of standard reference materials (SRM). Accuracy on-site and in situ can be problematic. Moisture content of the sample will vary from area to area due to a profusion of natural and man-made variations, which are not always quantifiable. In addition, holding four kilos perfectly steady for minutes at a time invites human error. With using pXRF, especially on-site, measuring absolutes cannot be an objective. As with all geochemical analysis in general, in situ results are not suitable for inter-site comparisons. It is the intra-site variability that is interpreted. Misinterpretation can occur, however, if the figures are affected by moisture, porosity and uneven surface geometry to the degree the results become unrepresentative or unreliable. So why not always do the analysis in a laboratory, where samples can be processed to be consistent, and suitable samples can be easily used without the added worry of contamination or other hindrances? The ability to answer questions on site is invaluable for targeting sampling or even excavation, and aiding in situ interpretation in order to improve recovery (Donais and George, 2013). As long as the limitations of the analysis are known, can data be useful without being accurate?

In a pilot study comparing pXRF on wet and dry samples to ICP using weak acid digestion, Nolan and Hill (2014) found that the wet samples analysed using pXRF were more broadly comparable to the ICP results than the dry samples. As Middleton (2004) suggested in his much referenced paper, when including the whole sample via total acid digestion for ICP, the geological signal can 'drown' out the anthropogenic enhancement. Nolan and Hill (2014) suggest this is the case with dry samples using pXRF, but offer no explanation as to why wet samples would be comparable to acid extracted samples for ICP. Logically, the attenuation of the signal from moisture, or indeed sample heterogeneity, would have equal effect on both the weakly held potentially anthropogenic elements and the soil matrix (see 2.4.2). However, they do note that dry pXRF samples did not appear to mirror the known distribution of archaeology on the test site, whereas wet samples and ICP results did. The fact that results do not meet predictions does not automatically mean the results are invalid; it could equally be the case that the predictions, based upon unexcavated archaeological features, were misinterpreted at the start. It is within the realms of possibility that archaeology has affected moisture retention, creating a 'false' reading with the wet samples that could be misinterpreted as elemental values alone, as opposed to physical sample properties. This illustrates the importance of carefully recording the soils during sampling in situ (and in cases where the sample is measured in laboratory conditions), as many desirable and undesirable effects on elemental retention can occur over short distances.

All the factors in this section were considered prior to and during the analysis of case study samples. Chapter 4 contains results from tests undertaken to assess instrumental accuracy and precision, moisture content and analytical time.

3.4.2 Elemental range

Considering the effective elemental range using pXRF, the limits of detection for quantitative or qualitative analysis need to be considered. Whist many manufacturers advertise that pXRF can analyse elements as light as Mg (Z=12), the limits of detection below Ti (Z=22) are often worse than parts per thousand and generally are in % by volume when used without the helium purge. The heavier elements, such as Rb (Z=37) and Sr (Z=38), which are frequently used for obsidian sourcing, are all within the ppm range, often detectable to under 10 ppm, and comparable with other instrumental results when calibrated (see figure 3.2 and section 3.4.6). Another limitation comes at the other end of the elemental range, at the elements around Ba (Z=56).

Ideally, the KeV should be 1.5-2 times the elements principle Ka/Kß line, but as no pXRF can produce more than 50 KeV at the moment, and the principle Ka/Kß for, for example, Ba is 32.19/36.38, this represents the limit of the instrument for ppm accuracy using K lines. The Ka/Kß line gives the sharpest peak and are the lines measured up to around Cs, above which, the L lines have to be measured (Berger et al., 2009). Background and peak distinction can be significantly improved, even for the heavier (Z=50+) elements, with the use of targets and filters, which should be suitable to the selected elements. Many instruments, such as the Niton/Thermo Scientific used in the case studies presented in this thesis, automatically select filters to optimise detection.

3.4.3 Comparing results: pXRF compared to extraction techniques

In a study of 79 samples from a modern plaza in Telchaquillo, Coronel et al. (2014) compared results from pXRF to DTPA (diethylenetriaminepentaacetic) extraction for ICP-AES, which is a weak acid technique suited to alkaline, carbonate rich soils. The study found the results for the elements of interest using both techniques (Fe, Cu, Mn, Zn) were able to answer the research question, whlst having the potential to save considerable time and expense. P was measured using Mehlich extraction methods (Fernández et al., 2002, Terry et al., 2004), as the study found that high Si content in the samples interfered with P results using pXRF.

Within archaeology, at present, there are few published studies directly comparing geochemical analysis methods on soils. As the use of pXRF is accelerating rapidly, due to the cost advantages named by Coronel et al. (2014) and Donais and George (2013) amongst others, this will undoubtedly change. In the research of contaminated soils, a study by Crooks et al. (2006) suggested that pXRF was not accurate enough for the purpose of measuring levels of pollution on brownfield sites to certified thresholds. The study used a Niton 700, which is now outdated technology; the new instruments have superior limits of detection and the use of pXRF has expanded in the field of environmental monitoring and assessment (Parsons et al., 2013, Ramsey and Boon, 2012).

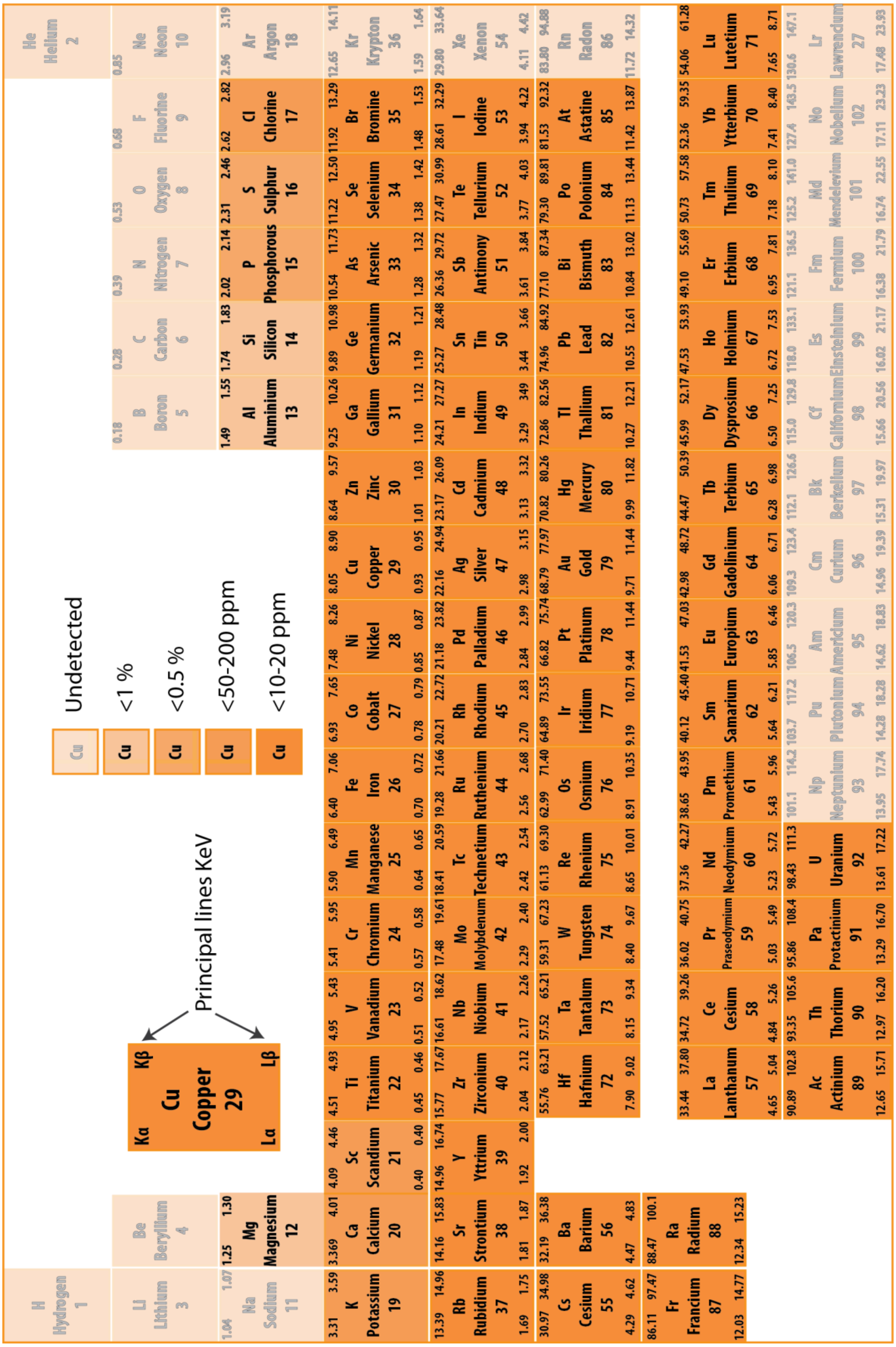

Figure 3. 2. The periodic table showing the principal lines in KeV (K_α, K_β, L_α and L_β) and the limits of detection using pXRF with a 50 KeV X-ray tube such as the Niton/Thermo Scientific Xlt3 GOLDD used in this study.

In their larger study on non-archaeological soil samples, Schneider et al (2015) found strong correlation between samples analysed using *aqua regia* digestion and ICP-AES when compared to pXRF. The samples were dried, sieved to 2 mm and ground prior to analysis which, as the previous sections have noted, is required to eliminate variables that can attenuate the X-ray's. The agreement between the values led them to strongly conclude that pXRF was a viable, cost effective alternative to more traditional ICP extraction based techniques.

3.5 Portable XRF, archaeological prospection and geochemistry

Geophysical data is often collected in the evaluation stage of an excavation or project, whereas sampling for archaeological geochemistry is undertaken on exposed surfaces toward the final phase of the excavation, often to simply bolster existing interpretations of the excavation records. The exception to this is phosphate analysis, which is occasionally used as a prospection method on topsoil or as a means to delimit sites beyond the area of excavation (e.g. Sarris et al., 2004). The success of multi-elemental analysis in delimiting sites (Abrahams et al., 2010) has to some degree extended to the functional division of sites as a prospection method (Entwistle et al., 2007). However, it has rarely been integrated with other prospection methods such as coring beyond the topsoil depth, or using geophysics to enhance sampling.

Remote sensing using geophysical techniques in archaeology has significantly advanced in the past four decades (Gaffney and Gater, 2003), and is now widely utilised as a non-destructive method of understanding archaeological sites on inter- and intra-site scales (Trinks et al., 2010). Whilst geophysics can identify and locate sites on landscape scales, interpretation of features is often restricted to well documented 'types' of feature, or simply presence or absence of archaeology, without the possibility of assigning a function, date or condition (Gaffney et al., 2012). To gain such information, ground-truthing or excavation is seen as necessary, which represents a destructive and costly intervention, as it not always possible due to issues of access and ownership.

Because prospection and excavation are not necessarily conducted at the same time, and use different tools and techniques to achieve their goals, they are often seen as one leading to another, rather than one and the same. However, archaeological geochemistry can be seen as a bridge between the two; equally applicable to prospection as to excavation. Space exists in all scales, after all. This conceptual flexibility is best met with equally flexible methodological and instrumentation approaches, such as pXRF. Coring is addressed in the next chapter, as a sampling method suitable for excavation and prospection, for ground-truthing and sampling for geochemical analysis.

Archaeological sites are not two dimensional, nor are they perfectly captured in stratigraphic stripping by hand or machine. Phases, deeper stratigraphy and intrusions are common, as are highly varying types of deposit. Geophysics, depending upon the method used, can provide three dimensional data, however geochemical sampling strategies are often designed to only capture one stratigraphic layer; one moment defined by physical constraints. But it is never truly a moment: it is an amalgamation of past and present processes. This is especially true of prospection applications, where only the topsoil is sampled, which is reliant on modern land use sufficiently truncating the past to allow us the capture it (Entwistle et al., 1998, 2007, Abrahams et al., 2010). This will over-simplify, by-pass, or amalgamate variation in activity or site function over time, and therefore limit the reliability of interpretations based upon prospective geochemical data. Sampling on more than one phase or horizon obviously increases the cost, and is beyond the realm of most studies. In order to understand geochemical signatures in archaeological soils and sediments, and to have sufficient data to analyse and understand the retention and mobility of elements over time, pXRF has to play a significant role in future research. The potential reduction in cost and the ability to work in situ, and well as on the horizontal and vertical planes, will allow research to begin to culminate sufficient data to assign function through elemental enhancement in a wide variety of environments.

3.6 Secondary contexts as a source

Many archaeological sites are under cultivated or otherwise utilised land. Under the cultivated soil, archaeological features are gradually truncated and eroded. The negative features that remain are exposed or discovered using remote sensing or mechanical topsoil stripping. It is easy to forget how recent these developments are. In Norway, it was only in the early 1990's, after the success of projects such as Forsandsmoen (Løken et al., 1996) and Åker (Pilø, 1992, 2002), that mechanical topsoil stripping became common in field archaeology. Now it is the standard method for excavation in cultivated areas. The consequence of this method is that soil is mechanically stripped until a strong contrast is seen, usually into the B horizon. Archaeological features are defined as contrasting sediments within the B horizon, preserved as negative features only. This is how archaeology becomes defined, and thus how it is expected to appear in cultivated areas. Expectation becomes reality.

Typically, the negative features exposed or identified are ditches and postholes, with cooking pits also being common. Less frequently hearths and graves are discovered. Truncated postholes, pits and ditches often form the sole remnants of settlement and houses, and they commonly consist of *secondary* backfills. That is, the sediments within the cut are often a heterogeneous mix of locally derived material from the last phase of occupation disturbed by that feature, and earlier activities. The sediments do not directly represent a sole activity or a deliberate assemblage. They can also be formed after abandonment by sinkage and compression filling the top of the feature with chronologically later material, although such distinctions can be hard to make. These compare to *primary* contexts, whose composition represents a deliberate act, and the spatial distribution of enhancements in the sediment reflects the activity or process that purposively created them. For example, the detritus of micro-flakes produced around someone striking a flint core with a hammer stone could potentially be considered a primary context.

The definition and use of the terms *primary* and *secondary* originate in Martin Carver's 'Digging for Data', who had his starting point in *Behavioural Archaeology* by Schiffer (1976). It is worth quoting the relevant passage in full:

'Assuming the laws governing behaviours are acceptable, contexts can be designated "primary" (produced directly by the occupants) or "secondary" (redeposited and to some extent distorted or contaminated).' (Carver, 1995: 105)

Schiffer also included the term *disturbed primary,* but even so, there is clearly an obvious gap between the ideal of primary and secondary contexts and reality. Even within this definition, there are immediate problems governing the laws of behaviour, as they are left undefined for another theory to fill in. Another way of seeing the distinction between secondary and primary is by in situ formation versus transportation. Due to this research focus being upon soils and sediments, the analogy to soil and sediment formation feels appropriate. Whereas a soil is weathered in situ to form a body of mineral and organic constituents that differ from its parent materials (Birkeland, 1999: 2, after Joffe, 1949), a sediment is a mineral/organic material that has undergone weathering, transport and re-deposition by one or many geographic agencies (French, 2003). This, of course, means a sediment can become a soil and a soil can become a sediment, but it is not to suggest that primary contexts are soils and secondary contexts are sediments by the definitions given here. If humans are agents of transport, which surely they are, then the definitions of primary and secondary relate to in situ versus transport and re-deposition. However, just as a soil can become a sediment and vice versa, a primary context can become a secondary, and vice versa. As Harris (1989) notes, context formation can invert stratigraphy, and the resultant context can be a mingling of many combined primary and secondary contexts. New occupation phases utilise, expand and alter previous layers and contexts and definitions do not always clearly function in reality.

The definition used here is not too dissimilar to that of Andrén (1985), suggesting that there are both deliberate and unintentional acts of deposition, and that all can have meaning. Some are manifest, with intent to display, convey or accumulate, others are not. Those that are unintentional, he terms latent, and these include the slow but steady accumulation of material by occupation. Whilst a context can be both primary and secondary, and often is from a geochemical perspective, it is the preservation of spatial patterning from intentional and unintentional acts that defines whether they can be considered primary or not. By that, it is suggested that, if the context spatially (and thus chemically) resembles in situ actions from the activities we define and seek, then the label of primary can be used. These can be latent, or manifest in their original creation. It can seem as if we are in a linguistic hole, attempting a binary classification of irreversibly intertwined things, and therefore an example may serve to clarify. If we return to postholes and ditches, which as previously stated are the main source of archaeological information in cultivated areas, then the deposits are frequently a mix of gradual infilling and deliberate acts of dumping. The act of dumping material may be primary, but the material deposited is usually a mix of occupational debris that no longer conveys any spatial patterning that can be related to the activities it represents. Only the *act* of rubbish disposal can be seen as deliberate. Andrén (1985: 10 and 248) rightly asserts that every act of deposition are sources of information to the archaeologist. Thus secondary deposits, whilst harder to decipher, have value and meaning that can be extracted.

3.7 Conclusions of chapter

This research will demonstrate that by integrating prospection and excavation approaches to archaeological geochemistry, and by developing a more intuitive sampling approach using coring and pXRF, a more complete and intricate interpretation of archaeological sites can be achieved with minimal intrusion. On the prospection side, this can then be used, for example, to design more realistic excavation strategies and costs, or to research delicate or protected sites. It can also capture details that excavation cannot reach due to limited time, resources or access. From the excavation perspective, the site can be seen for what it is; a complex, three dimensional mix of primary and secondary deposits that have spatial and temporal aspects. Working with and within excavation and prospection approaches, archaeological geochemistry using pXRF can potentially forward our understanding of the relationship between soils, human activities and what we can measure, by providing a quicker, cheaper, and more flexible strategy that can adapt to research questions and site conditions.

4. Methods

4.1 Introduction

Within this chapter is an overview of the field and laboratory methods employed in this research. It is divided into four broad sections, the first concerned with field techniques (section 4.2); the second with the laboratory (section 4.3); the third presents data from analysis designed to address some of the major concerns with the use of pXRF in soil analysis (section 4.4), which were outlined in the previous chapter (section 3.4); and the final section introduces the statistical methods employed (section 4.5).

The three case studies (section 1.5) are presented in subsequent chapters in a specific order that represents the development and application of differing aspects of the analytical method. The adaptions are in response to the archaeological and environmental conditions on each site, and the individual site research questions. Therefore the process of site selection and method adaptation is a two-way process. Sites were selected to meet the aims and objectives, and also methods were developed to meet the site conditions, both archaeological and environmental. This flexible approach was essential to obtain more relevant archaeological results, and to test the use of pXRF in geochemistry in real world scenarios. The general and site specific methods applied at all case study sites are detailed below.

Avaldsnes is the first case study (chapter 5), and represents the initial application of pXRF to geochemistry in this research. A horizontal sampling strategy was applied to a multi-period area of the site to assess the ability of the resultant data to provide a means of interpreting the use of space. In essence, this was a more established method of sampling for archaeological geochemistry, i.e. by grid on one horizon. In addition to the horizontal grid sampling, cores were taken to see if these, combined with the use of pXRF, could add a temporal aspect to the analysis.

Heimdalsjordet is the central case study for this research. The methods applied here were developed from the success of applying coring as a sampling method at Avaldsnes. High resolution ground penetrating radar (GPR) data (see chapter 6) was available for the site, which allowed for the expansion of sampling beyond the limits of excavation and into targeted prospection, using coring and GPR in combination. Because the site was truncated, ditches with secondary backfills formed the majority of the remaining archaeological layers. Coring was applied to these features in order to assess if these could be a source of spatial and temporal information on the past use of the site. In a development of the method applied at Avaldsnes, the pXRF was used directly on the core surface in laboratory conditions.

The final case study is Kaupangveien (chapter 7). This was a small scale, commercial site within a known Viking Age trading site. The application of methods here was based upon the successes of the previous two case studies, using coring and horizontal sampling where appropriate. These were adapted to the archaeology and the limitations of the commercial setting, as potentially this is where such methods are more likely to be applied in the future. In addition, limited in situ analysis using pXRF was applied to verify initial interpretations and to better target sampling.

4.2 Field methods

4.2.1 Summary of consistent methods

Sampling methods in the field reflected the topography, archaeology and research aims of each site, as well as reference data sets available for assessment and planning. The site specific sampling methods are outlined in sections 4.2.3-5. As certain aspects remained consistent, these can be summarised as follows:

Recording and surveying

- All sample points were surveyed in prior to sampling using a Trimble S3 total station theodolite. The site tolerance was 3 mm for each site as this is standard practice for MCH. The site based grid was geo-referenced using GPS accurate to 3 mm, again in each case study. The coordinate system used throughout this thesis is WGS 1984 UTM (zone 32N).
- The recording and survey system used on all sites was INTRASIS[1], a software database designed for archaeological excavation recording.

Cores

- All cores used for geochemical analysis were taken using a Van Walt (Eikelkjamp) soil corer for hard soils, which takes undisturbed cores in a single use clear plastic liner, each measuring 300 mm in length, with a 49 mm diameter. The cutting head on the corer is 50 mm, which means 50 mm is lost for the purposes of sampling between each core section, however, the sediment trapped in the cutting head can be recorded for soil properties in the field, or stored, depending on soil conditions. The corer is hammered into the ground.

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[1] http://www.intrasis.com/

- Cores were taken to subsoil (B horizon) that appeared devoid of archaeological material of interest, unless the core was specifically taken to sample the soil conditions. In these few cases, the core was taken to the C or R horizon, depending on the local conditions.
- Cores were labelled and sealed with plastic film to minimise moisture loss before being taped up and labelled. They were then stored in boxes until analysis. Storage conditions were cool and dark, but not refrigerated as this was not available.
- Where available, high resolution GPR data was used in conjunction with environmental and archaeological assessment to guide coring sample points.

Small samples

- Small surface samples were taken using single use plastic equipment to minimise cross contamination and speed sampling, and stored in marked bags.
- All samples were taken by the author, or under the supervision of the author, after contextual and archaeological assessment.
- With all case studies, all decisions were made in collaboration with other fieldwork staff to integrate research strategy and goals wherever possible.

4.2.2 Coring method

Section 2.6.4 introduced coring as a sampling method for archaeological geochemistry. This section outlines the common method, with site specific methods detailed under site specific sub-headings below.

Locations were selected either in reference to GPR data, or were selected as the area was marked for excavation. This was dependent upon the purpose of the core. Once the location was selected, a point was marked and its 3D coordinates recorded, and therefore the core was geo-referenced and numbered within the site based system. If the core failed as it hit a stone and had to be moved slightly and restarted, the new point was surveyed to reflect this. If the core was taken from topsoil, the excess vegetation was removed. This could remove the upmost 1-2 cm of topsoil. It was discovered that grass/vegetation putrefied within the core liner upon storage, thus the excess was best removed in advance. Each core was manually hammered into the soil and removed via vertical lifting by one or two people. Extension rods were added to the core as the depth increased. As each core was taken, major stratigraphic boundaries were recorded in a notebook, including Munsell colour, thickness, interface details and texture where possible.

The distortion of the stratigraphy and compaction to the cored soil is minimal in most conditions, although topsoil can be slightly compressed due to the higher organic content and porous structure. The author has also observed compression in waterlogged clays and histic (peaty) horizons; however, these factors were minimal at Avaldsnes and the other case studies. The maximum depth achieved was 2.35 m, although the majority of cores were less than 1 m in depth. At a depth of 2.35m, raising the core was challenging, and always required two people. Cores became stuck, especially in stonier conditions, and had to be lifted using either many people, levers, or digging it out with a shovel. As the soil at all sites was fairly stone free, despite the few setbacks experienced, the method was effective. The resulting core sample proved robust and stable when the plastic liner was wrapped in plastic film and tape to maintain the moisture content.

The verticality of the cores was also an occasional issue. If the core was begun at a slight angle, the whole core continued with this tilt. Practice did help reduce this, but it cannot be assumed all cores were perfectly vertical. Although the error is usually slight, this can have an effect on depth recordings, especially in the deeper cores. The recording of depth was generally done with a foldable measuring stick, and the depth recorded to the top of the topsoil or surface. As the cores were in set section lengths, in the rare instances where measurements were not done due to human forgetfulness, they were calculated based upon the core section lengths.

4.2.3 Avaldsnes

Background, geophysics and excavation

This multi-period site is detailed further in chapter 5. The site was investigated over two field seasons using excavation and prospection techniques. The excavation by the Royal Manor Project (RMP hereafter) was led by project leader Prof. Dagfinn Skre and excavation leaders Mari Arentz Østmo and Egil Lindhart Bauer, all from the Museum of Cultural History, University of Oslo. A major issue that arose during this fieldwork was that the archaeological excavation was often limited by more modern features, such as access roads, parking areas, upstanding buildings and vegetation. Figure 4.1 shows the areas of the site excavated by the RMP over 2011 and 2012.

Initial geoarchaeological research on the site was to assess coring as a prospection method in combination with geophysics and excavation. This was undertaken by the author, however, it was *not* directly connected to this thesis and research. In areas marked for trenching and excavation, cores were taken prior to excavation, and in reference to GPR data provided by a survey conducted by the Vienna Institute for Archaeological Science (VIAS) (Stamnes and Bauer, *in press*). Therefore a substantial coring campaign was undertaken in 2011 and 2012 on the site, which provided collaborative information on soil and site formation processes and background samples. The coring proved to be minimally disruptive and damaging to archaeology. Upon examining the cores, the only archaeological finds beyond charcoal were two very small slag fragments and tiny amounts of burnt bone, from a total of 364 cores. Previously, and also unconnected to this research, many surface samples had been taken for fractionated P and magnetic susceptibility analysis elsewhere. This accumulative experience from previous fieldwork on the site raised concerns over contextual security in light of the complex and disturbed archaeology. For this research, samples were selected and taken in an area that posed questions over the divisions and use of space in the later Iron Age, and offered sufficient contextual security to allow data comparison.

Coring for geochemical analysis

As the first case study, Avaldsnes was a testing ground for the use of pXRF and potential for three dimensional (thus temporal) geochemical data via cores, therefore some trial and error was anticipated. In the area selected for geochemical sampling, Area 6, the three dimensional aspect was investigated via limited coring, although the bulk of the samples analysed were surface samples.

Cores from without Area 6 confirmed the depth of the archaeological deposits and provided valuable site formation, environmental details, and material for later subsampling, and two of these cores served as background samples for geochemistry. However, within Area 6, only four such cores were used directly for geochemical analysis. These cores were taken in maintained sections as examples of the stratigraphy in Area 6.

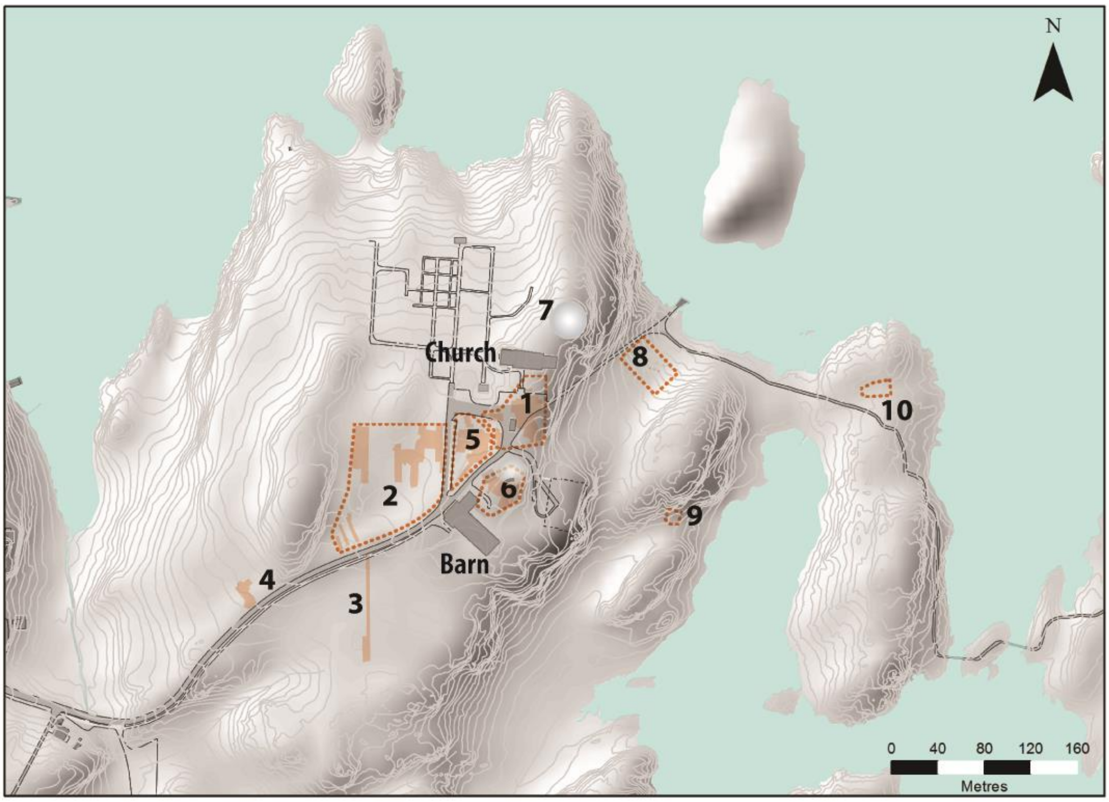

Figure 4. 1. Map showing the excavation areas at Avaldsnes as referred to in the text. The dotted lines denote the extent of each labelled area. These extents were used for geophysical prospection and excavation planning (Bauer & Østmø, 2013). Map source: Author/Ingvild Tinglum Bøckman, MCH/Norwegian Mapping Authority, 2016.

Horizontal sampling for geochemistry

The area of interest for horizontal sampling was selected on the basis of preservation, archaeological interest connected to the research aims and objectives, and suitability to the methods.

Area 6 is located in undulating terrain, with bedrock intrusions close to the surface in parts, including within the excavated areas. Naturally, this alters the soil's vertical profile, and the properties of the soil with changing depth. Samples near bedrock rises were excluded wherever possible. This, however, limited the size of the sampling grid and partly defined the sampled area. The sample area was also limited by a large kerbed Bronze Age burial mound (Kjellerhaugen) to the north, a maintained section over a modern pipe to the west, and a bedrock rise and modern intrusions to the south. The area was multi-period: dating from the site confirmed the main period of activity for Area 6 was late Iron Age, particularly the Viking Age. This reduces the *measured* duration of the *main* occupation, but it must be stressed this does not equate to single phase occupation.

During sampling, each sample point was scrutinised for the purposes of sampling consistency and quality. As detailed further in chapter 5, the site was affected, severely in places, by modern disturbances and contextual contamination. Samples deemed too close to such intrusions were discarded. In addition, sample points that were located within an identified archaeological feature were also excluded, as the purpose was to understand the spatial distribution and nature of the occupation within the selected area, and therefore sampling a specific feature would hinder this analysis. There was one exception; an oven was specifically sampled to test the use of the feature, obtain comparative data, and to see if this sampling approach could be used in future work.

Figure 4. 2. Sampling at Avaldsnes. Left: horizontal sampling, Area 6, with Mari A. Østmo surveying sample points and Jessica L. McGraw checking sample labelling. Right: Coring in Area 2, with the author and Magnar M. Gran. Photos: Royal Manor Project, MCH, UiO.

Geochemical samples were taken from an archaeologically defined layer over a predefined 1 x 1 m grid system. Each sample was taken with single use plastic spoons and placed in clean, marked bags. Samples were taken at the end of the excavation season to minimise disruption to the excavation of archaeological features. Where present, samples were taken from the base of archaeologically defined layer 25600, others from the immediate subsoil. These layers are pedologically very similar; a cambric, silty loam upper B horizon that undulates with the bedrock formation. Archaeologically defined layers do not always relate to soil horizon processes; samples can be from different soil horizons, and thus potentially have different processes and subsequent compositions. These factors can influence the chemical and physical composition of samples, hence the retention capacity of the sample for anthropogenically-sourced inputs. The samples taken from the grid represent a combination of potentially selective leaching and accumulation in the soil without temporarily. Obviously this has inherent problems for interpretation, which is discussed in chapters 5 and 8.

Challenges specific to Avaldsnes fieldwork

Two challenges dominated fieldwork at Avaldsnes. The first was all pervasive, to this research and the fieldwork, and was in the form of disturbance from modern construction activity. Cable trenches cut through areas and even the Bronze Age burial mound, Kjellerhaugen. Within area 1, the building of the car park some few decades previously had left deep tracks from a toothed digger bucket in the hearth and postholes of a Roman Iron Age house. Previous trenches dug in Area 6 for archaeological investigation also disrupted stratigraphy, and because digging in narrow trenches is always challenging, the archaeology was not recorded in corresponding detail to the RMP's observations. This was due to the accrued experience the RMP gained from working on larger scales and over an extended time frame. Areas 1, 5 and 6 were the most damaged by modern activity, however, in Area 6 it was far easier to delimit and thus manage compared to Area 1, hence the selection of Area 6 for this research The truncation of the archaeology had undoubtedly removed archaeological features and objects, a phenomenon familiar to archaeologists, and one which always complicates the interpretation process. Investments were made in sampling and analysis such as micromorphology, macrofossil, osteoarchaeological and metallurgical analysis, magnetic susceptibility and fractionated P analysis to optimise the information gleaned from the present evidence (see Chapter 5).

The second challenge was that the site was not a level field. The coring evidence strongly indicated that in the Bronze Age, the site consisted of undulating waves of thinly covered, low bedrock peaks and scarps over corresponding depressions. The shallow regnosols in the depressions formed histic, peaty layers because of impeded drainage. Land use changes; the gradual conversion of the land to agriculture began the incremental levelling of the terrain, which covered Iron Age cooking pits and earlier structures as ard-induced colluvium filled in the hollows. Upon excavation, the re-cutting of these hollows and depressions through the deep colluvium meant that one archaeological horizon would be composed of C horizon material against the weathering bedrock, and cambric, iron enriched B horizon material. Sampling on this plane would result in samples being compared that had contrasting material properties in grain size, organic content, chemical composition and thus retention mechanisms. This is difficult to compensate for without measuring these properties and including them as factors in the statistical analysis, as research has clearly shown these to be a major factor in elemental retention (Crowther, 1997, Oonk et al., 2009b, Cannell, 2011).

These issues were mitigated as far as possible by careful selection of the sample locations, choosing samples that appeared visually and texturally to be comparable, as measuring every parameter would have resulted in more laboratory work than could feasibly be contained with this research. The subject of measuring additional parameters with geochemical analysis is returned to in the discussion (chapter 8).

4.2.4 Heimdalsjordet

Background, geophysics and excavation

The extent and complexity of the site was identified by a geophysical survey undertaken on behalf of the Gokstad Revitalised Project (GOREV) by ZAMG Archeo Prospections in collaboration with the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro), the Vienna Institute for Archaeological Science (VIAS), and its Norwegian partner organizations NIKU, and Vestfold County Administration (VFK). The data used for this research were produced using a 16-channel MÅLA MIRA array with 8 cm in line and cross line spacing, using 400MHz antennas (Nau et al., 2015). The data provided three-dimensional information on the extent and form of the settlement site. Previous experience from Avaldsnes and from the coring of the nearby Gokstad burial mound using a combination of older excavation records and low frequency GPR data demonstrated the great potential of data integration (Cannell, 2012a). GPR data were first processed by the LBI team (for migration, Hilbert transform, background removal, gain, envelope and then frequency filter). The subsequent data set was then subject to visual filtering to enhance various aspects of the data set for interpretation. This GPR data are used with permission from the Gokstad Revitalised Project.

Excavation at Heimdalsjordet by the Gokstad Revitalised Project began in summer 2012 over a c.400 m^2 area, under the direction of project leader Prof. Jan Bill and excavation leader Dr. Christian Løchsen Rødsrud, both from Museum of Cultural History, University of Oslo. The areas investigated were selected from previous evaluation trenching and the GPR data to potentially encompass a road or track and two rectangular ditch features set either side of the thoroughfare (see figure 4.4). As can been seen in figure 4.4, the site is primarily composed of ditches arranged along a thoroughfare, and the ring ditches or footprints from ploughed out burial mounds. The excavation quickly confirmed the reliability of the positioning and depth of features present in the GPR data in both subsoil conditions present on the site, gleyed clay silt and sand. More detail of the geomorphological setting of the site can be found in chapter 6, section 6.2. Smaller trenches were opened to the north and east of the main excavation, again each confirming the interpretations of the GPR data. However, whilst the vast majority of features identified in the GPR data set were seen during excavation, there was one ditch that was not. This ditch was excavated, and samples taken to relate to geophysical properties.

Overall, the 2012 season of excavation demonstrated the reliability and accuracy of the GPR interpretations for sampling and research.

Coring for geochemical analysis

The first coring at Heimdalsjordet was initiated over the area identified as the likely shore/beach area in c. AD 900, the elevation of the coastline suggested from previous research at the 30 km distant Kaupang site (Sørensen et al., 2007). The intention was to identify possible disturbance within the subsoil from shoreline activity, shed light on the geomorphological features visible in the GPR data, and provide background information on soil formation for the proposed geochemical analysis. The majority of the data from coring the coastline area is not presented here, due to limited space and relevance, but it should be noted that this is the source of some of the background data on soil properties discussed in chapter 6.

In addition, from the shoreline cores, features interpreted as ditches in the GPR data set, which appeared to be as narrow as 20 cm, were successfully located by coring. This provided impetus to create a dual sampling strategy on the site, based upon coring. Initially, cores for geochemical research were taken from surfaces within the limits of excavation, and thus had the topsoil removed. During the 2013 excavation season, once again cores were taken from topsoil stripped surfaces. Further cores were then taken from features identified from the GPR data alone, using geo-referencing to locate features, all of which were easily located and samples taken. Labelling and recording cores and features was directly associated with the on-site INSTRASIS system used in the excavation areas for ease of collaboration and comparison. Thus the areas were labelled by parcel in numerical order, referring to each of the rectangular series of ditches sampled.

Figure 4. 3. Left: Kristján Mímisson lifting a core at Heimdalsjordet in 2012. Right: Kristján Mímisson and the author packaging and recording cores on site. Photos: Christian L. Rødsrud/MCH.

Figure 4. 4. Areas excavated as part of GOREV at the Heimdalsjordet site, by year. The background is the interpretations from GPR data. Map Source: Author/GOREV/Norwegian Mapping Authority 2016

In 2013, cores were also taken from an area immediately east of parcels 9-14 (referred to as the 'Labyrinth' see chapter 6, figure 6.8), as excavation suggested a series of deposits from waste accumulation near the Viking Age shore, and tentatively interpreted as a harbour area. These samples were taken from the topsoil near the limits of excavation. These cores are recorded and presented in Appendix 2, but were not included in geochemical analysis. The reason being that it was unclear if they represented the same type of occupation, or indeed exactly how they had accumulated due to the narrow trench excavation of the harbour area. Therefore the data set presented in chapter 6 is from coring of the parcel ditches alone, background information, and the oven feature detailed below.

Horizontal sampling for geochemistry

An area opened late in the 2012 excavation was tentatively interpreted as a truncated non-ferrous metal working oven. The area was small, no more than 50 x 100 cm, with a clear burnt clay circle within the dark, organic rich clay silt matrix. Surrounding this was a charcoal flecked scatter contemporary with the circular burnt feature. The area was marked with golf tees at 20 cm intervals in a grid pattern, and each point surveyed in. Small samples were then taken for later analysis in the manner described previously.

Challenges specific to the Heimdalsjordet fieldwork

When coring to understand soil processes and gain information on site formation processes, the fact the cores were in 30 cm sections was entirely manageable. Likewise, when sampling within an excavated area, 30 cm was usually sufficient to capture the archaeology. However, when coring archaeological features from the topsoil, this became problematic. The topsoil depth did vary over the site, between c. 20 cm to 28 cm, with the majority of areas being around 26 cm. In parts, the archaeology was heavily truncated and generally moving from west to east truncation increased to the point where some features were a few centimetres thick. Therefore the 5 cm lost in the cutting head between each section could often mean the loss of the majority of the archaeological stratigraphy. The solution applied to the parcel features sampled from the topsoil, was to core the first 8-15 cm of the topsoil and remove this. The depth was measured, a new liner taken, and the coring then continued to ensure depths of 20-40 cm below the surface were captured in cores. Although not a perfect solution, as long as the depths were carefully recorded, it alleviated the problem in most cases. This method was employed on all areas of the site where cores were taken from topsoil.

The 5 cm loss from the cutting head was also an issue when coring the 'harbour' area immediately west of parcels 9-14, and the well in parcel 2 (see chapter 6). Full profiles of the archaeological stratigraphy were needed, therefore overlapping cores were taken. One core was taken from the surface, another was started after the initial 8-10 cm had been removed in the manner described above. The cores were taken as close to each other as feasibly possible, however there are inherent problematic assumptions in suggesting they represent the same stratigraphical sequence.

Over the eastern part of the site, the subsoil is composed of laminated and layered sands. During 2012, in periods with little precipitation, the well-drained subsoil had a tendency to fall out of the corer whilst raising it, whilst the clay silt subsoil to the west became impossibly hard to core. In the clay silt, when coring beyond 30 cm, whilst the corer was in place and ready to raise, a small amount of water was poured into the hole and left to settle for a minute or two. The solution in the sandy area was to wait for rain as no other solution raised itself. These cores were generally not used for geochemical analysis, only site formation processes.

4.2.5 Kaupangveien

Background and excavation

No geophysical survey was used during the fieldwork at Kaupangveien. The site was excavated in summer 2015 under the auspices of MCH, UiO. It was a rescue excavation in response to a planning application, the excavation was directed by Jessica L. McGraw, and the project managed by Axel Mærum. The planning area was 157 m^2, and the excavated area just short of this figure at 153 m^2. The excavation area was within the proposed extent for the Viking Age trading site of Kaupang, and during the initial clearing of the site, archaeological features from the Viking Age were discovered. These included ditches comparable to wall ditches from similar Viking Age urban contexts, and near circular feature. This was discovered to be a smithy, sitting above an earlier well. Ditches alongside the house wall ditch were interpreted as possible parcel ditches reminiscent of Heimdalsjordet, or pathways (McGraw, in prep).

The methodology applied to fieldwork at Kaupang differed slightly from other sites discussed in this text. The site was a rescue excavation with a rapid turnaround, the reasons for which involve planning procedures in Norway, and unforeseen circumstances common in rescue archaeology. As such, it provided an opportunity to test the combined application of coring and geochemistry in a setting that is the most common circumstance in archaeology and where, if successful, it could be applied again. The invitation to sample on the site came from the fieldwork staff after the two week excavation had begun.

Coring for geochemical analysis

Sampling methodology was developed in close collaboration with the excavation director and the project staff from MCH, to ensure the sampling was orientated toward both the research needs for this study, and the excavation projects aims and objectives. This is essential, as producing data in this context that has no direct relevance for the site specific research aims does not allow complimentary work and feedback. It is also important to create methods applicable to the current state of local archaeology, in an adaptive, flexible manner for archaeological research, for all to benefit.

Figure 4. 5. Kaupang site under excavation. The house area is in the foreground and the smithy area in the centre background Photo: Jessica L. McGraw, MCH.

Sampling was limited by the excavation plans, and time. Three days were spent on the site in July 2015 to collect samples. The site was under considerable pressure to complete the excavation as rapidly as possible, and since more was discovered than envisaged, time was distinctly lacking. Core samples were taken through several features from the machine stripped surface, focusing on the ditch that appeared to define a post built house, two ditches of unknown function, a large negative feature that had originally been interpreted as pathway, but was reassessed as a waste pit. All samples were taken to 30 cm, i.e. a single core. In the majority of cases, this proved to be sufficient to capture the depth of the archaeology. A total of 10 cores were taken on the site.

Horizontal sampling and in situ geochemical analysis

In the smithy area near the post-built house, in situ pXRF readings were taken in an *ad hoc* manner over a stratigraphical layer to help select the number and location of samples. High levels of lead, together with burnt clay remnants of possible mould material confirmed the interpretation as a smithy, and subsequently small bagged samples were taken from defined layers, each surveyed using a total station theodolite. These were organised in rough transect lines with 15-20 cm spacing, however, it was not intended to be perfectly even in spacing. As the excavation continued after the core samples were taken, further small bagged samples were taken by Jessica L. McGraw in a similar manner from lower levels of the smithy.

As Kaupangveien was the final case study to be included in this research, experience from the other cases had developed a standardised approach for coring and surface sampling, and to this was added in situ assessment to improve sample locations. Initial views of the stratigraphy via coring helped field staff manage and prioritise during the excavation. This flexible approach, with standardised elements with flexible application was tested within the commercial, high pressure setting and moulded to fit the site research questions, and the type of archaeological features recorded.

Challenges Specific to the Kaupang Fieldwork

The primary challenge was the pace of the excavation. Without time to gain impressions of the site formation processes, subsoil properties and landscape setting, the sampling was immediately focused upon the visible archaeology. The area of the site was limited by the mandate to excavate, which was within a garden and therefore sampling outside this area to gain background information or soil profiles was impossible.

4.3 Laboratory methods

4.3.1 Summary of consistent methods

The methodology developed throughout the course of the research, however, certain aspects were maintained throughout. These are summarised below:

Instrument

- The instrument used was a Niton Xlt3 GOLDD[2] with a silver anode 50 kV, 0-200µA x-ray tube. The selected mode was Mining Cu/Zn, using fundamental parameters internal calibration. Two separate instruments were used, one for the Avaldsnes site, and another for the Heimdalsjordet and Kaupangveien sites. These instruments were identical in model and age.

Laboratory procedures

- Transferring samples from one container to another was always done with clean plastic equipment. These were either single-use or cleaned with acetone between samples.
- The plastic core liners were cut open using a clean, steel bladed knife or scalpel.

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[2] Geometrically Optimized Large Area Drift Detector

Small sample preparation

- All small surface collected samples and core sub-samples were dried for 24 hours in marked single-use containers. The temperature is given per case study.
- At first, all samples were sieved to 1 mm in a stainless steel sieve, and the sieve was washed, dried and wiped with acetone between samples. However, the fine particle size rendered this un-necessary, and only the Avaldsnes samples were sieved in this manner.
- After drying, many of the samples were hard silty clay blocks and resistant to anything gentle. All dried samples from Heimdalsjordet and Kaupangveien were gently crushed in a porcelain pestle and mortar and mixed to homogenise the sample. The pestle and mortar were cleaned with water, then dried and cleaned with acetone between samples. Crushing was not necessary for the softer Avaldsnes samples.
- For the dried and processed samples, a small subsample of the homogenised material was taken and placed in a plastic sample cup with a polypropylene sample window. The volume was dictated by the sample cup, which was filled halfway. As the method is surface analysis, the sample volume was not recorded.
- The sample was shaken and tapped to ensure even coverage over the sample window.
- All sample cups were purpose made for the field-stand used. These were washed with water, dried, and then wiped with acetone between samples.

Core handling and preparation

- Once opened, cores were cleaned using a sharp, clean knife blade to remove surface smearing from the coring process.
- All cores were then photographed, assessed and recorded in an Excel spreadsheet prior to analysis. Texture, inclusions, Munsell colour and archaeological and pedological stratigraphy were recorded (see Appendices).

Analysis

- Polypropylene X-ray film was used as a sample window on all samples. It was placed between the instrument on the sample on cores and for sub-samples, used as the sample window for the sample holders. The same grade and thickness was adhered to on a site-by-site basis.
- A systems check was conducted prior to each use of the instrument, by which it is meant that each time the instrument was turned on for use, a systems check was performed.
- The instrument was remotely controlled via a laptop, even if hand-held. This was for ease of use as the touchscreen on the instrument is small.

- The instrument was used under the manufacturers (Niton/Thermo Scientific) settings for mining mode (Cu/Zn) unless otherwise stated. This is a four beam/filter mode. The filter/analytical times are given on a case study basis.
- Standard/Certified reference materials (SRM hereafter) were used throughout, after ten or less samples. For Avaldsnes the SRM's were NIST[3] 2709a, NIST 2711a, and TILL4[4]. For Heimdalsjordet and Kaupangveien, NIST 1646a, NIST 2711a, Sigma-Aldrich Trace Metals Clay 2 and Sigma-Aldrich Trace Metals Loamy Clay 2. The number was necessary to ensure all relevant elements were represented in quantities similar to the analysed material. The certified values for the standards are provided in Appendix 1.
- Analysis of small dried samples was conducted in a field-stand to ensure consistent distance from the sample to the instrument during analysis.
- The limit of detection (LOD) is calculated by the instrument by continuous averaging of the detection energy on a per element basis. This was set to 2σ.
- The instrument calculates the counts per second (cps/µA) into ppm or %, which is user defined. All analysis here used ppm.

Calibration and data handling

- The data from Avaldsnes was not empirically calibrated. It relied on the internal fundamental parameters calibration in the instrument.
- The data from Heimdalsjordet and Kaupangveien was calibrated using the SRM data wherever possible and/or relevant. The calibration formula was as follows:

$$\frac{\text{measured value}}{\text{measured SRM value}} \quad \text{x} \quad \text{certified SRM value}$$

- All data was processed using IBM SPSS19 in the case of Avaldsnes, and IBM SPSS 23 for Heimdalsjordet and Kaupangveien. The statistical analysis is detailed further in section 4.5 and on a case study basis.
- All core samples were processed further using ROCKWORKS 15[5], a software for three dimensional visualisation and analysis, on a site-by site-basis.
- ArcGIS 10.2[6] was used for spatial analysis and the production of map-based illustrations.
- Adobe Illustrator CS5 was used for additional illustrations.

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[3] NIST: National Institute of Standards and Technology, U.S. Department of Commerce.

[4] Produced by Natural Resources Canada as a geochemical reference material.

[5] By Rockware, https://www.rockware.com/product/overview.php?id=165

[6] ESRI ArcGIS, http://www.esri.com/software/arcgis

4.3.2 Setting filter times

The filters selectively enhance the measurement of selected elements in relation to the predicted matrix properties of the sample. These are internal to the instrument, and for the instrument used here, cannot be altered individually. The instrument uses fundamental parameters calibration to predict matrix response per filter and element. For the pXRF analysis in mining mode (Cu/Zn), the filter times were set by incrementally extending the filter time from 20 up to 120 seconds. A similar method is also applied by Schneider et al. (2015). Initially, the main filter time was set, as all other filter times and results are dependent upon the main filter. Once this was set, the light, high, and low filters were incrementally extended in a similar manner (see table 4.1). The light and low filters were of primary interest as these measure lighter elements (Z=<24, light filter for Z=<17, low for Z=19–24), such as P (phosphorous, Z=15), which are reliable indicators of general anthropogenic inputs (see chapter 2). The results for error and the measured value of selected samples were plotted by element to determine the ideal measurement time per filter. This is the minimum amount of time required to obtain significant results, where the error is stable and ideally under 5% of the measured value, with a low (less than 5%) RSD (relative standard deviation). Figures 4.6 to 4.8 show the effect of analytical time for elements Cu and P on processed samples from Avaldsnes.

Table 4. 1. The filters for Mining mode on the Niton Xlt3 GOLDD (Cu/Zn), and the respective elements measured per filter.

Filter for Mining Mode (Cu/Zn)	**Main**	**Low**	**High**	**Light**
Elements Analysed	Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Sr, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd	K, Ca, Sc, Ti, V, Cr	Ag, Cd, In, Sn, Sb, Te, I, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, Tl, Pb	Mg, Al, Si, P, S, Cl

It is clear that whilst error decreases in both cases with extended analytical time, for the lighter element (P) analytical times 60 seconds or more are required to improve instrument precision. As a helium purge was not used, longer analytical times were necessarily to mediate the effects of atmospheric interference on lighter elements. The limits of detection (LOD) are calculated by the instrument, and were set to 2 standard deviations (2σ). In addition to this process, data was regularly scrutinised to ensure a balance between time and error.

The format used to indicate filter times is as follows. The filters are always given in the same order; main, low, high, light, in the format 30-60-30-60, the times are in seconds. As a general rule and a guide provided by the manufacturer, the light and low filters should be twice that of the main and high. If papers using comparable instruments do list there filter times, this does not seem to be a rule universally applied (e.g. Gauss et al. 2013), however here it was a valid system based upon extending analytical times per filter.

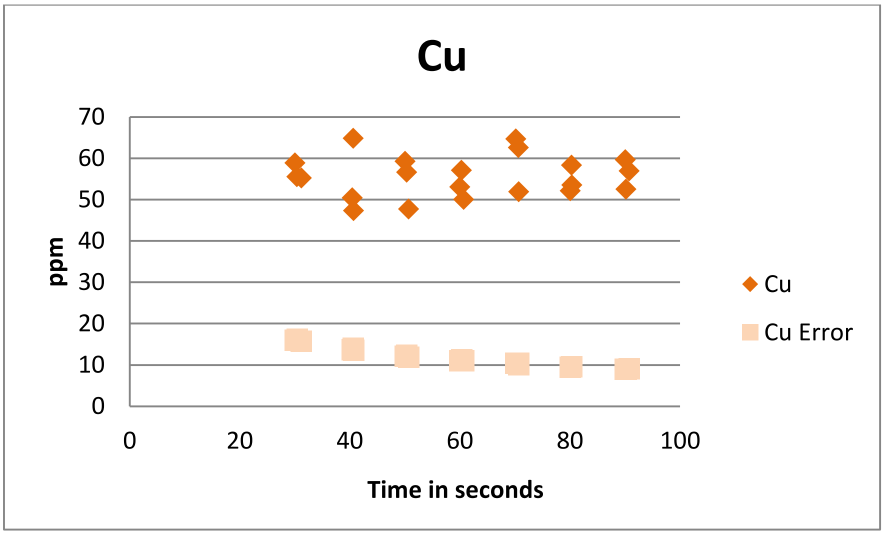


Figure 4. 6. The effects of analytical time, in seconds, on the measured value of Cu on a dried sample from Avaldsnes. Note that time was increased in 10 seconds intervals, and each measurement was repeated 3 times.

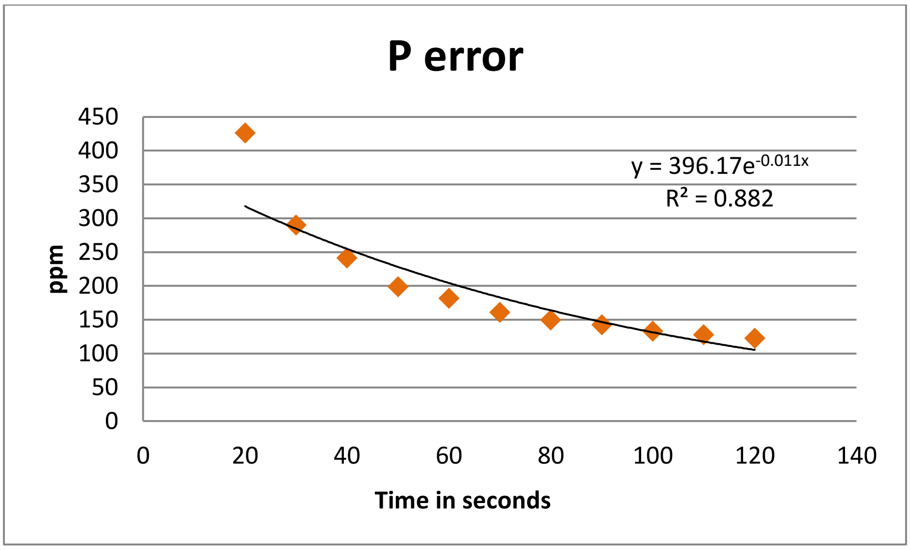


Figure 4. 7. The effects of analytical time, in seconds, on the measured error value for P on a dried sample from Avaldsnes. The exponential trend line merely illustrates the strong correlation between analytical time and error. Note that time was increased in 10 seconds intervals. This is the same sample and analysis as figure 4.6.

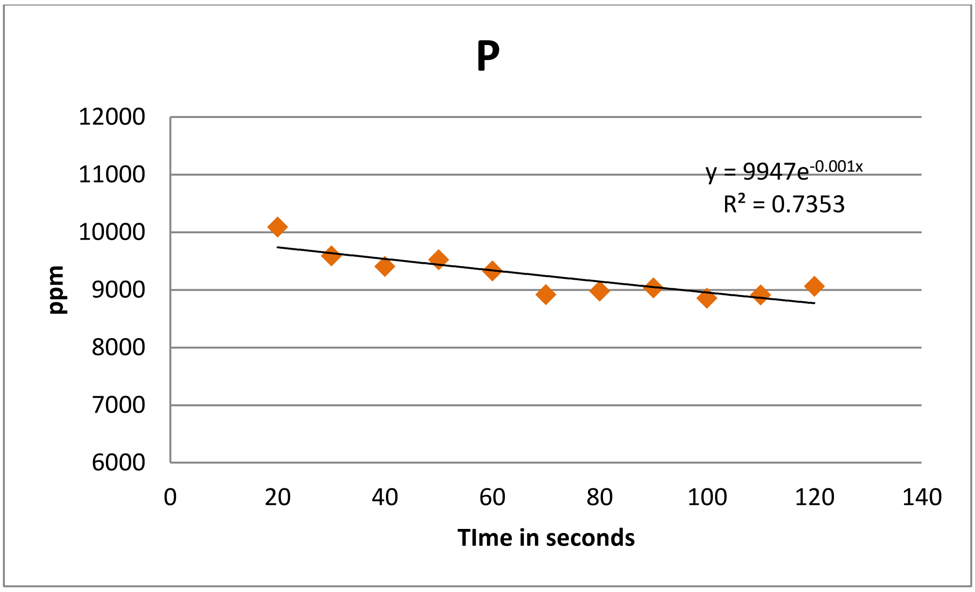


Figure 4. 8. The effects of analytical time, in seconds, on the measured value for P on a dried sample from Avaldsnes. The exponential trend line merely illustrates the strong correlation between analytical time and measured value. Note that time was increased in 10 seconds intervals. This is the same sample and analysis as figure 4.7

As is discussed further in section 4.3.5, two cores at Heimdalsjordet were measured using the 30-60-30-60 filter times in mining mode. Querying the data, it was decided that the remaining cores would be analysed at 50-100-50-100 times to improve light element detection. Table 4.1 indicates the differences in detection by filter time on dried and ground sub-samples from core 7495, for selected elements. As the data shows, error is consistently reduced with the longer analytical time (50-100-50-100) for all elements, which formed the basis for this decision.

4.3.3 Mode selection

Mining mode on the Niton/Thermo Scientific pXRF is used in similar research, such as Gauss et al. (2013) and Hayes (2013), because it contains all elements of interest to archaeological research. However, as stated in chapter 3, each mode assumes a set sample composition. This was tested using SRM NIST 2711a. As table 4.3 shows, lighter elements, in this case Ca, are closer to the certified value in soils mode. Strontium values are also closer to the certified value in soils mode, but with marginally higher instrument error (set to 2σ). The reverse is true of Cu, although here the differences are minimal. The heavier element Pb, is notably closer to the certified value in mining mode, with little difference in instrumental error.

Table 4. 2. Table showing the effect of different in filter times on measured values and error. All figures in ppm, with filter times in seconds, for the filters main, low, high and light, in that order.

SAMPLE	**Filter times**	**Sr**	**Sr Error**	**Pb**	**Pb Error**	**Cu**	**Cu Error**	**Ca**	**Ca Error**	**P**	**P Error**
S1	30-60-30-60	109.83	2.79	21.04	4.36	38.7	13.04	10193.12	226.77	2153.69	122.43
S1	**50-100-50-100**	**111.6**	**2.1**	**24.73**	**3.36**	**35**	**9.67**	**10310**	**174.17**	**2191.12**	**93.44**
S2	30-60-30-60	139.9	3.22	21.67	4.58	30.73	13	12354.48	262.72	2070.06	148.02
S2	**50-100-50-100**	**141.44**	**2.46**	**16.28**	**3.3**	**32.97**	**9.94**	**12290.44**	**198.94**	**2099.51**	**112.03**
S3	30-60-30-60	135.25	3.18	20.16	4.46	24.68	12.73	10931.17	237.71	1257.76	137.27
S3	**50-100-50-100**	**131.67**	**2.38**	**17.89**	**3.34**	**33.6**	**9.94**	**11023.34**	**188.52**	**1224.23**	**105.08**
S4	30-60-30-60	137.53	3.18	14.93	4.21	39.09	13.2	11150.57	239.42	1091.61	139.4
S4	**50-100-50-100**	**133.22**	**2.34**	**16.06**	**3.2**	**34.62**	**9.77**	**11099.41**	**189.15**	**1299.61**	**106.64**
S5	30-60-30-60	151.13	3.4	17.54	4.42	30.54	13.18	13189.67	262.47	2660.2	154.94
S5	**50-100-50-100**	**150.91**	**2.57**	**15.69**	**3.3**	**29.28**	**9.9**	**12966.01**	**194.57**	**2500.15**	**112.59**
S6	30-60-30-60	130.37	3.22	13.65	4.41	< LOD	23.01	10944.64	277.78	1603.3	145.46
S6	**50-100-50-100**	**129.07**	**2.46**	**14.44**	**3.41**	**< LOD**	**14.93**	**11245.06**	**214.3**	**1595.88**	**109.98**
S7	30-60-30-60	137.76	3.35	13.7	4.47	< LOD	19.92	11391.69	280.94	1179.32	150.08
S7	**50-100-50-100**	**135.12**	**2.52**	**12.88**	**3.37**	**< LOD**	**18.37**	**11430.65**	**217.62**	**1217.27**	**111.69**

Therefore, the selection of inbuilt filter settings is dependent upon the elements of interest and the sample matrix. In general, lighter elements such as Ca, K and Ti performed better under soils mode, however, this mode does not measure P or S, which are both historically and currently seen as central to archaeological geochemical interpretation.

Table 4. 3. Analysis of SRM NIST 2711a in two modes: mining (Cu/Zn) and soils. Each mode was repeated three times and an average taken. The certified values for the selected elements are also shown. All values on ppm, all times in seconds.

Mode	Duration	Filter settings	Sr	Sr Error	Pb	Pb Error	Cu	Cu Error	Ca	Ca Error
Mining	301.25	50-100-50-100	158.15	2.73	1366.86	18.88	124.36	12.25	21747.02	267.52
Mining	301.06	50-100-50-100	154.01	2.7	1360.56	18.89	130.51	12.41	21919.23	272.32
Mining	301.9	50-100-50-100	156.04	2.73	1376.59	19.08	123.05	12.29	21918.28	273.23
	904.21	**Average**	156.07	2.72	1368.01	18.95	125.97	12.32	21861.51	271.02
		Certified value	**242**	**10**	**1400**	**0.1**	**140**	**2**	**24200**	**6**
Soils	200.05	50-100-50	202.37	3.37	1281.07	18.62	117.12	10.2	22507.27	124.38
Soils	200.35	50-100-50	204.36	3.42	1280.92	18.83	123.68	10.49	22468.2	125.12
Soils	200.17	50-100-50	203.99	3.39	1274.22	18.64	127.34	10.46	22406.92	124.54
	600.57	**Average**	203.57	3.39	1278.74	18.7	122.71	10.38	22460.8	124.68
		Certified value	**242**	**10**	**1400**	**0.1**	**140**	**2**	**24200**	**6**

The remainder of this section outlines variation in methodology in response to the sites individual research questions, environmental and archaeological restraints. Within this was also a process of evolution as the method was refined by experience. The methodological variation is expanded on a site-by-site basis in the following sections.

In the following section, the deviations from the standard laboratory and analytical procedures are given on a site-by-site basis.

Figure 4. 9. An opened core being directly analysed using pXRF. Photo: Marianne Hem Eriksen/author.

4.3.4 Avaldsnes

Process

As the majority of the Avaldsnes samples were small bagged samples, no direct pXRF measurements were undertaken, not even on the cores. The cores analysed were recorded as detailed above prior to sub-sampling at stratigraphic intervals. The aim of using the cores for the geochemical analysis was either as background samples to assess soil formation or to see if cores could add temporality to geochemical datasets. The data was intended to be comparable to the individual samples; therefore regular interval sampling on cores would have served no purpose, as the bagged samples were from a specifically identified pedological horizon. All samples were dried at 105^{0}C for 24 hours, before being sieved to 1 mm in a stainless steel sieve, as detailed above. In many cases, as the sample was composed of fine silt, sieving made no difference to the sample composition.

Samples were then placed in purpose made sample cups, the base covered by a 4 µm polypropylene film, before being placed in the field-stand for analysis. Prior to each analytical 'run' and at an interval of ten samples, the SRMs were analysed using the same filter times and settings as the samples. In addition, a Si sample with c. 400 ppm Ca was analysed after the SRMs. This was used as a blank to ensure the instrument window was clean and as a quick method to check the basic instrument response. This frequency of re-measuring the SRMs was necessary to calibrate for potential drift and to have a statistically significant and relevant data set for calibration purposes if required.

Time and variation

Sample time was 180 seconds, in mining (Cu/Zn) mode, with the filter times being 30 seconds for the main filter, 60 seconds for the low, 30 seconds for high and 60 seconds for the light. This was selected based upon other's experience (Gauss et al., 2013, Doonan et al., 2014, Vos, 2016) and the test data presented above and in Appendix 1. The use of a helium purge was strongly considered to improve the detection of lighter elements. Access, however, was a problem, and therefore it was not used.

Initially, each sample was analysed three times and averaged. After evaluating the data, the trebling of the analytical time was deemed too time consuming, although it did highlight occasional instrumental errors when the results were viewed in spreadsheet or spectra format. These were rare, and almost exclusively connected to P and S. As these errors were detectable by examining the data, and the analysis non-destructive and therefore ensuring repeats were possible, it was decided upon to pursue single analysis per sample.

Through the evaluation of the data set, it was considered that 180 seconds was not sufficient without the use of a helium purge to sufficiently reduce error in the lighter element readings. A few samples were run on a longer filter time of 300 seconds (50 main, 100 low, 50 high, 100 light), and this reduced error. Therefore in the second case study, Heimdalsjordet, considering that helium was not available, longer filter times were employed.

Limitations of the data set

The variation in analytical time is a concern for the Avaldsnes data set. It is not possible to standardise the data after the analysis is complete nor, due to time restrictions, was it possible to repeat a large number of the samples. In total 493 readings were taken from 189 samples, the time taken to process and analyse the samples and check the data was approximately one month. The data was not empirically calibrated to test the internal fundamental parameters calibration of the instrument.

4.3.5 Heimdalsjordet

A different approach was employed with the Heimdalsjordet samples in response to the archaeological conditions, as detailed in chapter 6, section 6.4. The site was intended to be the central case study in this research, where the methodology of using pXRF directly on minimally prepared cores would be employed with the aim of gaining high-resolution, three dimensional geochemical data sets from secondary contexts. Therefore data from core analysis forms the bulk of the data for this case study.

Process

As stated in section 4.3.1, all cores were assessed and recorded prior to analysis. Each core was photographed, the soil structure, Munsell colour, inclusions and interfaces observed, and an interpretive archaeological stratigraphy created as an Excel spreadsheet (see Appendix 2). Prior to analysis, 6 µm polypropylene film was placed between the instrument and sample point to keep the instrument window clean. Unfortunately the finer 4 µm film was not available. The instrument window also has a 4µm polypropylene film. This was checked between each sample to ensure no stray material was on the pXRF detector window. The instrument was handheld for the direct core analysis, however it was controlled via a computer, and an automatic cut off at 300 seconds was used to ensure comparable times. The sample time was therefore 300 seconds for all but two cores, using mining (Cu/Zn) mode, as described in section 4.3.1. Cores were analysed at 2 cm intervals using pXRF, the distance measured from the top of the core using a manual ruler. Data was viewed in real time via the instrument screen and the connected laptop computer. Repeats were taken where readings suggested an error had occurred, and at random points to verify repeatability. Sub-samples from cores were taken from selected cores after direct analysis to verify differences in values and error as a result of sample processing. The selection of cores for sub-sampling was per parcel, which ensured variations in subsoil composition were represented in the sub-sample data. The sub-samples were dried at 40°C for at least 24 hours in single use containers. The lower temperature came from concern that organic content may be lost with the higher temperature of 105°C used on the Avaldsnes samples. On reflection, this is probably not the case, however this was pursued at the time. All data is presented in section 4.4 or Appendix 2.

Time and variation

A 30 cm core had potentially 15 sample points, although in practice this was 14 as the upmost and lowest 1 cm were avoided as these could be composed of material displaced by coring. Therefore 2 cm was the first sample point, and 28 cm the final. Before any sampling commenced for the day, there was a system check on the instrument and then four SRMs were measured. Sampling was begun at 2 cm, and preceded logically in 2 cm intervals, each sample point requiring a new polypropylene film. After ten or less samples, the SRMs would be reanalysed. Depending upon the complexity of the stratigraphy, sampling problems and challenges and required sub-sampling, between one and three cores could be processed in an eight hour day. Therefore, in theory, between 5 and 15 cores could be analysed per standard working week, and it was not difficult to achieve 10-15 per week. The bulk of the analysis was completed in a one month period, allowing for processing of sub-samples and checking the data. Additional analysis was done at a later stage, using the same methodology.

Some cores were not entirely composed of 'archaeological' sediments. The lowest centimetres in many of the cores represented undisturbed subsoil, and in cores taken from the topsoil, there was up to 26 cm of topsoil. Initially the 'non-archaeological' layers were sampled at 2 cm intervals, as it was thought it would be of interest to assess leaching and contamination. As time progressed, it became clear this was both time consuming and unnecessary for all cores. Therefore, per parcel and plot, at least one core was analysed at 2 cm for all contexts, archaeological and non-archaeological. In the remaining cores, 4 cm intervals were employed on the non-archaeological contexts. The statistical treatment of the data from the topsoil, subsoil and archaeological layers is detailed in chapter 6, section 6.4.6.

Challenges specific to Heimdalsjordet

The instrument sample window is 8 mm, making a higher sampling resolution possible. However, once the instrument is placed, the bulk of the instrument nose makes millimetre precise sampling challenging, and higher resolution obviously significantly increases the time required per 30 cm core. Few identified contexts were thinner than 8 mm, ensuring that the sample window represented one context only per sample. Interfaces and very fine contexts were avoided, as were inclusions such as bone, charcoal or other archaeological objects. As these rarely dominated any context, this was simply a matter of turning the core and placing the instrument with great care. Avoiding ferrous and ochre mottles, a product of hydromorphic processes, was sometimes more challenging as they appear in dense clusters and in several contexts, and were often large and dominant. The data clearly showed when such a mottle had been analysed by the high proportion of Fe. As this would distort the archaeological information, these readings were not included in the statistical analysis. On rare occasions, a sample interval was left without analysis as gaining a representative 8 mm wide sample point was impossible.

In an interval between processing and analysing the Heimdalsjordet samples, the instrument was returned to the retailer for repair and calibration after it developed a fault. The consequences of this are covered in section 4.4.

The first two cores from Heimdalsjordet had analytical times of 30-60-30-60, giving a total of 180 seconds. This was selected as holding the instrument perfectly still for 5 minutes was taxing. These are cores 7936 and 7945. After viewing the error for the lighter elements, longer filter times were chosen for all other cores, and a better positioning reduced movement and strain. The readings from the two cores are not greatly dissimilar to the other cores, although error values are slightly higher. After the experience gained from analysing 40 cores, some with several sections, it was observed that the slightly shorter filter times of 40-80-40-80 would have been equally sufficient for the majority of elements, however, without the use of the helium purge, relatively long analytical times are necessary.

Limitations of the data set

In short, the major limitation is stratigraphical comparability. Depths are precise to 2 cm, however as each sample is isolated, no contextual continuality can be assumed. This subject is discussed further in chapter 6, section 6.8. As far as the data itself is concerned, there are unquantifiable sources of variation. These occur as the instrument is handheld, meaning that despite all efforts, there will be slight variations in the distance between the instrument nozzle and the sample surface. The intervals for sampling are by eye and ruler, and therefore will not be perfectly consistent. The moisture content of the cores was low as they had lost some moisture during storage, but they were not completely dry when analysed. The moisture content was essential for seeing the stratigraphical changes within the samples, as without it all samples are rendered to a hard white lump. Without measuring the moisture content, the known disproportionate effect this property has on individual elements cannot be quantified.

These, and other factors named here, render the analysis semi-quantitative, despite calibration using SRMs. Figure 4.10 contains a summary of the analytical process.

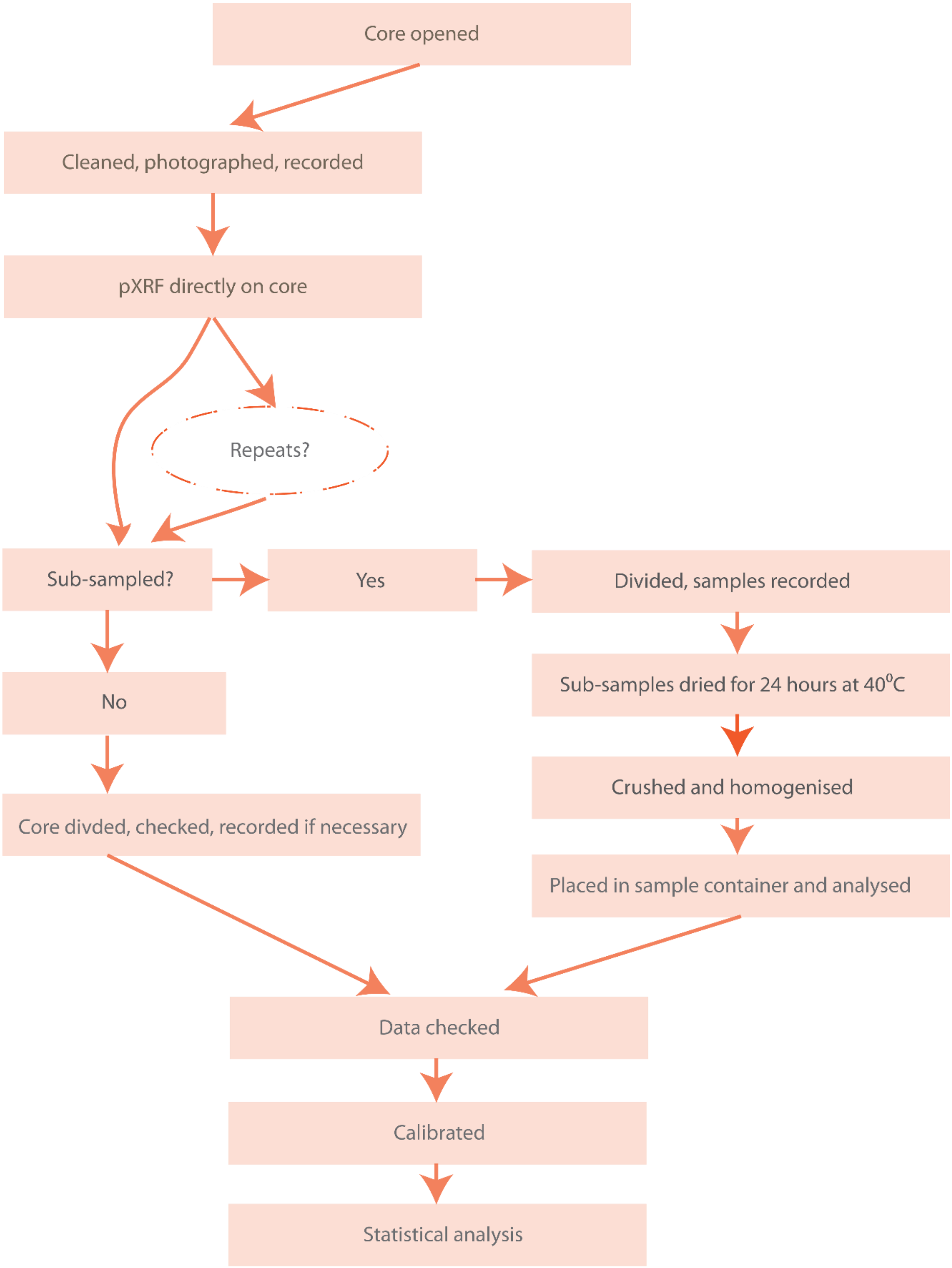


Figure 4. 10. Flow diagram of the sample processing and analysis for cores from Heimdalsjordet.

4.3.6 Kaupangveien

Process

The general method for Kaupangveien is broadly comparable to Heimdalsjordet, as previous experience had highlighted effective approaches and lessons in consistency had been learned. All ten cores were taken from an excavation surface, where the topsoil was mechanically removed and archaeological features identified as negative features in the subsoil. Therefore, cores were treated similarly, being cleaned, recorded, and analysed directly. Sample intervals were 2 cm for archaeological layers, and 4 cm for non-archaeological layers. As topsoil was not present, this consisted of subsoil only. Analytical time totalled 300 seconds for all filters, in mining mode (Cu/Zn). The SRMs were identical to those used for the Heimdalsjordet analysis, as was the frequency of analysis.

Time and variation

Sub-samples and bagged individual samples from the smithy were dried at 40^{o}C for 24 hours in single-use containers.

The issues with the sample window, the error in measuring intervals distances on the cores and avoiding large inclusions were largely similar to Heimdalsjordet, although there were no mottles from hydromorphic processes in the soils to avoid. As with the Heimdalsjordet samples, the first and last 1 cm of each core were avoided.

In situ readings were not processed further, as the data is inherently varied and incomparable.

Challenges specific to Kaupangveien

The subsoil exposed by topsoil stripping at Kaupangveien was medium to coarse, moderately sorted sand representing the former back beach from shoreline retreat (see chapter 7). The substrate under this was marine clay silt, becoming increasingly gleyed and laminated with depth, but most cores did not reach these depths and thus the substrate in the cores was beach sand. The majority of cores were archaeological material, with a high organic content and a sandy loam matrix. Upon opening the cores, the poorly consolidated sands lost their form, as did the non-archaeological part of the core. Interfaces were very sharp, and the archaeological deposits, stabilised through the organic content and matrix, proved possible to analyse directly. However toward the base of these deposits, the weight of the instrument began to crumble the remaining core. Therefore, many sections of the cores had to be sub-sampled rather than recorded directly. Where the depth of the archaeological deposit was thin (<10 cm), the entire core was sub-sampled at 2 or 4 cm intervals (cores 1936, 1938, 1939 and 1942, all from the wall ditch).

Limitations of the data set

As stated in the previous section, the analytical method was inconsistent due to the collapsing of the cores. Therefore the comparability of the data is questionable and semi-quantitative. In the final section of this chapter, data comparing direct core analysis to sub-sampled material is presented and evaluated.

From this experience, the efficiency of method of directly measuring cores is dependent upon the soils and sediments present on the site.

4.4 Validating methods

4.4.1 Calibration of measured values: Heimdalsjordet

Calibration issues were common to all sites, however, the samples and data from Heimdalsjordet was complicated by events, and is taken as an example that covers all eventualities for all sites, as well as those unique to the Heimdalsjordet data set.

For the majority of elements, the instrument tends to produce results under the certified value for SRMs. This is in part the matrix effect, the use of films, the interference of air between sample and receiver, and the inaccuracies of the instrument. That said, through the use of standard reference materials (SRM) and evidence from published studies (Shackley, 2010, Frahm and Doonan, 2013, Schneider et al., 2015), for the majority of elements pXRF is internally consistent and precise. Inaccuracies, which are common but consistent, can therefore be calibrated to bring the measured values from samples closer to the 'true' value. The result is a better, more accurate representation, which should not be confused with the actual amount of any element within the sample. If the aim of research is to obtain as close to true values as possible, high resolution instrumentation is required, such as MC-ICP-MS coupled with strong acid or total digestion of samples. Using pXRF is a compromise between accuracy and cost efficiency and flexibility, as discussed in chapter 3 and 8.

For Heimdalsjordet, the sample analysis was completed in two periods, between which the instrument used developed a technical fault, and was returned to the manufacturer for repair and calibration. It appears the peltier cooler was failing to hold the internal temperature at the required -25^{o}C, therefore it was subsequently repaired. The returned instrument was recalibrated by the manufacturer, and as a consequence the instruments response, as measured by using SRMs, had altered. The difference was significant for many of the elements of interest to this study, such as Cu, Pb, Zn, Fe, P, S and K. In almost all cases, there was an improvement in both precision and accuracy. The very thorough calibration process by the manufacturer involves calibrating every element on every filter against matrix matched, certified materials. The only negative effect was that after the recalibration, the instrument had developed a slight drift, which was only significant with S after prolonged use in a single day. The majority of the samples had been analysed after the recalibration, however to apply a general method for calibration from all measured SRMs values would inevitably be unrepresentative of the instrument response pre and post recalibration. Therefore the results prior to recalibration were calibrated to SRMs measured at the same time. Unfortunately, as the number of samples analysed was small, there were only 5-7 results for each SRM available for calibration, however, this was deemed preferable to using results from the instrument after calibration. In essence, it can be compared to using a different instrument, as the calibration fundamentally alters the instrument response. After the instrument was recalibrated, a large volume of samples were analysed, thus there were over 20 results from SRMs available for data calibration.

Each data set, divided by site, was calibrated separately using the same SRM values. For each element calibration, the selected SRM from the four available depended on the quantity of each element in the sample group, and the precision and accuracy of the SRM values. Almost without exception, the SRM chosen had the lowest standard deviation and %RSD (relative standard deviation) values. For some elements, most notably Fe, calibration was unnecessary, as the SRM values were exceptionally accurate and precise (see table 4. 4).

Table 4. 4. Statistical summary of Fe results from the analysis of SRM NIST 2711a, measured 22 times.

Fe	**ppm**
Mean(*n*=22)	**28584.12**
Standard Deviation (1σ)	**236.26**
%RSD	**0.83%**
NIST 2711a Certified value	2.82% (28200 ppm)

To ensure all values were comparable for statistical analysis, all elements that could be calibrated, were calibrated. There are limitations with the use of SRMs. As obtaining suitable matrix match SRMs that include the relevant elements in similar quantities to the sample material is challenging, due to the great variation in archaeological soils and the limited choice of purchasable SRMs, there has to be a balance between using sufficient reference material to identify drift and imprecision in the analysis. The analysis of SRMs is also time-consuming. Within each run, four SRMs were analysed, at the start of each session, and periodically during analysis, usually between every 10 samples. This takes 25 minutes using the same instrumental times and filters as the sample analysis, so an hour from every four can easily be lost to SRM measurement.

This process is essential, however, for identifying inaccuracies, drift and contamination of the instrumental window during analysis. Calibration of some elements may seem superfluous, especially when using an instrument that is intended to be for general screening and quick analysis over high precision. However, in this case it has proven essential for identifying the changes in instrument response after repair and recalibration, including the drift, and allows for calibration of data. For the statistical analysis, all data has been standardised and similarly treated and is therefore comparable.

4.4.2 Quality of Standard Reference Materials

The majority of samples were calibrated to NIST 2711a, as it was repeatedly the most accurate and precise, as well as containing proportions of elements closest to the measured values in the samples. The SRM is produced from topsoil in Montana, U.S.A., from an agricultural field near an old smelting works. Also from the National Institute for Standards and Technology, was NIST 1646a, produced from a gleyed estuarine sediment. In comparison to the two other SRMs used, produced by Fluka Analytical/Sigma-Aldrich, the results from the NIST standards were consistently more accurate and precise. Although produced to rigorous standards, all traceable to NIST, the method of production differs between the manufacturers. Whereas NIST collect a material, and the certified values are based upon the original composition of the source material, therefore soil matrix, a proportion of the trace metals in the Fluka Analytical SRMs are added to the original soil matrix, presumably to increase the range of application for the product. Soil is a highly complex chemical and physical substance, and the matrix in relation to the element retention varies due to a plethora of factors such as pH, grain size and structure. It would appear that the differing production methods of the SRM, combined with the use of pXRF, has resulted in the Fluka Analytical/Sigma-Aldrich SRMs producing less accurate and less precise data for the majority of elements, including elements such as Ti, which is exclusively related to the inherited geological composition of the sediment or soil.

4.4.3 The analytical blank

For the Heimdalsjordet and Kaupangveien sample analysis, a true analytical blank was not available. An alternative was tested, in the form of a blank film. The use of a blank polypropylene 6 µm film is effective for identifying contamination on the instrument window, however it is not ideal as a blank. A true blank, composed of elements with atomic weights below the instruments limits of detection would be more effective. Within the polypropylene films, there are trace element impurities, which varied over the surface area of the film, and from film to film. These were generally under 100 ppm, whereas contamination, usually in the form of a sediment grain, would give far higher readings (100s to 1000s ppm), particularly of Si, Al and P. This happened frequently, and the sample window was subsequently brushed and then wiped with acetone, or if this proved ineffective, it was replaced.

4.4.4 Sub-samples from cores vs direct measurement

Five cores were sub-sampled from Heimdalsjordet for comparison to directly measured values using pXRF. Sub-sampling depths are not as precise as direct measurement for pinpointing where in the core the sample was actually taken, plus the sub-samples are then homogenised and sub-sampled again. Therefore some discrepancy must be expected. The highly heterogeneous nature of the anthropogenically influenced soils and sediments at Heimdalsjordet meant that no one point would ever be completely comparable. That is the nature of archaeological deposits, soil processes, and a weakness of archaeological geochemistry in general. As the aim was to understand trends and patterns of input into the soil, minor differences caused by analytical method were considered acceptable and inevitable. Despite the fact that there were no illusions that this was a truly quantitative methodology, error must be monitored and reduced wherever possible for the data to have any value.

Table 4.6a&b highlights the differences in analytical results between processed sub-samples and direct core measurement for two different cores at various depths. It must be noted that these cores were taken from the topsoil, and therefore the depth of 4-6 cm is topsoil, and similarly, the depths of 56-58 cm represent subsoil, in this case gleyed clay silt. There is clear variation. The data in tables 4.5 and 4.6, and data for two other cores similarly assessed (see Appendix 2), suggest that the greatest discrepancies are for the proportionally high elemental concentrations. This could be because very high values are highly local, which was often observed during analysis. A metal fragment or burnt bone in the order of a few millimetres would produce a peak in respective elements, whereas the general matrix values, whilst sometimes enhanced, did not have equivalent peaks. Inclusions were avoided wherever possible. This is also a reflection of the form of the element in the soil. In figure 4.11, the samples furthest to the right are subsoil. The gleyed clay silt has a low organic content, the P is most likely held in mineral form adsorbed to the soils sesquioxide and clay matrix. This is contrasted to the highly organic anthropogenic soils above, where P is held in various forms, concentrated in humic matter. This heterogeneity will inevitably create strong variation over short distances.

Without doubt, direct measurement results in an inconsistent sampling surface, more greatly affected by surface geometry, moisture and slight variations in the distance between the instrument receiver and the sample due to an unsteady hand. This was to be expected. Overall, this has the effect of reducing the measured values; that said, there are a few exceptions, as can be observed in tables 4.5 and 4.6.

Figure 4.11 illustrates that lower concentrations of an element result in less discrepancy between direct analysis and processed samples. The lower ppm value in figure 4.11 is the direct measurement, in all but one case.

Table 4. 5. A selection of direct core measurements versus processed sub-samples from cores, for elements selected by relevance to this research. All values are in ppm, and are calibrated.

Direct/sub-sample	Sample	Depth (cm)	Core-Context	Sn	Ag	Sr	Rb	Pb	Zn	Cu
Sub-sample	S13	4-6		24.70	0.00	199.86	107.43	73.15	81.97	88.33
Direct		4	14813-1	11.82	0.00	164.40	93.71	72.38	67.12	95.12
Sub-sample	S14	16-18		10.18	0.00	222.82	115.78	85.22	80.77	90.46
Direct		16	14813-1	18.19	0.00	186.08	91.33	59.86	61.40	69.72
Sub-sample	S15	24-26		0.00	0.00	203.90	106.54	21.66	54.63	37.73
Direct		24	14813-2	0.00	0.00	179.94	100.77	44.24	64.07	58.40
Sub-sample	S16	28-30		0.00	0.00	206.54	129.88	49.80	85.49	84.47
Direct		28	14813-2	17.05	0.00	185.70	115.08	47.44	63.72	87.84
Sub-sample	S17	50-52		0.00	0.00	182.31	153.48	21.23	94.56	40.26
Direct		52	14813-3	0.00	0.00	155.29	126.97	12.91	67.50	31.58
Sub-sample	S18	56-58		0.00	0.00	184.72	162.05	13.58	99.27	26.11
Direct		56	14813-3	0.00	0.00	154.12	131.06	9.95	73.21	30.46
Sub-sample	S20	28-29		248.29	4.30	209.20	111.48	2747.91	134.71	2321.16
Direct		28	14825-2	257.91	0.00	147.90	74.62	4478.33	163.60	4391.79
Sub-sample	S21	36-37		87.46	211.07	223.55	128.63	701.03	114.22	664.40
Direct		36	14825-2	36.88	5.90	169.34	102.28	275.07	95.31	668.32
Sub-sample	S23	40-44		0.00	0.00	189.88	141.37	30.65	86.64	51.60
Direct		42	14813-3	0.00	0.00	192.76	125.25	23.42	68.99	52.26

Table 4. 6. A selection of direct core measurements versus processed sub-samples from cores, for elements selected by relevance to this research. All values are in ppm, and are calibrated.

Direct/sub-sample	Sample	Depth (cm)	Core-Context	Fe	Ti	Ca	K	P	S
Sub-sample	S13	4-6		22348.19	3888.69	10798.73	18758.47	2827.35	828.12
Direct		4	14813-1	19311.77	3203.45	8412.39	16056.88	2148.897	517.26
Sub-sample	S14	16-18		23207.06	4100.69	11842.97	18246.13	2746.23	720.52
Direct		16	14813-1	18698.02	2847.23	9190.27	15455.43	1950.916	451.01
Sub-sample	S15	24-26		19683.54	4299.70	11954.16	19371.30	1374.58	320.98
Direct		24	14813-2	19804.72	3946.66	10193.97	19022.62	1626.662	409.61
Sub-sample	S16	28-30		27846.84	5048.86	11838.75	21594.34	1269.68	407.63
Direct		28	14813-2	23684.27	3740.65	9199.58	18063.08	1350.306	201.39
Sub-sample	S17	50-52		31067.75	5408.46	9650.36	25362.05	752.87	383.48
Direct		52	14813-3	24316.12	4160.77	7887.26	23785.60	695.322	261.71
Sub-sample	S18	56-58		34323.80	5363.89	9900.27	26511.63	825.51	413.41

Direct		56	14813-3	26650.38	4379.41	8316.81	25126.22	742.9566	327.04
Sub-sample	S20	28-29		36494.38	3806.71	14195.01	18279.44	6713.69	2085.12
Direct		28	14825-2	28639.36	2265.46	11015.78	12467.79	4312.187	2395.06
Sub-sample	S21	36-37		29021.48	4498.51	14020.12	19705.83	2926.44	579.27
Direct		36	14825-2	26389.27	2603.19	9435.08	14920.91	1719.702	384.79
Sub-sample	S23	40-44		31224.23	4894.05	10155.84	23230.50	1042.94	377.11
Direct		42	14813-3	25991.79	4446.60	10352.32	23438.91	1016.58	200.31

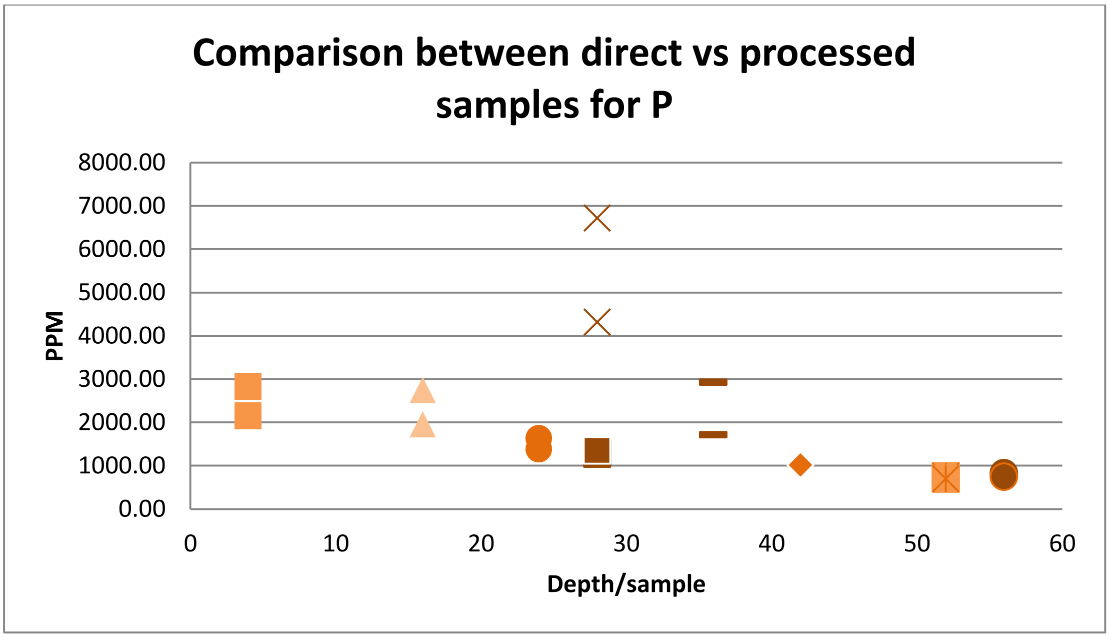


Figure 4. 11. The difference between direct measurement and processed samples for P values, using the same data as tables 4.5 and 4.6. All values in ppm, all data is calibrated. The identical symbols indicate the same sample point on the core and corresponding processed sub-sample. The higher value is the processed sample.

4.4.5 Repeats

On all sites, selected samples were repeated in order to test the consistency of the produced data. This applies to both sub-samples dried and analysed in the field-stand, and direct, handheld measurements. Table 4.7 shows repeated analysis from selected samples, all of which were dried, crushed and homogenised prior to analysis. Between each repeat, the sample was shaken within the sample container, and then tapped to ensure the sample window was evenly covered. The data is consistent for the majority of elements, close to the instrument's margin of error (2σ). Lower values appear to be more inconsistent, such as sample S24 for Sn. However, values under the instruments LOD are shown as 0, thus one reading is below the LOD, whereas the other, at 14.26 ppm, is just above. A similar occurrence explains the values for Cu in sample

S27. More concerning is the variation in Pb in sample S14. The instrument measures Pb in concentrations of 10 ppm or less, and the SRM data shows precision and accuracy for Pb in NIST 2711a. The discrepancy of near 90 ppm therefore is likely to be heterogeneity in the sample, which would indicate poor sample processing in this case. As the data for the other elements is consistent, other sources of analytical error must be the cause.

4.4.6 Moisture content

As discussed in chapter 3, moisture attenuates the signal between sample and receiver, disproportionally affecting lighter elements. Several of the samples from Avaldsnes were measured for moisture content. The method was fairly rudimentary, weighing the sub-samples prior to and after drying for 24 hours at 105°C. Samples came from both sub-sampled cores and individual samples, and represented the range of sediments and soil conditions on the site. For 49 of the moisture tested samples, the calibrated data was subject to factor analysis (PCA, see Appendix 1), with moisture as a dimension. The results are presented in Appendix 1, and unsurprisingly illustrate that moisture content has considerable effect on measured values. The data shows that, on average, undried samples from Avaldsnes had a moisture content of 20.96%. The highest moisture content values (over 1 standard deviation above the mean), were from layers with higher organic content, such as buried soils. This, of course, is as expected. Of the 115 moisture values, 85 are within one SD of the mean, and those from the horizon for geochemical analysis generally have values around the mean or below. This suggests they are similar, although it does not mean that the differences in moisture have minimal effect.

This was alleviated by drying all sub-samples, although moisture remained a factor in the direct analysis of cores. As the moisture content for each sample point cannot be measured, no statistical correction can be applied. Without doubt, this leads to the lighter elements being under-represented in sample data taken directly from the core surface. Experience from processing these cores indicated that an open core left to air dry overnight would quickly dry into a solid lump, which of course leaves this as an option to consider for future research. Alternatively, freeze drying is a possibility (Carey et al., 2014). The drawback is that once dry, it is impossible to see the fine stratigraphic details necessary when recording, and it becomes very difficult to finely slice for sub-sampling; however this could be overcome by planning. Yet this would not help with cores with a high proportion of sand, as the reduction in moisture increases the already fragile stability.

Table 4. 7. A selection of sample repeats from Heimdalsjordet core sub-samples, for selected elements. All measured values in ppm. Filter times were 50-100-50-100, in seconds. Samples were shaken before repeat analysis

SUB-SAMPLE	CORE-CONTEXT	DEPTH (cm)	Sn	Ag	Sr	Pb	Zn	Cu	Fe	V	Ti	Ca	K	Al	P	S
S25	14865-1	12-13	0.00	0.00	212.62	23.43	96.38	73.32	26268.85	78.20	4034.33	12982.76	18046.30	48205.06	5515.88	652.89
S25	14865-1	12-13	0.00	0.00	210.26	25.75	107.98	72.30	27391.11	84.92	4017.27	13208.98	17881.95	48613.32	5415.67	667.20
S25	14865-1	12-13	0.00	0.00	205.72	28.15	102.92	78.47	27304.14	91.24	4062.12	13199.60	17795.90	49110.76	5591.51	690.89
S22	14823-3	38-43	0.00	0.00	214.10	35.69	86.40	126.33	24883.97	104.01	4934.86	12528.90	20508.90	55936.57	1655.77	391.40
S22	14823-3	38-43	0.00	0.00	215.43	31.04	83.32	121.73	25056.00	98.55	4939.59	12520.90	20413.84	56220.23	1579.30	360.86
S20	14825-2	28-29	248.29	4.30	209.20	2747.91	134.71	2321.16	36494.38	106.73	3806.71	14195.01	18279.44	48209.92	6713.69	2085.12
S20	14825-2	28-29	265.49	7.61	214.56	2742.33	144.78	2297.61	36854.83	113.49	3700.27	14056.72	18287.70	48591.14	6371.86	2011.33
S14	14813-1	16-18	10.18	0.00	222.82	85.22	80.77	90.46	23207.06	85.90	4100.69	11842.97	18246.13	46972.35	2746.23	720.52
S14	14813-1	16-18	20.72	0.00	195.01	175.98	77.00	90.54	23747.44	89.62	4023.37	12198.03	17695.53	49913.53	2784.68	772.28

S24	14865-1	5-6	0.00	0.00	215.16	27.07	99.05	78.93	28034.06	74.62	4068.20	13919.27	17567.55	49046.19	7422.67	732.86
S24	14865-1	5-6	14.26	0.00	228.65	28.12	103.06	72.49	28721.47	80.92	4120.82	14240.18	17393.96	50276.50	7908.90	762.14
S27	14865-2	26-27	0.00	0.00	188.91	16.18	71.48	22.31	28269.92	83.45	4361.91	11000.48	19951.44	53886.67	4696.79	612.78
S27	14865-2	26-27	0.00	0.00	192.28	19.25	75.24	0.00	28124.95	86.70	4208.47	11247.77	20210.79	56006.82	4470.56	611.61

4.5 Data processing and statistical analysis

For each case study, the statistical methods applied are detailed within the respective chapter. This section is a general consideration of the hindrances presented by the data sets.

Interrogating and disseminating large geochemical data sets is often many-staged and complex. Typical methods are kriging (Carey et al., 2014, Fleisher and Sulas, 2015), cluster analysis (Vyncke et al., 2011, Dirix et al., 2013), or principal component analysis (PCA), often in combination with each other, or alternative measures of correlation or covariance. The limitation of the data sets presented here is the acquisition method for the coring data. When analysing the dried and processed sub-samples, which are calibrated, and from one pedological horizon, then quantitative analysis can be applied to the quantitative data. The application is more problematic for the core data. The data volume requires statistical analysis to extract significant covariance. The large volume of data is necessary in order to have representative samples, but the requirement for a large volume results in quantitative data becoming so costly, quicker semi-quantitative methods are all that are affordable, resulting in data that is not necessarily suitable for the analysis that would decipher what the data means. It is worth noting that others using semi-quantitative geochemical data sets derived from XRF analysis have applied fully quantitative analysis (Mikołajczyk and Milek, 2016), as essentially the data is quantitative, but the analytical method is not.

Relating to the Heimdalsjordet data set, certain aspects are comparable; they are from similar archaeological contexts in similar environmental conditions. That is where it ceases. Any predictive modelling or spatial interpolation then has to include the assumption that the spaces between the cores are represented or predictable, which they are not. From the excavation at Heimdalsjordet, it appears the ditch backfills are a heterogeneous mix of in-washing, re-cutting and waste dumps (see chapter 6)

All cores, both the stratigraphic and geochemical data, were visualised and assessed in Rockworks 15. This software allows visualisation and analysis of three dimensional data, and was used to create the core diagrams in the case study chapters. Unfortunately, the wealth of information held in the cores cannot be fully exploited in this thesis, as information such as leaching, the effects of soil processes in different environments on geochemical data, how archaeological and geochemical stratification vary, and changes in soil conditions with anthropogenic activity are beyond the remit of this study. These subjects will be considered superficially here, in full acknowledgement that these important factors require future research.

Principal component analysis (PCA) was selected from previous research and personal experience as a means of reducing the data set into the dominant covariant clusters. As pXRF is a total method, the use of PCA in combination with site specific pedological and geological information can identify which elements are primarily sourced and exchanged from non-anthropogenic sources. The software used was IBM SPSS 19/23, and the parameters for each analysis are available in Appendices 1-3. PCA simplifies complex data into factors that influence the overall results by assigning each variable a value and assessing the degree to which this contributes toward underlying common trends within the data set. In every PCA, the number of factors is equal to the number of variables. The factors are weighted in terms of their influence and correlation. Varimax rotation was chosen as this highlights the most influential factors whilst limiting the influence of medium- or low-influence factors (Barona and Romero, 1996). The eigenvalue is a measure of how great a proportion of the variance in the observed variables is explained by each factor. Any factor with an eigenvalue ≥1 explains variance greater than does a single observed variable.

4.5.1 Avaldsnes

Prior to statistical analysis using PCA, for each element, values lower than twice the LOD were removed, as were the few rare values where the spectra suggested peak overlap or interference had occurred. Although the data distribution for the majority of elements was negatively skewed, the data was not normalised. PCA is sensitive to extreme outliers (Visconti et al., 2009), which is reduced with normalisation or, for example, log-transformation. The majority of the elements had a maximum value below +100% of the mean, with the exception of elements with a sparse number of measured values about the LOD such as Pb and Sn (data is presented in Appendix 1). Therefore the data was not transformed or normalised. Furthermore, individual elemental results were plotted two-dimensionally in ArcGIS, and core data was plotted in three dimensions using Rockworks 15. The data from the Avaldsnes samples is quantitative, and therefore, after considering the PCA results, further geostatistical analysis was undertaken. From samples considered to be from comparable contexts, a semivariogram was created, per element, using ArcGIS 10.2 Geostatistical Analyst. This clarified the spatial correlation for elements the PCA analysis had highlighted as potentially anthropogenic in origin. For each principal component (PC or factor), co-kriging (simple, linear) was used to create a predictive model of the covariance between the elements within each factor. Co-kriging is often applied where data sets have one dominant element that appears to have covariance with a less prevalent trace element, which is the case in two of the three factors identified at Avaldsnes via PCA. The second variable is dependent on the first, more dominant element. Kriging in various forms has been previously applied to geochemical datasets to visualise and analyse geospatial covariance (Entwistle et al., 2007, Mikołajczyk and Milek, 2016).

4.5.2 Heimdalsjordet

The initial step after calibrating all data was to enter all stratigraphic and geochemical data into Rockworks 15. Handling the three dimensional data set was challenging both to visualise and analyse and disseminate. Of the 40 cores taken for this research, 23 with geochemical data were selected for further analysis. The geochemical data set then consisted of 309 readings from the cores alone. Additional data from repeats and sub-samples were not included in the statistical analysis. The stratigraphy recorded from the cores was included, and the stratigraphy and geochemistry was evaluated, with a focus on the archaeological contexts. The data was normalised (Z-score) and PCA was applied to the data from archaeological contexts in the first instance, then a separate PCA analysis with identical parameters was applied to both the archaeological and 'non-archaeological' contexts from the cores, in order to define the effects of soil processes on the geochemical data.

In addition, the horizontal samples taken near the oven feature 12263 were separately analysed using ArcGIS 10.2. Ordinary, linear kriging was applied after the creation of a semivariogram for elements connected to non-ferrous metalworking. This was used to confirm the geospatial patterning and covariance. Importantly, geospatial analysis often can produce visual aids for dissemination. Whilst the appropriate methods are dependent on the parameters of the data set production, complex geochemical data sets can be challenging for the non-expert to understand. The advantage of creating encompassing, visual interpretations should not be ignored.

4.5.3 Kaupangveien

The data set from Kaupangveien was considerably smaller than the other two case studies, due to the dimensions of the accessible site. The various methods of data collection (coring, direct and indirect core measurements, stratigraphic sampling, in situ analysis) meant that the potential for statistical analysis was limited. Therefore, experience from the previous two case studies was applied to the calibrated data set. Core data was visualised using Rockworks 15, and horizontal samples were spatially analysed using ArcGIS 10.2.

4.6 Summary of chapter

There are many potential sources of error or limiting factors within the methodology outlined here, some more quantifiable that others. To work logically through the methodology, initial sources of error and/or limitation relate to taking cores and sampling contexts. Core locations were selected from a cumulative process of interpretation of both GPR and exposed archaeological features. This contains many inherent biases based upon personal experience, technological ability and interests. Another factor that dictated sample locations was time and access. Whilst the site was under excavation, interpretations for areas were discussed, but many contexts can only be interpreted during their removal, thus making them impossible to directly sample using a core. This is because the stratigraphy revealed in section cannot be assumed to be present in a core taken even a few centimetres distant, even if the upmost, visible context can be demonstrated to be consistent. Therefore comparisons to excavation data are steeped in problems. However, this is not a unique situation in archaeology. Contextual disruptions from later disturbance are common in field archaeology, and as long as these are acknowledged as a limiting factor to any interpretation, observation and cumulative evidence can create plausible arguments.

Within the analysis using pXRF the instrument calculates error, in this case to 2σ. The limits of detection (LOD) are also calculated by the instrument to 3σ. These do not encompass all sources of error using the pXRF. When using the stand to hold the instrument, and the sample is within a container with a polypropylene window, it can be reasonably assumed that the distance and interference between the sample and analyser is constant and comparable between all samples. This is not the case when the instrument is handheld. Every precaution to standardise the method has been made, such as using the automatic cut off time within the instrument to ensure analytical time was near identical from one sample to the next – however - human error is unavoidable. The hand may move a fraction, altering the sample point by a millimetre, and the contact between the sample and the analyser may vary ever so slightly over the analytical time. This source of error has not been quantified here, nor has moisture content of the cores, and these render the produced data semi-quantitative. The use of standards to calibrate all data means that samples analysed in the stand by a standard methodology are quantitative, however if hand-held, this cannot be achieved.

Within each case study in the subsequent chapters, the strengths and limitations of the methods and results will be discussed in relation to the research aims and objectives on a site by site basis.

5. Avaldsnes

The first of three case studies is presented in this chapter in the familiar introduction, methods, results, discussion format. As the first case study, Avaldsnes was intended to test the application of pXRF in archaeological geochemistry, and begin to address the issues already presented, including method integration, defining space, and using cores as part of the sampling strategy.

5.1 Introduction to Avaldsnes

The archaeological and historical significance of Avaldsnes has been the subject of inquisitive antiquarian, archaeological and historical speculation for some time (Skre, 2015, Bonde and Stylegar, 2016). The landscape remains a testament to past demonstrations of possession, command and belonging, sculpted into physical longevity. Avaldsnes faces the sea but, unlike land, the sea is impossible to truly possess. Now, the medieval stone church of St. Olav dominates the peninsula skyline (figure 5.1). Built around 1250, it is one of a handful of such stone churches built in Norway, and their presence pertains to historic wealth and status. Until relatively recently, Flagghaugen stood on the brink before the church. Rising four or five metres from the bedrock scarp, the burial mound was clearly visible from the sea; the narrow passage of Karmsund between the main land and the island of Karmøy, where Avaldsnes sits. The passage was part of the sailing route - *Norðvegen*, the way north - which in turn gave the country its name (Skre, 2015).

Figure 5. 1. St. Olav's Church, dated to c. 1250, dominates the landscape at Avaldsnes. Photo: Royal Manor Project, MCH, UiO

Listing toward the church wall, *Jomfru Marias Synål* (Virgin Mary's Needle) is a 7.2 metre high standing stone, once part of a stone setting but now solitary after the others were taken down or fell. Further south along the bedrock scarp, the smaller Kjellerhaugen still stands. Flagghaugen was removed in 1834 to provide soil to improve and expand the graveyard of St. Olav's Church. Inside the burial mound was a wealth of objects from the mid-Roman Iron Age, including weapons, a gold torc and imported bronze vessels. The assemblage found within make it one of the wealthiest Roman Iron Age graves in Scandinavia. Kjellerhaugen (Cellar Mound) was unceremoniously converted into a potato cellar, a not-too-uncommon practice in Norway in the past century or two. No finds were reported, although local folk tales imply that the farmer lived a very good life afterwards. Kongshaug is a little further inland upon another elevation. Here, a sword and a gold bar have been found in the past.

Stray finds from the Avaldsnes area suggest the site had been a focus for human activity since the Neolithic, and the nearby mound cemetery, Reheia, demonstrates that it was already an important settlement site in the early Bronze Age. Once far larger, the cemetery now consists of six large mounds. Previous evaluation work at Avaldsnes found continual settlement evidence from 200 BC to the present day (Bauer and Østmo, 2013). The wealth of the sea could be afforded and accessed from the vantage point of Avaldsnes. This is in terms of connections, trade and control, which continued to attract settlement into the Middle Ages, when the Hanseatic League established a post within view of St. Olav’s Church.

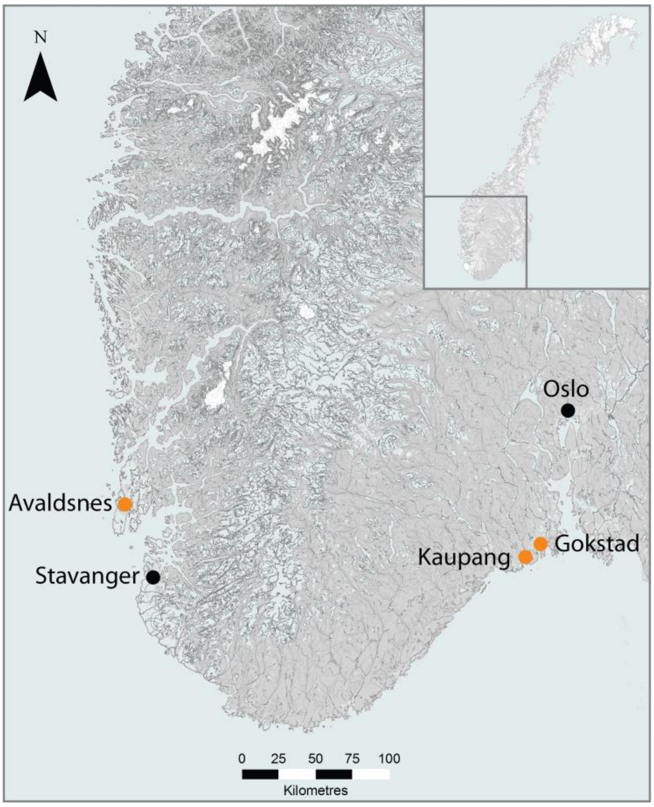


Figure 5. 2 Location of case study sites. Map source: Author /Norwegian Mapping Authority 2016.

References to Avaldsnes in Olav Tryggvasson’s saga, together with the wealthy finds and past and present monuments, have created an aura of national importance over the site. This has been capitalised upon by the construction of a purpose-built museum and educational centre which has been constructed with respect towards the aesthetics and homogeneity of the landscape. A reconstructed Viking Age farm and a substantial boathouse have also been erected on the nearby island of Bukkøya. The heritage of Avaldsnes, and especially its possible role in early kingdom formation, makes it locally and nationally important in terms of past and present economics and identity (Bauer and Østmo, 2013).

The Royal Manor Project (RMP) is directed by Prof. Dagfinn Skre of the Museum of Cultural History, part of the University of Oslo. The project's overarching aim is to deepen archaeological understanding of early royal power at Avaldsnes in late Iron Age Norway. This includes its economic and military roles and its position as a centre for the manufacture and trade of high-status items, as well as control of primary economic resources such as food (Bauer and Østmo, 2013, Skre, 2010).

This doctoral research project was conducted within the framework of the RMP, and therefore its aims were incorporated into these research aims and objectives. The potential for geochemical analysis to provide evidence to forward the RMP's research aims was identified prior to excavation as a method capable of measuring and locating production and storage activities, particularly in situations where the physical remains available to archaeologists are scant or tenuous. Thus, as a technique complementary to the other scientific and traditional methods employed during the excavation and the research project as a whole, geochemical analysis could provide supporting evidence for the interpretation of excavated archaeological features and areas.

5.2 The physical setting and sampling

5.2.1 The geology and pedology of Avaldsnes

The Cambric, silty loam soils of Avaldsnes overlie undulating bedrock. Bedrock is exposed over low peaks, typical of the wet, cool, West Norwegian maritime climate and landscape. Soil depths vary greatly over the site, and beneath the deepest areas are buried soils, which appear to be organic rich, fairly stone-free and shallow, developing directly over weathering bedrock, and typical of Regosols. The geology of Karmøy consists of both sedimentary and igneous rocks, and previous geological studies have focused on the volcanic trenching and intrusions between the dominant rock types (Poppleton and Piper, 1990). There are various published maps of the geology, and the general consensus is that the site lies upon the Karmøy ophiolite group, formed 495-485 million years ago (Fossen *et al.*, 2007). The origin of ophiolites (part of the amphibolites group) is the oceanic crust and mantle, and they are generally seen as the result of ocean floor spreading and later uplift. Volcanic activity associated with this has resulted in igneous granites, metamorphic sandstones, quartz and pillow lava deposits in a series of intrusions as the sea floor spread. The composition of amphibolites is a SiO_4 tetrahedra, which are often iron and magnesium rich. Due to the alkaline base, they also contain calcium in the mineral structure, and under the present climatic conditions produce near-neutral to slightly acidic soils. The granites and metamorphic rocks are unusual on Karmøy in that they are very varied in composition from the melting of the continental land mass, and contain everything from limestone to marble within the granite amalgamation. The site lies close to a geological boundary between the green schist which underlies much of the archaeological site, and volcanic metamorphic sandstones and quartz (N.G.U, 2013). The alkaline, iron rich geology has produced fine silt loam soils that are very productive where of sufficient depth for cultivation. The area of the site where the samples are taken contains no glacial deposits. Therefore all samples are directly related to the geology and subsequent weathering to soils, and anthropogenic activity.

5.2.2 Site specific aims and objectives

In chapter one, the overall aim was stated as assessing the potential of integrated geochemical analysis using pXRF to better understand the use of space and the range of activities in Viking Age settlements. The objectives include the use of coring as a sampling method to capture temporal and spatial change. As part of the RMP, the targeted areas fit within the project aims of understanding the economic diversity and structure of the site as a power centre in the Iron Age. The long Iron Age in southern Scandinavia shows upheaval and change in land ownership, hierarchy and social structure, cultural and cultic foci, settlement and household forms, in fact in every way but for the elongated exterior form of the longhouse (Herschend, 2009). Therefore generalisations should not be made. By the later Iron Age, when hierarchy becomes more pronounced in architecture, the specialisation and delineation of production areas within high status sites appears more strongly (e.g. Järrestad and Tissø) (Jørgensen, 2002, Söderberg, 2005). The division of space in other comparable high status settlements, by the Migration Period suggest that divided cultural and economic functions indicate specialty beyond the intermixed domestic and industrial typical of the farmstead. This is simultaneously a social and economic division. How divisions are manifest, whether by deliberate and/or accidental waste accumulation, they demonstrate ingrained practices if they endure over time, and geochemistry is reliant on repeated action. The aim was, via geochemistry using pXRF, to see if these divisions were apparent, how they were structured, and the types of activities that could be identified. Temporality is a challenge to geochemistry. Therefore at Avaldsnes, the first case study in this research, cores were taken to test if they could provide an additional dimension to the single, horizontal layer sampling and analysis. This came from the extensive coring done over the site during the excavation seasons of 2011 and 2012, which was aimed at understanding site formation processes and archaeological prospection (see 4.2.2).

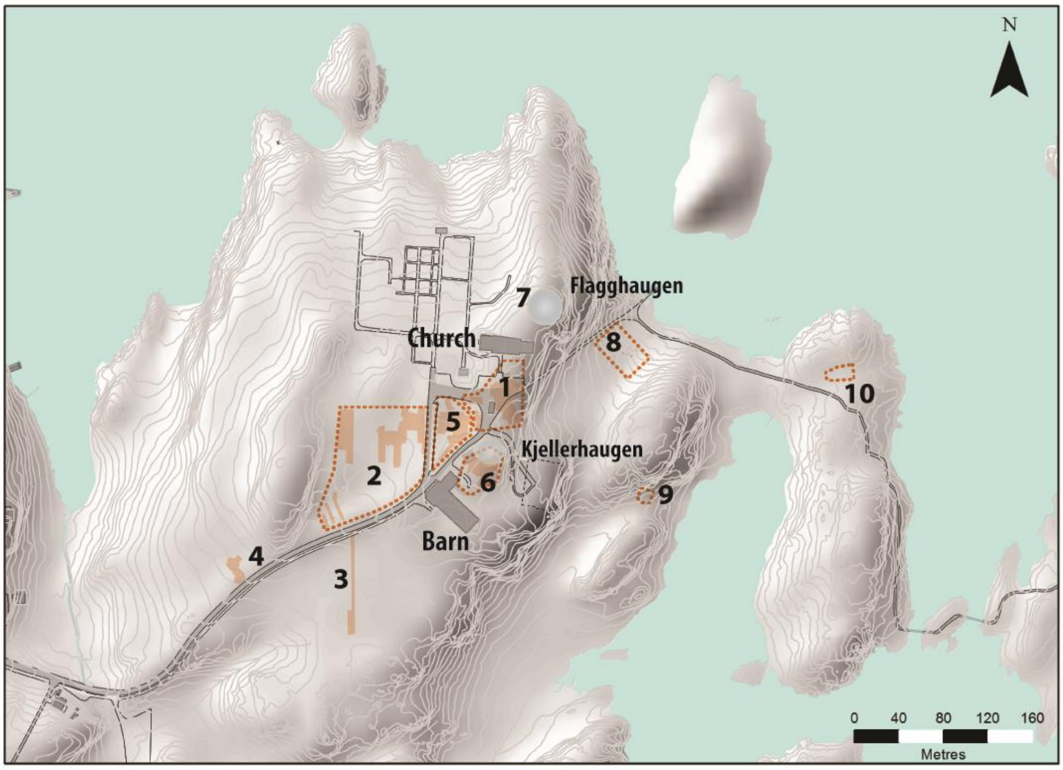


Figure 5.3. Map showing the areas excavated by the Royal Manor Project in relation to current buildings and roads at Avaldsnes, Karmøy, Norway. Map source: Author/RMP/Norwegian Mapping Authority, 2016

5.2.3 Sampling methods and hindrances

The geochemical sampling for multi-elemental analysis at the site was focused on Area 6 (figure 5.3), which was excavated in 2012. This area was selected for practical and archaeological reasons. The silty loam cambric subsoil appeared consistent on the selected archaeologically defined surface. The revealed archaeology was complex and multiphase; however there was no immediately visible structure or pattern, such as a clearly defined house as discovered in other areas, complicating interpretive efforts. Modern disturbance presented a constant challenge during the Avaldsnes excavations, as noted in chapter 4. In Area 6, although modern intrusions such as cable trenches are present, these were nevertheless isolated and appeared demarcated, hence sampling could potentially avoid these areas.

Area 6 can be physically defined. A bedrock scarp, formed by changing geology from green schist to metaphoric sandstone, limits the area to the east and south; the scarp allows a vista over the land and coast to the east, toward Bukkøya, Karmsund, and the mainland. Modern disturbance, buildings and raised bedrock limited the available surface to the immediate south and west, whilst to the north the substantial Kjellerhaugen burial mound formed another boundary, delimiting an area for study. Of course, it cannot be assumed these defined boundaries had the same, or indeed any, relevance in the past.

Figure 5.4. Photo of the mechanical topsoil stripping of Area 6, Avaldsnes. Taken facing south, with the flank of Kjellerhaugen, the Bronze Age burial mound, sloping up in the far right foreground of the picture. The boulders visible in the centre for- and middle-ground are from what has been interpreted as a revetment or fortification. Photo: RMP, MCH, UiO.

During the excavation of Area 6, 85 postholes were recorded, along with several oven features, cooking pits, stakeholes, and stone settings (figure 5.4 and figure 5.5). There is clearly a multi-period aspect to all areas of the site; according to ^{14}C results, Area 6 was occupied from 300 BC to AD 1160, excluding the modern disturbances. Hence, in Area 6 there were not one, but several spaces representing different phases of use. The change or continuity of use within the geographically constrained space, as well as the activities represented within it, could be highly enlightening in regard to understanding the role of the site throughout the period as a centre for royal power. The majority of the dates relating to the area sampled for this analysis fall within the Viking Age (see figure 5.6). Geochemical results could potentially define features and specific activity areas, as well as detecting the function of oven features. For example, the purpose and use of an oven, such as for metalworking, domestic activities, or large-scale food processing, can have significant implications for the economic and social structure of the site. This was demonstrated for the Silchester site by Cook et al. (2009), who analysed samples from hearths and furnaces using laboratory-based XRF in order to specify hearth and oven function to the metals worked or domestic activity. Within buildings, ‘zones’ or ‘functional areas’ can be chemically defined in environments as varied as Neolithic Orkney to Hellenistic Turkey, and could therefore help define the use of space in Area 6 (Jones et al., 2010, Vyncke et al., 2011).

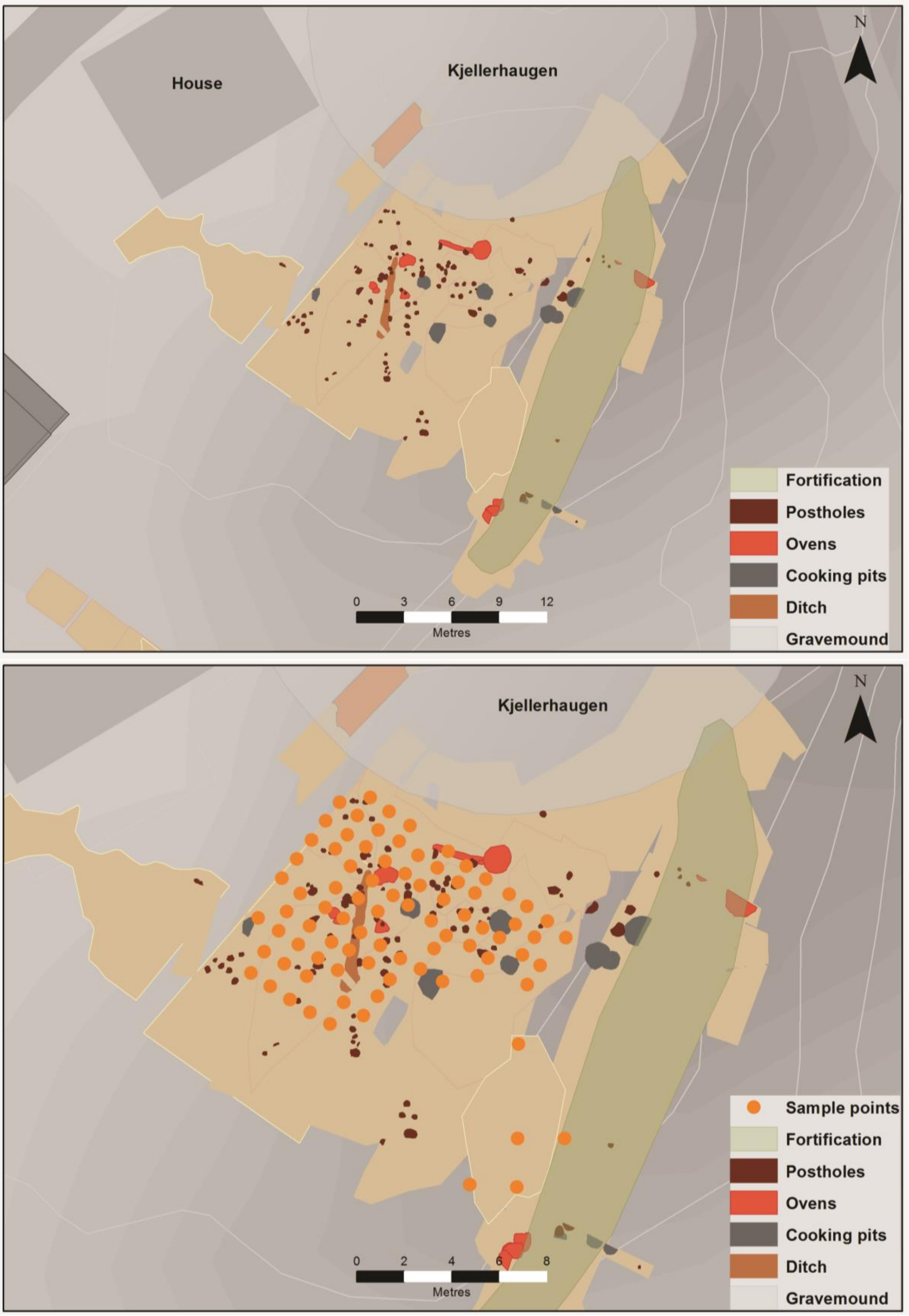


Figure 5. 5a &b. Top: The archaeological features in Area 6. Note all features are shown here; the figure does not relate to one single phase of the site. The ditch A12178 is in brown, and oven A44031 is the key shaped oven. Bottom: As figure 5.5a, with sample locations. Map Source: Author/ RMP/ Norwegian Mapping Authority, 2016.

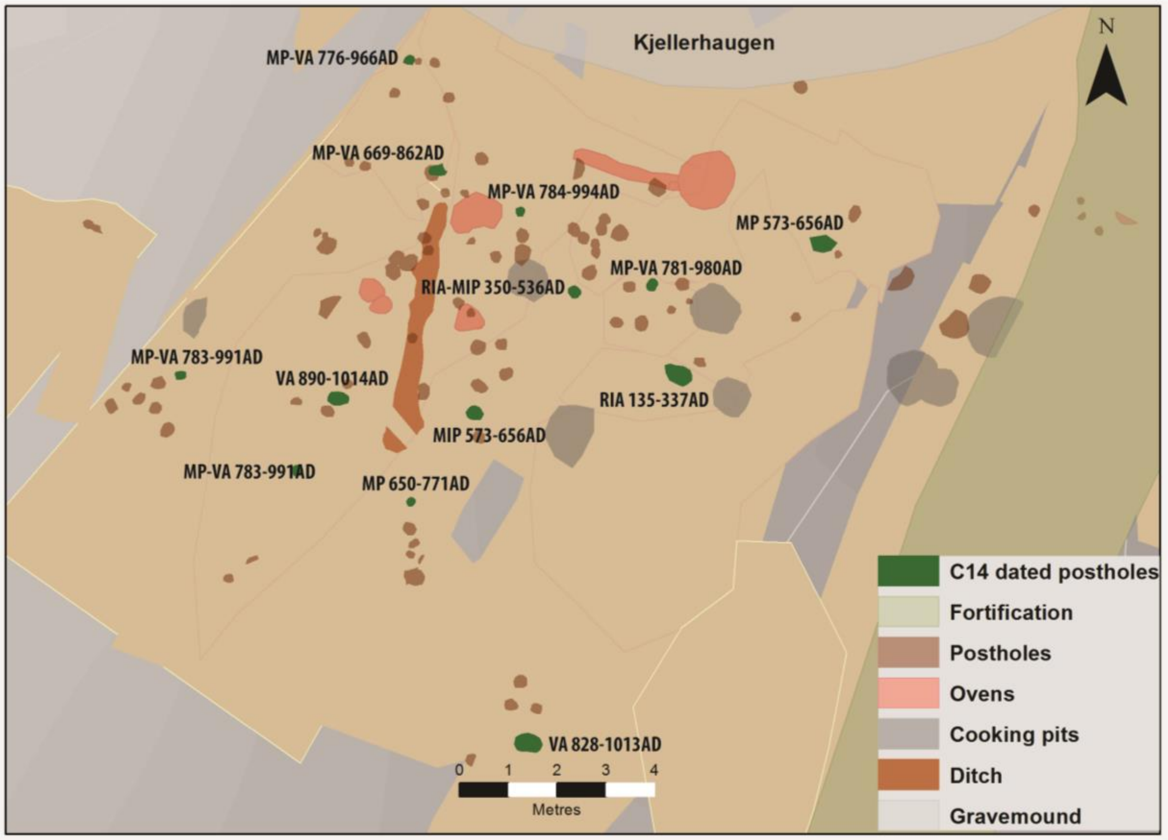


Figure 5. 6. Postholes in Area 6 that have been radiocarbon dated via material in the backfill. The majority were dated using grains found in these backfills, and the dates are to 2σ. Key to abbreviations: VA= Viking Age, MIP= Migration Period, MP= Merovingian Period, RIA= Roman Iron Age. The similar and wide date ranges are a product of the flat calibration curve in the later Iron Age. Map source: Author/RMP/Norwegian Mapping Authority, 2016. All ^{14}C dates courtesy of the RMP, taken from Bauer & Østmo 2013: 127.

5.3 Results for Area 6

5.3.1 PCA results

The results presented in tables 5.1 and 5.2 are for Area 6 samples only, which were taken from an archaeologically defined subsoil horizon with negative features primarily dated to the Viking Age. However, the features are cut from an upper archaeological horizon, i.e. the sampled horizon is stratigraphically earlier and without any archaeological features exclusively associated with it. The highlighted results are those having more than ±0.6 influence (or 60%) on that factor – that is, those elements playing a significant role in the underlying covariance in that factor. Table 5.1 includes elements that have proven, through peer-reviewed research in comparable projects (Entwistle et al., 1998, Middleton, 2004, Oonk et al., 2009a, Oonk et al., 2009b, Wilson et al., 2009, Jones et al., 2010, Vyncke et al., 2011), to produce significant *and* interpretable results relating to past anthropogenic activity. Table 5.2 includes all elements that produced significant results, which in this case is twice the instrument’s limits of detection (LOD) for each element, calculated to 2σ. This data set is used in the subsequent interpretations and discussion. Possible interpretations of the cause of each factor are reported in each table, as well as the proportional influence rendered by each factor. The data set used for PCA analysis included core sub-samples from the layer relevant to the horizontal sampled area, where present. The six highlighted factors account for 73% of all variance in table 5.1, and 70% in table 5.2.

Table 5.1. Results for varimax rotated principal component analysis on selected elements from samples from Area 6, Avaldsnes. Background values are excluded.

Varimax Rotated Component Matrix						
	Factor					
	1	2	3	4	5	6
Influence (%)	**20**	**15.99**	**11.37**	**9.93**	**9.15**	**7.35**
Al	.713	.422	.431	.042	-.031	.021
Ti	-.213	.884	.103	-.051	.047	-.120
Mn	.032	.784	-.233	.134	.140	-.033
Fe	.030	.864	-.031	.242	.102	-.054
Cu	.081	.095	.145	.844	.066	.089
Zn	.003	.195	.118	.824	.080	.018
As	.140	.242	-.061	.005	.618	.334
Rb	.804	-.032	-.260	.084	.204	-.149
Sr	.222	-.213	.764	-.168	-.057	-.080
Cd	-.114	.031	-.106	-.160	-.032	.738
Sn	.060	.010	-.136	.399	-.101	-.093
Pb	-.148	-.382	.075	.258	.115	.729
Si	.741	-.170	.458	-.061	-.144	.104
P	-.071	.156	-.086	-.034	.855	-.248
S	-.509	-.193	.087	.057	.674	.166
K	.894	-.018	-.122	.118	-.144	-.031
Ca	-.265	.071	.813	.234	.011	-.060
Ba	.808	-.056	.097	.044	-.067	-.164
Mg	.385	.565	.522	.218	-.104	.111
Possible Interpretation	Mica clay	Opholite geology	Organic waste; bones, shell sand or ashes	Copper alloy working	Organic waste; dung or midden material	Modern contaminants

Table 5.2. Results for varimax rotated principal component analysis on all elements from samples from Area 6, Avaldsnes. Background samples are excluded.

Varimax Rotated Component Matrix						
	Factor					
	1	2	3	4	5	6
Influence (%)	**18.48**	**17.92**	**9.86**	**9.29**	**7.90**	**6.32**
Al	.759	.415	.350	.043	-.019	.035
Ti	-.162	.925	.066	-.075	.052	-.080
Mn	.058	.737	-.288	.135	.157	-.031
Fe	.047	.845	-.103	.291	.097	-.076
Cu	.107	.099	.150	.812	.079	.076
Zn	.023	.195	.117	.811	.086	-.008
As	.139	.201	-.098	.040	.630	.312
Rb	.763	-.090	-.315	.118	.196	-.203
Sr	.254	-.189	.749	-.142	-.065	-.090
Cd	-.116	.014	-.124	-.116	-.024	.732
Sn	.072	.041	-.115	.316	-.092	-.031
Pb	-.147	-.382	.102	.267	.131	.717
Si	.775	-.155	.427	-.093	-.129	.128
P	-.082	.161	-.082	-.051	.849	-.255
S	-.514	-.159	.136	.049	.669	.162
K	.869	-.074	-.187	.156	-.145	-.077
Ca	-.216	.131	.816	.249	-.003	-.060
Ba	.811	-.077	.064	.029	-.057	-.168
Mg	.433	.553	.435	.262	-.102	.105
V	-.057	.933	.144	.093	.033	-.073
Zr	.448	.278	.274	-.440	.035	.094
Pd	.128	-.143	-.081	-.158	-.016	-.045
Possible interpretation	Mica clay	Opholite geology	Organic waste; bones, shell sand or ashes	Copper alloy working	Organic waste; dung or midden material	Modern contaminants

5.3.2 Background values

Cores 25055 and 25088 were taken in Area 4, approximately 250 metres south-west of Area 6 (figure 5.3). After comparing the cores to the excavation record and local environmental data, the geology, soil-formation processes, and land use, these cores were deemed similar enough to be taken as representative of 'background' levels. The area was not completely devoid of previous settlement traces, as would have been ideal. Here, past settlement was represented in the form of some stakeholes and a cooking pit to the north of the background cores.

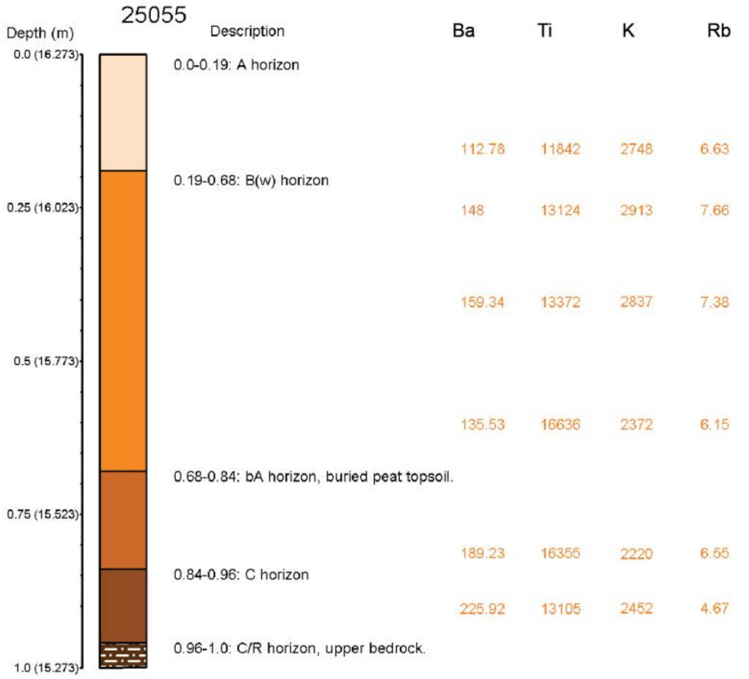


Figure 5. 7. Background core 25055 with measured results for elements barium (Ba), titanium (Ti), potassium (K), and rubidium (Rb).

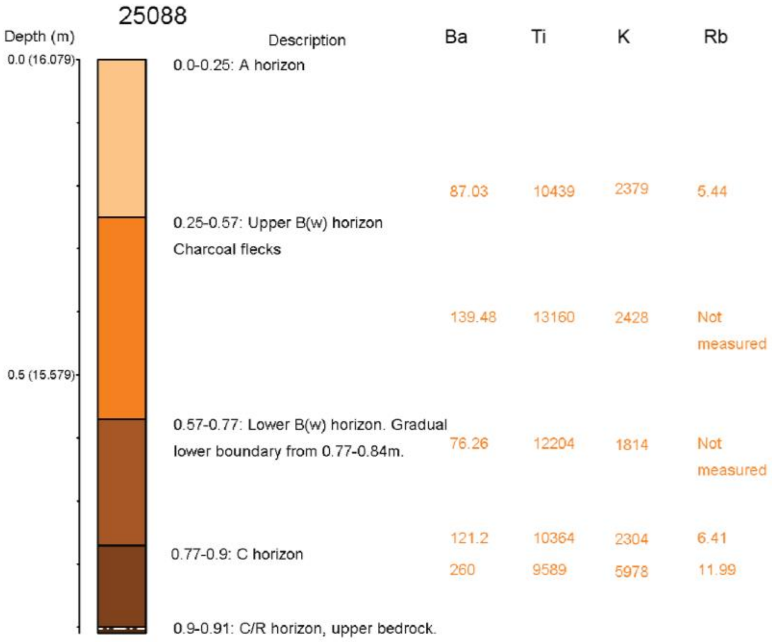


Figure 5. 8. Background core 25088 with measured results for elements barium (Ba), titanium (Ti), potassium (K), and rubidium (Rb).

Middleton (2004) considers background samples from undisturbed contexts essential; however, confidence placed in finding background samples that represent undisturbed conditions is naive at best (Oonk et al. 2009a). Even in sparsely populated areas, both past and present, the cultural land use over time is highly likely to have influenced the soil to some degree. Therefore, the values are taken as a guide rather than an absolute, especially with regard to the upper horizons. The background values indicate that, as expected, there is considerable variation in elemental values. This is accounted for within the PCA analysis. The cores are presented in figures 5.7 and 5.8, with geochemical data related to soil formation.

5.4 Interpretation and discussion of PCA analysis and geochemical variation

5.4.1 Factor 1: Soils and sediments

Factors one and two (see table 5.2) are interpreted as the influence of the soil and geology, respectively. Unsurprisingly, as pXRF analyses the samples in their entirety rather than extracted elements (Gauss et al., 2013), the soil matrix exerts the greatest influence on the results. In Factor 1, the strong influence of Al (aluminium) and Si (silicon) indicates that this is the influence of the soil type, more specifically the clay type and sesquioxides. Barium (Ba) and rubidium (Rb) are common substitutions in the clay lattice of mica clays; the clay at Avaldsnes appears to be of this type (Tan, 1998). Ba has a similar ionic radius to K (potassium), and is therefore often a substitution within K sheets in clays (Entwistle et al., 1998). Sheets of K are found in certain mica clay types, such as illite and muscovite. These are micaceous phyllosilicate, often rich in magnesium (Mg) and containing many isomorphic substitutions, such as the Rb and Ba mentioned above (Eylem et al., 1990, Tan, 1998). Potassium (K) has geochemical properties similar to Rb, and the association has been previously noted (Entwistle et al., 1998). Factor 1 is therefore undoubtedly the influence of the soil matrix. Confident assignment to a clay type, however, requires further analysis. Silts, sands, and amorphous phyllosilicates, such as sesquioxides, also contribute to the factor.

It is important to note that the influence of an element within a factor is not a measure of abundance, but rather of impact on covariance. Rb has a mean of 19 ppm and RSD of 35.1%, whereas Ba shows greater variation and abundance (mean 197 ppm, RSD 45.53%) but similar degree of influence.

5.4.2 Factor 2: Geology

The geology of Karmøy is described in section 5.1.1. The site lies on green schist, which is rich in iron (Fe), and manganese (Mn). The geology also appears to be rich in vanadium (V), which is common in iron rich deposits, including ores. Other than these elements, naturally Si in the mineral is influential.

Titanium (Ti) has been successfully used in geochemical analysis as a proxy for geological influence, as it is essentially a direct product of minerogenic erosion – it is neither utilised by plants, nor prone to leaching from the soil (Kylander et al., 2011). The geological origin of this factor is confirmed by combination of Ti, V, Fe and Mn as strong elemental influences.

5.4.3 Factor 3: Settlement waste

The two elements significant in this factor are calcium (Ca) and strontium (Sr). This factor explains 75% of the Sr variance, and 82% of the Ca variance. There is a considerable difference between the highest and lowest recorded values, suggesting an anthropogenic factor (figures 5.9 and 5.10). For example, the lowest Sr value is 19 ppm, the highest 274 ppm. The values are generally below the mean ‘background’ values for strontium (Sr 195 ppm) and for calcium (Ca 39432 ppm) from the B horizon sampled for background readings, which is comparable in environmental and geological formation to that of the on-site samples. Background readings for strontium in all horizons are fairly consistent (11.72% RSD) with a low error (1.6%). The reason for values in Area 6 falling below the average could be the addition of acidifying material via organic waste to the soil, which would increase Ca depletion (Cook and Heizer, 1965), or the removal of the Ca by plants as a required macro-nutrient. In addition, the background samples cannot be assumed to perfectly represent all ‘natural’ inputs and variation; they are guidance values only. Despite the fact that the Sr and Ca values are below background values, they have a correlated significance, which is highly unlikely to be geological. The values above background produce a very distinctive cluster in the area with the greatest number of preserved archaeological features alongside and to the west of the wall ditch A12178. This suggests that anthropogenic inputs over time have acidified and depleted the soil of geologically sourced Sr and Ca, while adding the anthropogenically sourced elements, resulting in the distribution suggested in the data.

Strontium and calcium are present in bones and shells, with elevated concentrations found in fields where waste has been used as fertiliser or in midden areas (Entwistle et al., 1998, Wilson et al., 2008). Alternatively, although the composition of ash can vary depending on the fuel source, almost all types of ash contain elevated levels of Ca (Canti, 2003). Ashed grasses are likely to have elevated silica contents, whereas ashed seaweed is likely to have elevated potassium (K), magnesium (Mg), and sulphur (S), and possibly also barium (Ba), although this is not exclusive to this type of plant ash (Entwistle and Abrahams, 1997, Canti, 2003, Milek and Roberts, 2013). Another possibility is shell or shell sand, which are rich in Ca, Sr and Si, but these elements show limited influence with Mg. Shell sand is used to improve acid soils (Entwistle and Abrahams, 1997), or more precisely as a means to increase pH and thus the availability of essential plant macronutrients. The soils at Avaldsnes are unlikely to have required extensive shell sand addition, as the pH is at or above 6 in almost all horizons while the local shore is poor in shell sand; therefore, alternative sources must be considered. This includes shells being added as part of the processing of seaweed ash for salt or as a preservative, as identified by Ballantyne et al. (in press). As the values are highest in proximity to the postholes containing the seaweed ash identified in macrofossil analysis, this interpretation fits with the excavated and sample evidence. However, although shells could accompany harvested seaweed, the impact and quantity is entirely unknown, and therefore highly speculative. Alternatively, Ca and Sr levels would also be enhanced by bone from the storage or processing of meat or by-products for which the seaweed ash was potentially used. Experimental work by Photos-Jones et al. (2007) on making ‘cramp’, a vitreous ashy slag from seaweed burning, and the ashing of kelp, found high levels of Ca and Sr. In this laboratory experiment, the proportion of Sr is higher than that of archaeological bone while the Ca content is lower. These factors, however, can be environmentally dependant. In a context of an age similar to the Avaldsnes context, Milek and Roberts (2013) found clear evidence for the storing of seaweed ash or seaweed by raised levels of salts, Mg, Ca, K, and S within a Viking Age house dated to c. AD 890. This confirms that the practice of using seaweed as a fuel or ashing seaweed as a preservative was known from similar contexts, and that it leaves geochemical traces. The interpretation could perhaps be strengthened by testing the salt content using electrical conductivity, but the combined geochemical and macrofossil results strongly suggests a food-processing area using seaweed ash in some form as fuel or to preserve or process food, such as meat. The geochemical traces stem directly from this process or from the by-products of processing seaweed or bone.

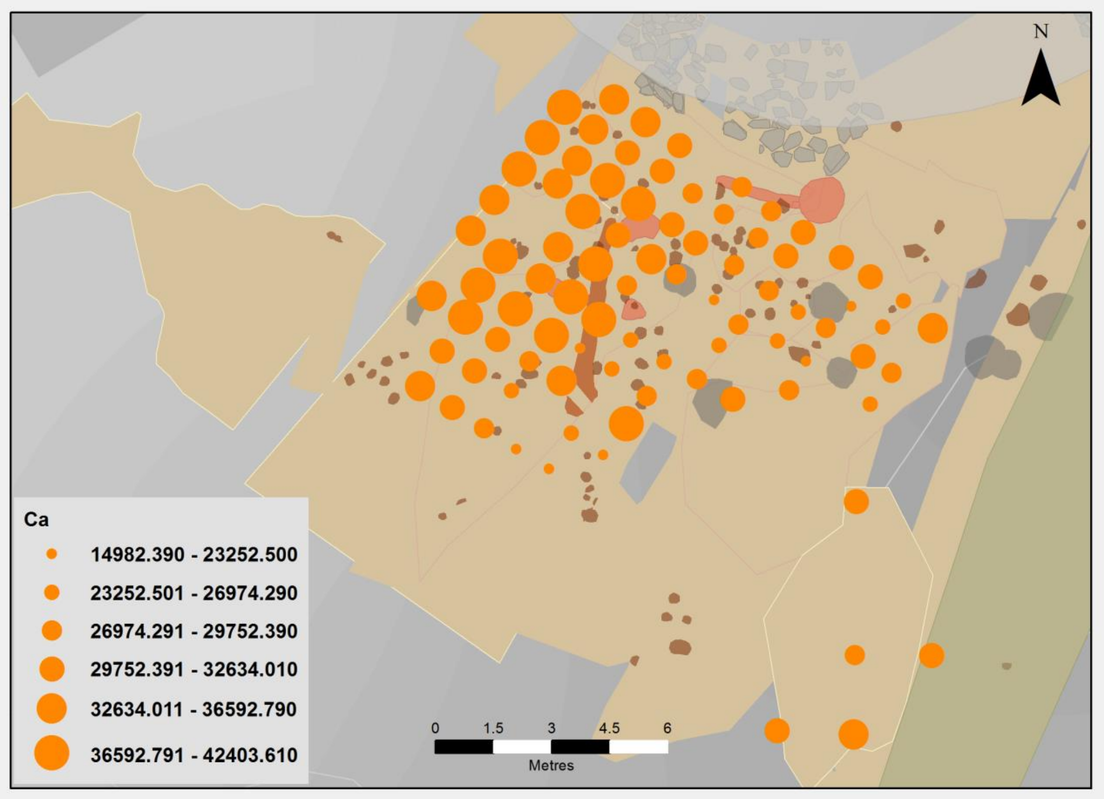


Figure 5. 9. The measured values for calcium (Ca) in ppm by sample for Area 6. Map source: Author/RMP/ Norwegian Mapping Authority, 2016.

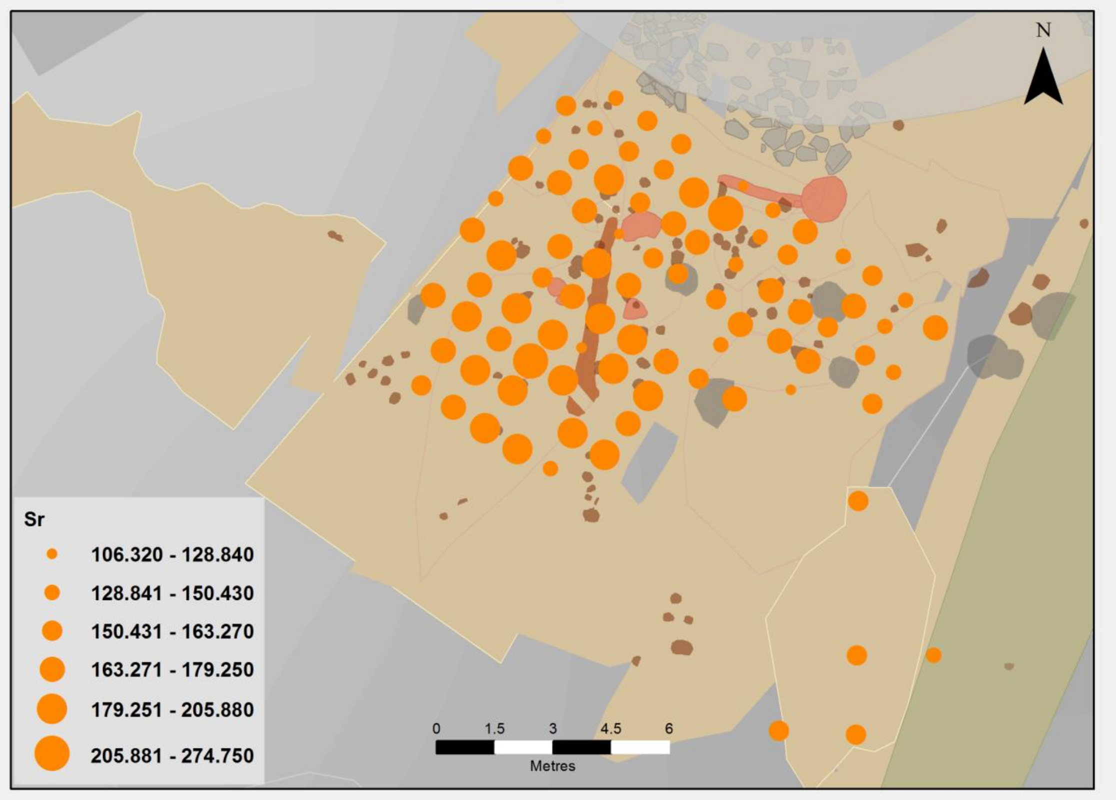


Figure 5. 10. The measured values for strontium (Sr) in ppm by sample for Area 6. Map source: Author/RMP/ Norwegian Mapping Authority, 2016.

5.4.4 Factor 4: Copper alloy working

As stated above, the results of PCA analysis indicate the amount of influence that elements have on that factor, but not the abundance of those elements. The fact that copper (Cu) and zinc (Zn) are almost equal in influence indicates that they function in tandem to create their own factor, where 81% of the spatial variance for both elements is explained. In this context, Cu and Zn concentrations are unlikely to be natural phenomena. These metals are better adsorbed and retained in soils with neutral-to-alkaline pH, such as the soils at Avaldsnes (Arias et al., 2005).

The anthropogenic activity they most logically represent is metalworking, although these elements have also been associated with human settlement more generally (Entwistle et al., 1998). The clustered distribution of the metals, with the lesser influence of tin (Sn) in this factor, suggests metalworking (figures 5.11, 5.12, and 5.13). This could be in the form of the working of already processed products, either by reworking existing artefacts or working with ingots. The scale is undoubtedly small, as the measured values are low, although a proportion will have been leached and/or taken up by plants as a required micronutrient. Higher P concentrations also increase the adsorption and retention of these elements from the soil solution, although this is also pH dependent (Pérez-Novo et al., 2009). Were this the decisive factor, the interpretation would be of a general settlement; P would also be a strong influence in factor 4 – which is not the case. The elevated Cu and Zn levels in Area 6 appear in the area associated with features dated to the Viking Age/early Middle Ages, and not the P concentrations identified toward the eastern part of Area 6 in factor five and by Macphail and Linderholm (in press).

The higher Cu and Zn values are concentrated to the south-west of the postholes and wall ditch alignment (A12178), which corresponds well with the enhanced magnetic susceptibility values observed by Macphail and Linderholm (in press), although any connection cannot be asserted. Finds of slag were also more abundant in this area; however most slag appears to have been disturbed and within secondary deposits (Bauer and Østmo, 2013). Zinc was also enhanced near oven A44031, which in similarity to the wall ditch A12178 is dated to the late Viking Age and/or early Middle Ages. Tin (Sn) has limited influence on this factor compared to Zn and Cu. The cause of this disparity is perhaps the scarcity of samples with tin present; the little tin that was measured is clustered in the same area to the north and west of Area 6. This is not concrete evidence that direct metalworking was taking place near these features at this time. However, it is possible that small-scale copper alloy working has taken place in association with these features.

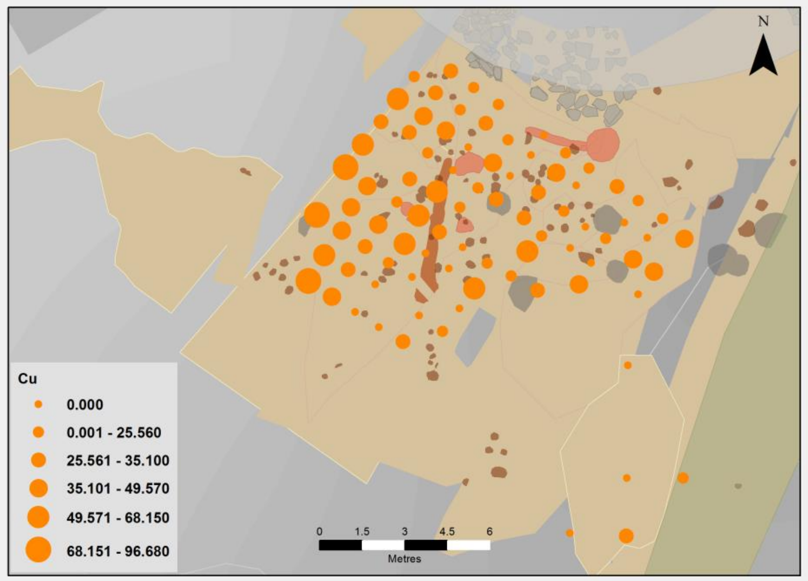


Figure 5. 11. The measured values for copper (Cu) in ppm by sample for Area 6. Map source: Author/RMP/ Norwegian Mapping Authority, 2016.

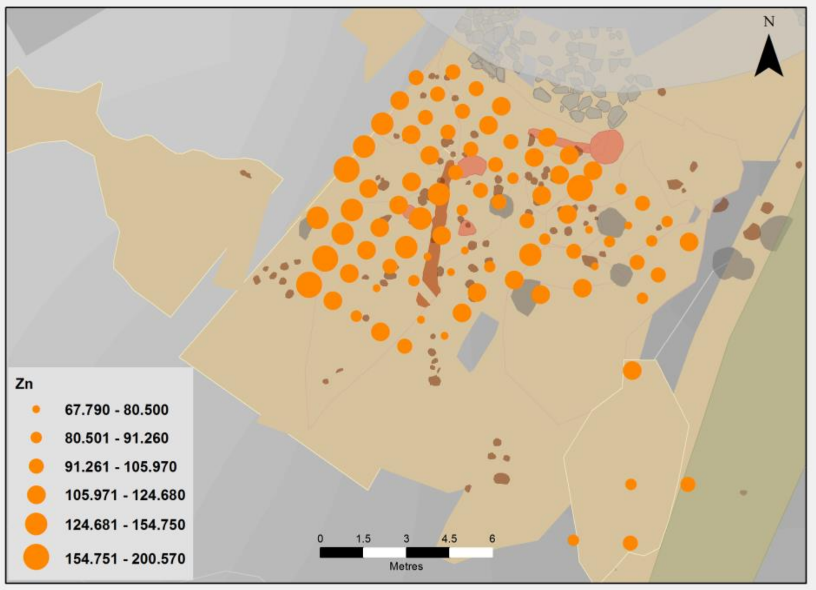


Figure 5. 12. The measured values for zinc (Zn) in ppm by sample for Area 6. Map source: Author/RMP/ Norwegian Mapping Authority, 2016.

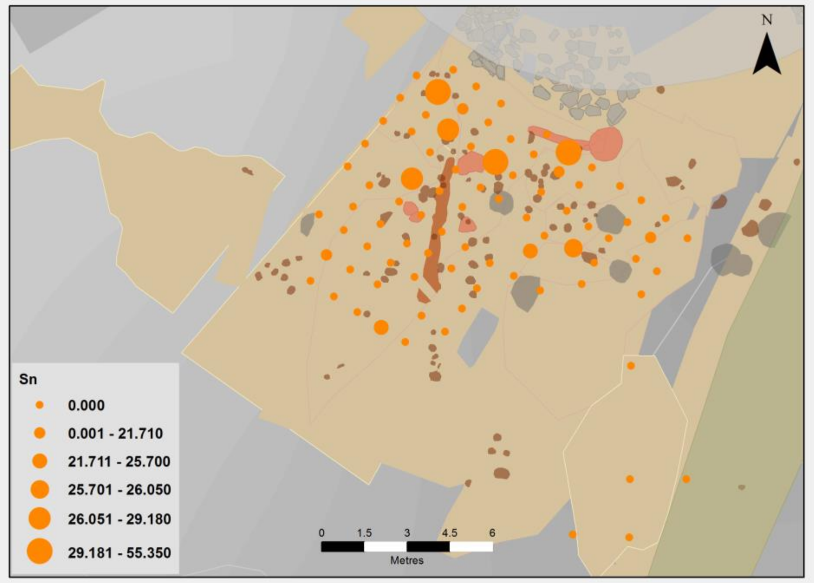


Figure 5. 13. The measured values for tin (Sn) in ppm by sample for Area 6. Map source: Author/RMP/ Norwegian Mapping Authority, 2016.

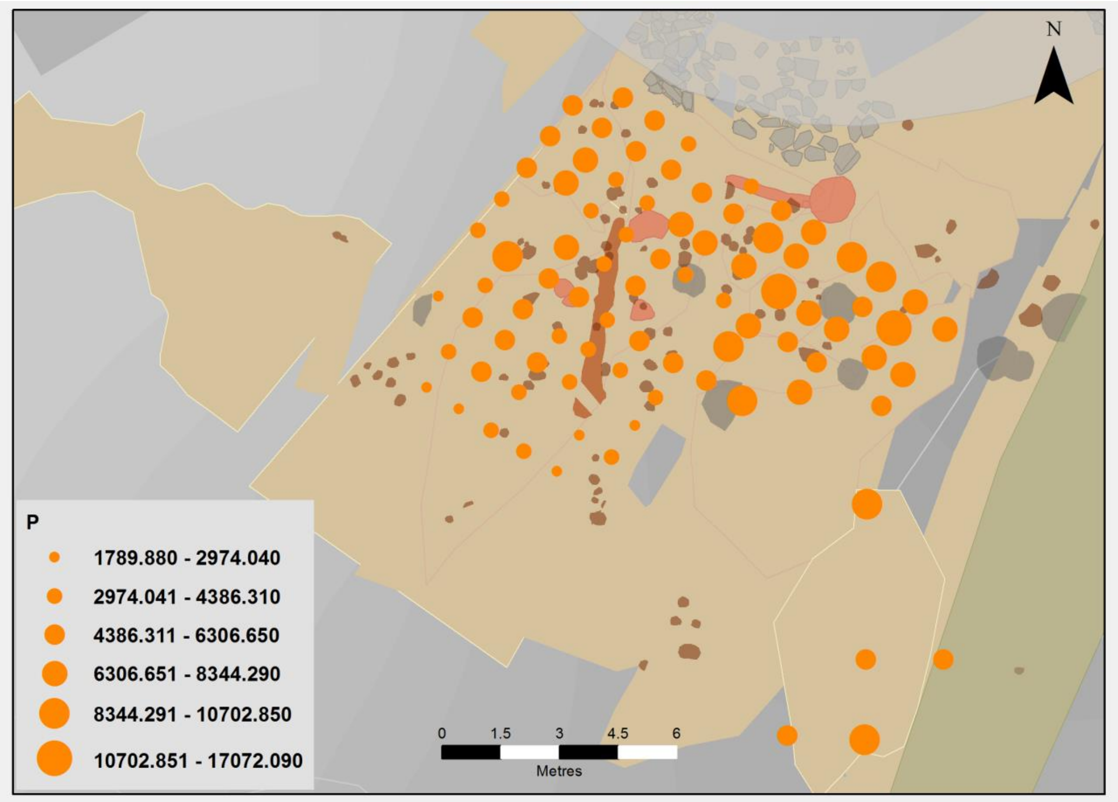
A slag fragment was found in core 32991, associated with layer A25600, which is dated to the late Iron Age (see factor 5). The slag is certainly from iron production, and it contains up to 34.82% Fe (error 0.64% 2σ). Of interest is that the slag also contains elevated levels of Cu and Zn of up to 0.6% and 0.9%, respectively. The soil immediately surrounding the slag fragment showed levels of Zn and Cu consistent with average background levels and was thus not directly enhanced. Again, if iron slag were the source, Fe would be the prime influence on the factor, which is not the case. Therefore, copper alloy working is the most viable conclusion to be drawn from the statistical results and archaeological evidence.

5.4.5 Factor 5: General waste or midden material from two phases

Phosphate (P) and sulphur (S) are the main causes of variation within this factor; 85% of P variance is explained by this factor. Phosphate mapping has a long history in archaeology as a reliable means of delimiting past settlement and defining activity areas (Bethell and Máté, 1989, Holliday and Gartner, 2007). Phosphate is present in organic waste including midden material, natural fertilisers, and animal waste. Under the right conditions, the soil has the capacity to retain quantities of P many times the ‘natural’ quantity over prolonged periods of time.

The majority of samples for Area 6 showed values for P above the average background values, with the highest values clustered around oven A44031 and to the south and east of this feature (figure 15.4). Elevated S values are fewer and form a more distinct cluster in the same area, with a second cluster on the southern edge of Area 6 (figure 15.5). This second cluster is associated with very shallow soils and was not completely excavated. On the horizontal plane, phosphate values are highest where the bedrock dips, allowing for the accumulation of deeper soils, better preservation conditions, and a natural drainage sink. This mirrors on a much smaller scale the results from previous large-scale phosphate mapping at Avaldsnes in 1990, in which the results clearly map the drainage and depth to bedrock, as demonstrated by the coring and GPR data since collected (Forsberg and Haavaldsen, 1990). This is due to both the mobility of P in soils between 6 and 7 pH, and the fact that much of the archaeology, particularly the cooking pits, is concentrated on the well-drained bedrock slopes and deeper soils (Brady and Weil, 1999).

That P and S are the main influences in this factor but differ in distribution from Ca and Sr, which suggests a source of the enhancement different from that of factor 3, although all elements are associated with biological waste. The elevated P and S values match well with the P concentrations measured by Macphail and Linderholm (in press). Sulphur is commonly



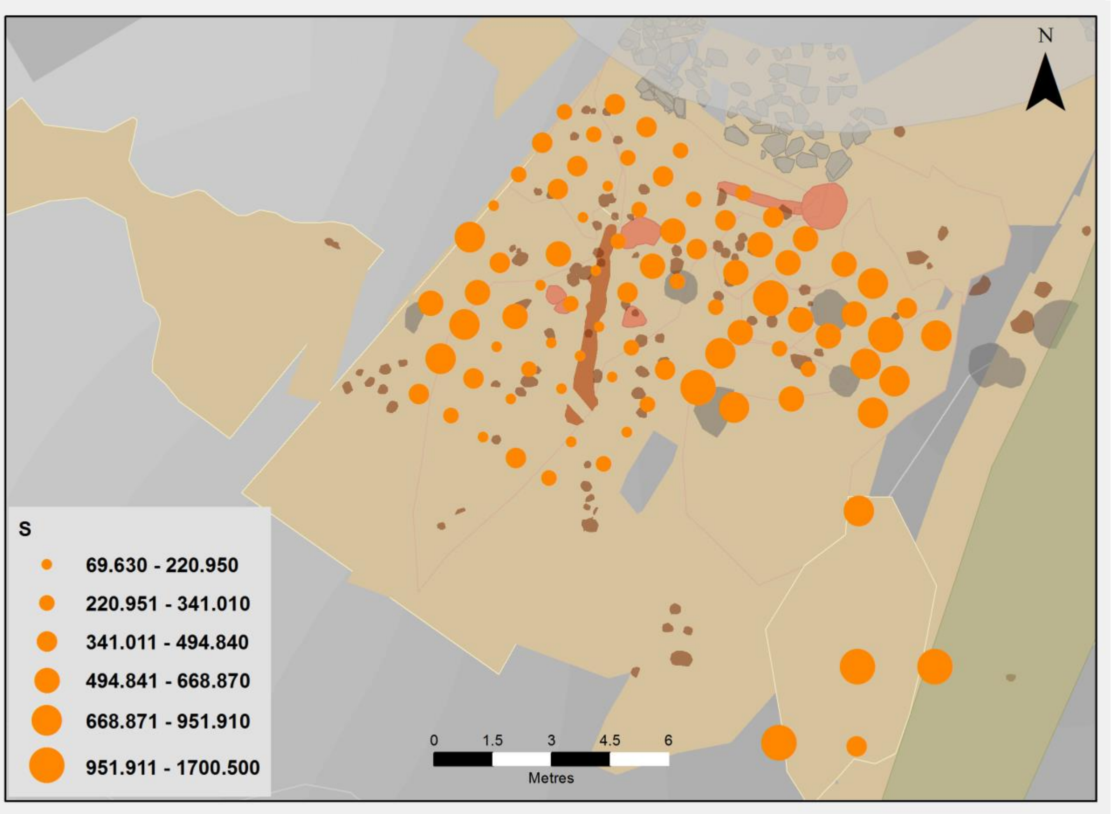


Figure 5. 15. (top) The measured values for phosphorous (P) in ppm by sample for Area 6. Map source: Author/RMP/Norwegian Mapping Authority, 2016.

Figure 5. 14. (bottom) The measured values for sulphur (S) in ppm by sample for Area 6. Map source: Author/RMP/Norwegian Mapping Authority, 2016

associated with highly organic, waterlogged turfs and peats, marine environments, and atmospheric deposition from industrial or volcanic sources – or from pyrite, a common mineral in primary and secondary ferrous minerals (Tan, 1994, Tan, 1998, Schaub and van Gemerden, 1996). The elevated S levels in peat are due to the reducing conditions found in waterlogged organic sediments, where S exerts considerable influence on the mobility of Fe, Mn, Cd, and other, less abundant metals (Sullivan et al., 2013). In oxidising conditions, sulphur and sulphides are highly soluble, and therefore would have been washed away over time.

With iron, S can form pyrite (FeS_2) or ferrous sulphide, and remain in situ. Sulphur readily forms pyrite in iron rich, organic conditions that are prone to reducing conditions (Mees and Stoops, 2010). Iron is abundant in the environment and thus in the resources utilised by humans. Large quantities can be found in rocks and sediments, but it is also present in a wide range of organic materials, in greatly varying quantities. Therefore, using Fe, based on chemical abundance alone, as an indicator of any activity other than direct ironworking is dubious at best. Here, the iron forms no particular pattern and has no influence on this factor, although it may have contributed toward the retention of S. The influence of Fe may well be lost, or drowned out, by the geological inputs. This is a weakness with total methods of analysis, such as XRF.

Buried peat horizons were found in cores taken in Areas 2, 3, and 4 at Avaldsnes, which were partly associated with Bronze Age settlement. Background readings from a peat layer in area 4 contained 1901 ppm sulphur (core 25088), far higher than the sample mean of 586 ppm and greater than the highest measured Area 6 sample value of 1700 ppm. Elevated sulphur is associated with organic settlement waste, fertilisers, and marine influences; and as noted previously P is also associated with a wide variety of settlement activities (Sayle et al., 2013). Although P and S are associated with a wide variety of sources, the combination of elevated phosphate and sulphur in connection to domestic buildings has been found by Derham et al. (2010).

In the few cores sampled vertically in Area 6, P and S decrease toward bedrock. In core 32991, layer A25600 contains the highest S and P concentrations. This layer is stratigraphically related to the layer from which the horizontal soil geochemistry samples were taken, as the samples were taken at the lower interface of this layer. Nearby, core 32990 (see figure 15.6) shows a similar pattern, with a distinctive increase in S and P at the base of layer 32050, which is of stratigraphic age similar to that of layer A25600. This fits well with the interpretation of the layer as a re-deposited midden or refuse layer. The elevated values for P in cores 32990 and 32991 are consistent with the identification of dung-mixed trampling features in the micromorphological samples M31122 and M42185 (Macphail and Linderholm, in press).

The statistical significance of arsenic (As) in this factor is misleading. The mean measured As value from background samples (*n=11*) from all horizons is 7.64 ppm, with RSD of 22.81%. For Area 6 samples, this figure is 9.81 ppm with RSD of 30.56%. The value is consistently very low, with only one value above 15 ppm. The trace presence means it is difficult to use the element in any interpretation.

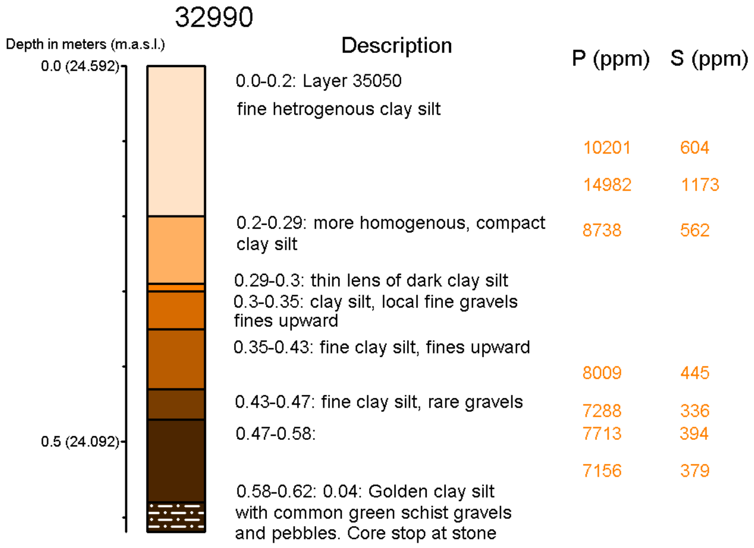


Figure 5. 16. Core 32990 with archaeological layer divisions and measured values for phosphate (P) and sulphur (S) in ppm.

Oven feature

A cluster of samples were taken around the fairly well-preserved oven feature A44031, in order to define function. These samples were taken separately and do not form part of the sample grid. Grain was found in macrofossil samples from the oven, which suggests corn-drying as a function (Ballantyne et al., in press) whilst the find of three slag droplets could indicate metalworking. There is a concentration of tin in one of the samples, but this is isolated and therefore unsuitable for reliable interpretation. Additionally, there is otherwise insufficient evidence for metalworking, such as highly elevated Fe or other metals (Pettersson et al., 2004). Oven A44031 is cut into an earlier layer stratigraphically associated with A25600, from which the samples to the south and east of this feature were taken. Five samples taken from the oven context also show slightly elevated P levels over average background readings. There is little evidence from which to define function beyond an organic process, as suggested by the grain, and that use of the feature for metal working is highly unlikely.

5.4.6 Factor 6: Modern contamination

The final factor is predominantly influenced by cadmium (Cd) and lead (Pb). Although both have been associated with historical settlement in previous research, the distribution here suggests modern contamination (Entwistle and Abrahams, 1997, Aston et al., 1998a, Wilson et al., 2007). In a separate analysis from cores from Area 1, lead values are consistently higher in the 'Brinken' area of the site, in layers associated with the partly excavated medieval building and in those of later horticulture. The use of lead for an expanding range of domestic artefacts from the Viking Age onwards results in generally elevated lead levels in deposits. The increase in atmospherically deposited lead in the modern era has resulted in elevated lead in many topsoils, which in disturbed areas can easily contaminate the immediately surrounding soils (Tack, 2010). The distribution of lead in Area 6, and the associated Cd, is clustered around areas known to have been disturbed by recent activity, either for archaeological purposes, or associated with recent settlement. There are rare elevated lead readings within the more secure archaeological contexts, but these are too few to allow confident interpretation.

5.5 Discussion

5.5.1 Sample integrity and statistics

There is undoubtedly a degree of leaching, mobility, and contamination of the samples from one period to another: soil processes are never static. The method of horizontal sampling presented here is dependent upon these processes, and whilst the 'one horizon represents all' approach is a common method of sampling for geochemical analysis, it is not ideal. Whilst directly sampling the stratigraphic context would not mitigate every complication caused by soil processes, results would have more stratigraphic and thus chronological relevance. However, sampling would be more intrusive in the excavation process, and potentially result in many more samples, causing greater expense. This data set, as the first case study, demonstrated that the use of cores can combine with horizontal grid sampling to assert greater chronological resolution, without multiple sampling stages. There are drawbacks, such as the intrusive nature of cores and the issues of reconciling stratigraphy between cores, and the subsequent case studies will focus on addressing these issues.

The uneven topography of the site, frequent thin soil coverage, and bedrock intrusions also present problems to strip-and-map archaeology, especially when using mechanical excavation. There is a tendency to create smooth, flat surfaces which results in archaeologically defined surfaces or layers that represent the excavator's convenience and time constraints rather than a single archaeological period. Whilst archaeological excavation can reconcile these issues, for the purposes of geochemical sampling this can be problematic: to be suitable for comparison, all samples should be from contexts comparable in the occupation phases they represent and must bear similar pedological properties. This obstacle cannot be ignored as, at a minimum, the topsoil had inevitably been removed by excavation by the time samples were taken, and few reference soil sections were available when sampling. To mitigate these issues, the author was present on site throughout the excavation to take samples together with the project archaeologists, whilst also scrutinising the samples during collection. In this case, the close integration of excavation and specialist sampling improved data quality and relevance. This can be further improved by more targeted specific sampling at different stratigraphical horizons in close collaboration, which will be considered further in the further case studies. It is clear from the data that the occupation represented in the results spans several phases, and without comparative data sources this would be impossible to reconcile. Whilst the majority of activities represented by negative features are associated with the Viking Age to early Middle Age occupation, some appear to represent early Iron Age activity related to middening or other high-organic waste deposition. This can be somewhat reconciled during interpretation thanks to the sampling integration within the project and the use of cores to add a temporal aspect to the study.

The issue of modern disturbance on the site must also be addressed. Overall, the effect of modern activity is less than expected. Modern disturbance over the site in the form of trenching, both archaeological and for services, modern buildings, mechanical levelling, and horticulture have damaged the archaeological stratigraphy, which in places was exceptionally shallow. Nonetheless, the results suggest that the conscientious sampling methodology has, to a degree, mitigated the effect on the findings. More significantly, the data indicates that these factors can be statistically isolated from the potential archaeology.

Relative depletion is discussed in several published studies (Middleton, 2004, Oonk et al., 2009b, Vyncke et al., 2011) as a consequence of human activity. General relative depletion in elemental values is attributed to high-traffic areas; these are difficult to trace with 1 m sample spacing in a multi-period site without any identifiable buildings or paths. Oonk et al. (2009c) does note that the loading of soils and sediments with large quantities of organic matter can result in the relative depletion of Mn- and Fe-oxides as they become bound to decomposing organic matter. To some degree, this can be seen in factor 3, where values for Mn are generally, but not universally, lower in the area of elevated Ca and Sr. Fe shows a still weaker pattern to this effect. The study by Oonk et al. (2009c) also stresses the effects of local soil conditions on relative enhancement and depletion of elements in soil as the result of anthropogenic activity. Relative depletion of an element in relation to a factor identified through PCA is not significant here, although this can be attributed to the dominance of the local geology and soil conditions – a product of the instrumental technique. Mn in particular shows clear positive and negative tendencies for each of the anthropogenic factors, but as it is a component of the geology, this will have served to mute this trend. As a nutrient required for plant growth, Mn is naturally present in organic matter. The spatial distribution of Mn visually correlates with that of P and S, suggesting it is a result of organic inputs. However, this is statistically inconclusive.

5.5.2 Food processing and middens

The correlation between S and P in factor 5 suggests highly organic inputs in a concentrated area such as a midden, or perhaps the result of animal stabling/penning. As mentioned previously, sulphur is associated with peats and turves of high organic content. Where organic materials are concentrated, bacteria thrive and break down the organic material. The intense activity can quickly deplete the available oxygen in dense or wet layers, giving rise to local reducing conditions. In these conditions, sulphur-producing bacteria begin to dominate the breaking-down of the organic matter (Mees and Stoops, 2010). This produces eventual areas of enhanced sulphur and phosphate; phosphate will remain in most soil conditions for prolonged periods of time, whereas sulphur combined with iron is soluble when re-oxidised. This interpretation is somewhat reinforced by the generally below-background levels of Fe in the area with raised P, although the pattern is not as clear cut as the others. With large amounts of organic inputs, Fe, and also Mn, in oxide form act as receptors for decaying organic matter, becoming reduced and thus soluble (Oonk et al. 2009c). This has the effect of removing Fe from areas where there has been high organic input.

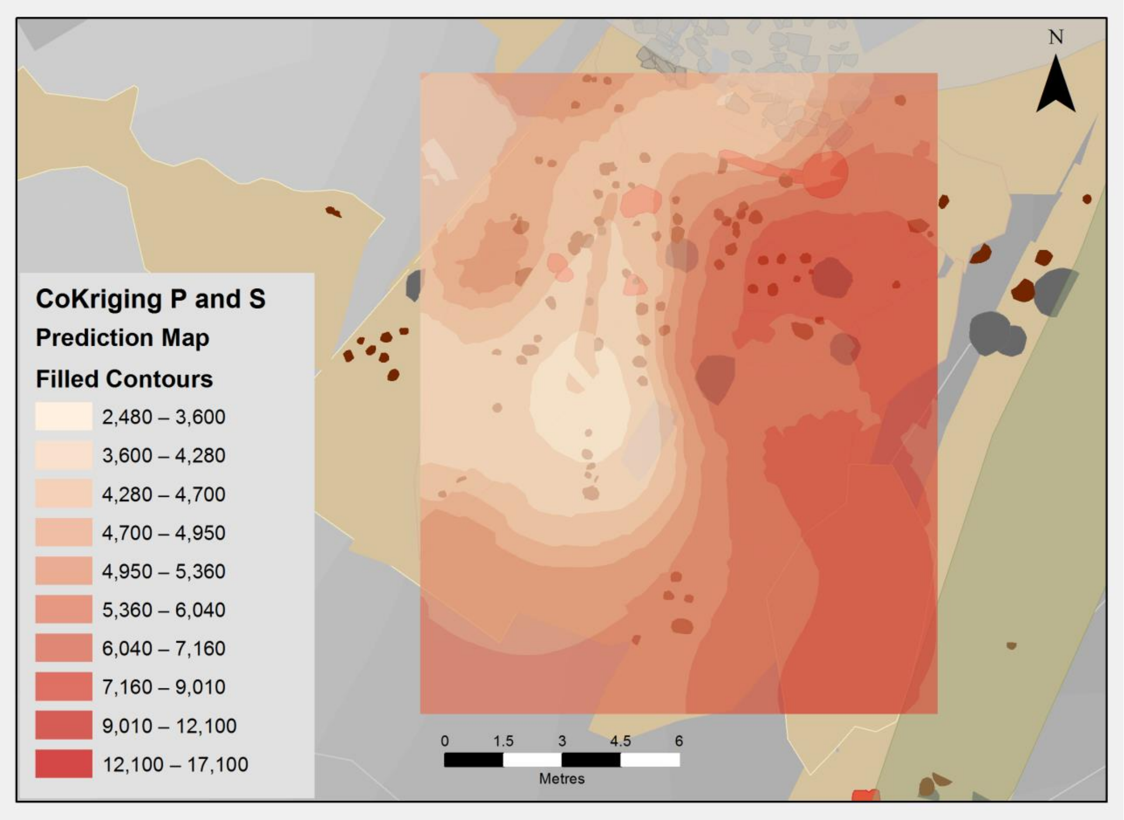


Figure 5. 17. CoKriging of factor 5, P and S, to indicate the defined concentration of elemental enhancement on the eastern side of Area 6, between the fortification and Kjellerhaugen's southern flank. Note that there are fewer sample points on the eastern part of the site. Map source: Author/RMP/ Norwegian Mapping Authority, 2016.

Considering the pattern of elemental enhancement and depletion associated with factor 5 (figure 5.17), this suggests that against an imposing Bronze Age burial mound, midden-like rubbish was accumulating. The deposits in the mound make-up of the second phase of Kjellerhaugen include cuts filled with food remains; as these are in an area of disturbance and digging into the mound construction, they could be associated with ritual as opposed to an accumulation of waste material (Bauer and Østmo, 2013). Beyond the implications for the regard in which the monument was held, in combination with the micromorphology and excavation evidence, this suggests a sustained settlement in the area in the later Iron Age.

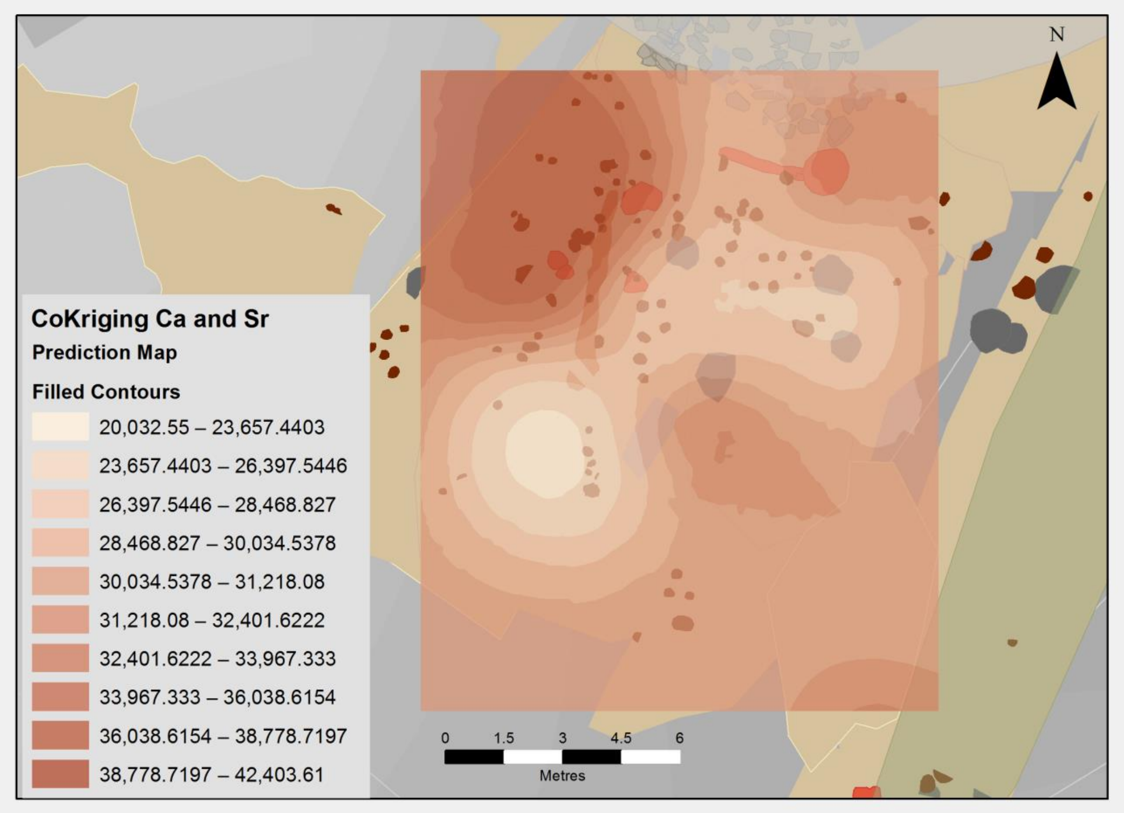


Figure 5. 18. CoKriging of factor 3, Ca and Sr, to indicate the defined concentration of elemental enhancement on the western side of wall ditch A12178. A second, lower enhancement appears north east of oven A44031, which was identified as a potential corn-drying oven from the late VA. Map source: Author/RMP/ Norwegian Mapping Authority, 2016

The use of seaweed ash as a preservative, or as a material basis for salt extraction, as mentioned above, is also suggested for other Viking Age sites (Milek and Roberts, 2013). The process is discussed in greater detail in Ballantyne et al. (in press) based upon the macrofossil results from the site. Of interest is that, without the collaborative evidence, it is unlikely that confident activity identification from geochemical results could ever be achieved. This is primarily because of the sparse reference material available and that elements from organic processes alone can vary proportionally from site to site due to taphonomic and pedological processes.

5.5.3 Copper alloys in the Viking Age

In passing, many objects of copper alloy are referred to as bronze or bronzes, when in fact they can be composed of copper and tin (true bronze), brass (copper and zinc), leaded brass or bronze, or gunmetal, which is a mix of copper, tin, and zinc (Sindbæk, 2003). Without scientific analysis, the true composition cannot always be recognised. The earliest brass objects are found in the Middle East from around the 13th century BC. Brass became a common metal in the Roman period, used in coinage from the 1 century BC and soon adapted into military equipment and personal ornamentation. Both the frequency of brass as the preferred copper alloy and the quantity of zinc in brass declined in the later Roman Empire, suggesting a reworking of older objects and reduced access to zinc-rich ores. Brass re-emerges in the west after a brief scarcity from the late Roman Period to the Vendel Period in Sweden, when it re-appears; for example, the brass and gunmetal objects found at Järrestad, Sweden, dated to the 7th century (Grandin and Hjarthner, 2003). In the 9th century, brass was used in early Northumbrian coinage, and during the Viking Age, it has been argued that the production became standardised in terms of form and presence in major trading ports such as Hedeby, Ribe, and Birka. It is also found in some hoards from the period (Sindbæk, 2003).

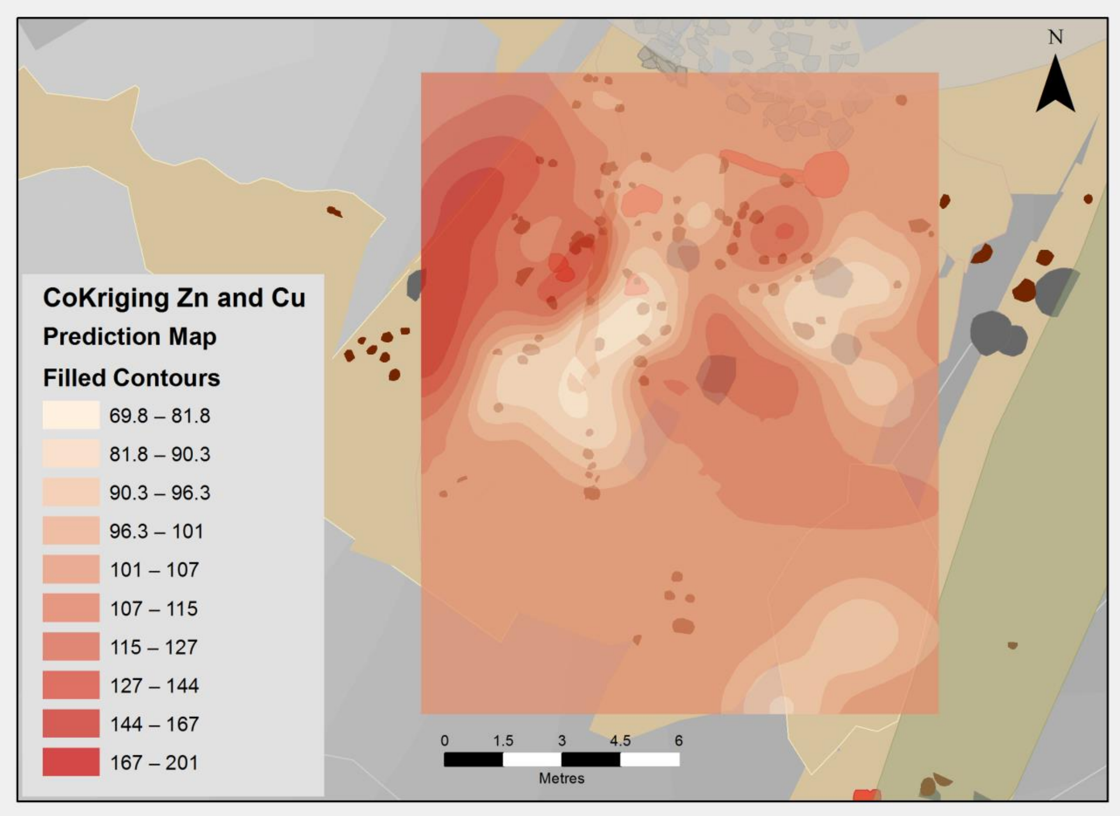


Figure 5. 19. CoKriging of factor 4, Zn and Cu, to indicate the defined concentration of elemental enhancement on the western side of Area 6, with lesser concentrations in the centre of the sampled area, primarily caused by single sample concentrations. Map source: Author/RMP/Norwegian Mapping Authority 2016

The combination of copper and zinc, i.e. brass, is known from the Viking Age as an alloy used for plating objects composed of other metals, such as iron. Less commonly, brass was used for the objects themselves (Pedersen, 2010). Lead is commonly added to copper and zinc to lower the melting point of the alloy and make pouring easier (Dungworth, 1997). The addition of lead became more common during the Viking Age and early Middle Ages (Jouttijärvi et al., 2005). This is evidenced at Avaldsnes as well, where the inclusion of the layers dating from the Middle Ages in the 'Brinken' area results in lead becoming a significant influence in the results, in exclusive combination with Cu and Zn. Lead enhancement is seen in Area 6 as well, although the highest values correlate with areas of suspected modern disturbance, as is noted under factor six.

Occasional copper alloy working required little space or formal structure and thus leaves few traces, a subject that is considered in more depth in the following case studies and chapter 8.

5.5.4 Cultural habit, practicality or authority?

What is striking about the three factors extracted from the geochemical data set is their enduring separation within a small, structured area. The late Iron Age represented at Area 6 potentially covers hundreds of years, so for it not to be an indecipherable mix of major and minor trace elements without any notable distribution requires consideration. As discussed previously, these activities are unlikely to have been contemporary with each other; the middening in all likelihood predates the metalworking and salt extraction. However, they appear all to be concentrated within their own space, albeit the latter two not too distant from each other (figures 5.17, 5.18 and 5.19). This could be a product of sampling and preservation, and as the sampled horizon is a cumulative product of human activity and soil processes, thus a temporal amalgamation rather than a specific moment, interpretation must be cautious. That said, the factors do appear localised and do respect one another to some degree. The area was used throughout the later Iron Age, but the intensity is difficult to estimate. This subject is considered further in chapters 6 and 8. We do not have considerable stratigraphic accumulation comparable to other high status sites of the period (e.g. Åker Gård, Hedmark, Norway (Pilø, 2002)), and as all periods from the Roman Iron Age to the Middle Ages are represented, although some truncation and disturbance has undoubtedly occurred, this did not obliterate all previous evidence. Therefore it appears likely that this was utilised space, perhaps on the periphery of a larger settlement complex, with a defensive statement of a revetment or fortification standing before an area once used for waste, then turned to an area for food processing and storage.

That the same activities appeared to have had their place, and were stable in practice long enough for the traces to remain in the soil, tempts interpretation into another tier. This is often defined by perspective; economic, power politics, social acceptability, cultural adherence, for example. Being binary and deterministic, as say Bourdieu (1977) may have once suggested, one could say that by repeated action, repeated learning creates a self-perpetuating mode of ‘how things are done’, i.e. a social acceptability and thus the manifest and unintentional waste becomes stationary, and yields the geochemical results we see today. This ignores any possibility for political control, aspiration, or agency. These are harder to extract from geochemical data sets without better preservation and subsequently larger contemporaneous buildings and material evidence.

If we take the stance suggested in chapters 2 and 3, that the physical features (or manifestations) we reveal are formed after cultural acceptance, from a range of possibilities, then the poorly preserved remains at Avaldsnes speak of division. Focusing solely on one set of statistical results will not, however divulge all. The site contained two longhouses, one potentially a high status building dated to the mid-Roman Iron Age and the other certainly substantial, evidence of furnaces/ovens, stone walkways, substantial cooking pits, and not least a possible fortification. All of this hints, but nothing confirms. Therefore, the small pieces of evidence from many methods that were integrated into the excavation proved to be essential sources of information on a disturbed site. However, remaining within the remit of geochemistry, the only thing conclusive is that there is a suggestion of deliberate, conservative division, and specialisation in activities, which all suggest social and political hierarchy over the means of production, although the issue of temporality and what was contemporary with each other cannot be resolved.

5.6 Conclusions of chapter

Statistical analysis is essential to multi-elemental geochemistry, as a means of assessing a complex, large dataset for the purposes of archaeological research. Here, the use of principal component analysis successfully defined separate activities and localised them within a small but complex multi-period site. To be of use, scientific data must be made comprehensible to an audience beyond the author(s); to that end, this method in combination with comparison with other data sources has produced results that can be used to enhance the archaeological understanding of the use of space in Area 6. It has not, however, allowed the identification of specific buildings from the maze of postholes. The areas identified in figures 5.16-5.18 highlight the topological focus of each factor, although the pattern is not sufficiently defined to suggest individual buildings or features as a source of focus. Neither has the data allowed for certain results, such as copper alloy working, to be placed confidently in a specific time frame other than general technological chronologies. Nonetheless, in combination with other data sources, a far more specific interpretation of the geochemical values can be drawn. In addition, activities identified in a specific feature, such as the seaweed ash in postholes or the middening in micromorphology, can be related to areas rather than points isolated in time and space. Indeed, it becomes a self-defining space from the past discard of waste. It appears that space was structured and enduring, but we cannot say how that was defined.

The results from geochemical analysis suggest that a limited amount of copper alloy working could have occurred on the site, probably in the Viking Age. The values allow for nothing more than intermittent metalworking; in all probability, the re-melting of objects rather than the processing of ores. Although not unknown from other contemporary high-status sites (Söderberg, 2004, Jørgensen, 2008), copper alloy working is rarely identified in Viking Age Scandinavia outside towns (Pedersen 2010). This is undoubtedly due in part to the lack of physical evidence intermittent work leaves behind (chapter 8), but its presence also reflects the status of the Avaldsnes Royal Manor site. At Järrestad, Sweden, a high-status farmstead in a complex, multi-period landscape, ironworking *in situ* with various raw materials was identified; for a shorter period in the 7th century, small-scale copper alloy working also occurred there (Grandin and Hjarthner-Holdar 2003). Whilst this is earlier in date to the main phase sampled for geochemistry at Avaldsnes, and the preservation conditions somewhat better, it potentially represents a similar phenomenon: a skilled craftsman working on site either as an itinerant worker or, as we cannot say there were no other structures occupied at Avaldsnes that remain undiscovered, moving to work elsewhere.

Possibly in the same period or earlier, the area was used for food storage and processing. The oven feature A44031 was used for corn-drying or similar organic processing, rather than metalworking. The occupation appears structured, as activities appear defined within Area 6, rather than by the natural, physical constraints. This is unsurprising, as the quantity of postholes would suggest buildings or other upright structures. Factor 3, dominated by Ca and Sr, represents an activity that perhaps drew bone, shell, ash, and/or sand into the area, such as meat processing and the ashing of seaweed as suggested in Ballantyne et al. (in press). The distribution suggests a sustained activity associated with either a building or a fixed location. Representing a different process and an earlier phase is factor 5, with organic waste producing P and S in large quantities. Elevated P and S measured by pXRF match well with the elevated P levels in Macphail and Linderholm (in press). Layer 25600, with which the elevated P and S are associated, is dated to the Roman Iron Age to Viking Age (Bauer and Østmo 2013:42), and micromorphology results suggest that the area was used for stocking animals and the subsequent collection of manure.

To some degree, there are always discrepancies between the surfaces created by the archaeologist, the soil processes, and the archaeological and 'natural' stratigraphy. The distribution patterns generated by geochemical analysis are in part a result of this process. However, methods are bound to function within reality and not the ideal. The results suggest that the method applied here, the integration, and the careful sample selection managed to reduce the potential impact of such unavoidable issues. In addition, vertical cores were also sampled in order to assess sample integrity, leaching of elements, and add potential chronology to the interpretations. This in particular was carried onto the next case study.

6. Heimdalsjordet

6.1 Chapter Introduction

The second case study in this research project is Heimdalsjordet, located at Gokstad, Sandefjord Municipality, Vestfold County, in Southern Norway. The Viking Age site is part of a complex and ever changing cultural and physical landscape that has been settled for thousands of years. Therefore this chapter begins with a brief description of the landscape developments and the known archaeology in the vicinity, culminating with the ongoing Gokstad Revitalised Project (GOREV) which has provided support and information to this part of the research.

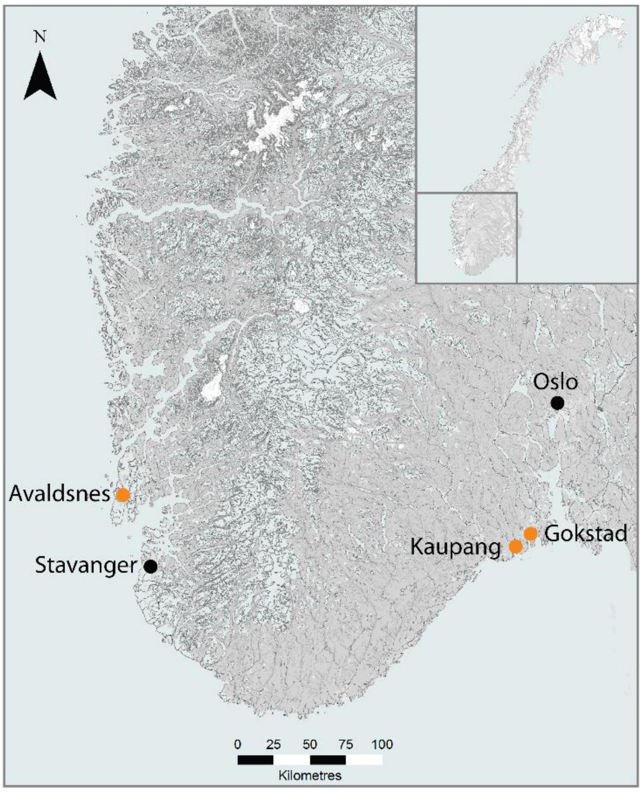


Figure 6. 1. Location of case study sites. Map source: Author/ Norwegian Map Authority 2016

The Gokstad Revitalised Project is directed by Prof. Jan Bill at the Museum of Cultural History, University of Oslo. The project aim is to bring the Gokstad finds into the forefront of current Viking Age research using new advances in science alongside traditional research, in order to create a context around the sparsely researched burial (Bill, 2013). The research presented in this thesis worked within this project framework, by focusing upon a contemporary trading settlement site near the Gokstad burial mound, with the archaeological objective of improving the characterisation and knowledge of the use of the settlement in a cultural and economic framework. This was to be achieved by combining coring, GPR data, and pXRF to create three dimensional data sets in order to understand the changing use of space on selected areas of the site. The aim and objectives of this research are reiterated and expanded upon in section 6.4.

After the cultural and physical background of the site and the case study aims, this chapter continues by presenting firstly the original data collected and analysed for this research, before integrating sources of data available from GOREV. This includes micromorphology data, finds distribution, excavation records and GPR data.

For the sake of clarity, once again the name Gokstad is used to refer to the landscape setting, the term Gokstad Mound to the burial site, and Heimdalsjordet refers to the trading site only.

6.2 Site Background

6.2.1 The geology and geomorphology of Gokstad

Stretching between Mjøsa to the north east of Gokstad to Porsgrunn in the south is the Oslo Graben, formed 310-240 million years ago, from the late Carboniferous and throughout the Permian (Sundvoll and Larsen, 1994, Neumann et al., 1992). It is over 400 km long, and was formed by crustal depression and rifting, causing volcanic intrusions. These magmatic intrusions and lava flows formed the igneous geology of the area, such as Kjelsås-larvikite, more commonly referred to as just larvikite, which was formed around 277-268±3 million years ago (Neumann et al., 1992). This rock type underlies much of the Vestfold region, from Larvik to Tønsberg (Sundvoll and Larsen, 1990). Rocks and sediments formed in and after the Triassic, that once overlay the lavikite, have largely been eroded away, therefore the rift geology still dominates the landscape. The influence of the bedrock is limited in regard to soil resources, due to the overlying marine sediments; however, it has significantly influenced the terrain. The frequent, glacially scoured bedrock hills and scarps are testimony to glacial flow over the resistant rock, smoothing and accentuating the lava flow patterns and magmatic intrusions.

Gokstad is located on the seaward side of the Ra moraine, in a landscape that is dominated by marine deposition (figures 6.2 and 6.3). The Ra is a terminal moraine from the Younger Dryas, formed between 12,350-12,650 BP in the sudden climatic deterioration that caused the glacial re-advance (Sauer et al., 2009). There are other, near parallel moraine ridges in the area, however these are less extensive and substantial. The moraine ridges overlie sub-glacial sediments from the previous glacial maximum, prior to 13,000 BP. Directly under the Gokstad Mound, these consist of compacted glacial till; a mid-brown clay loam which creates a perched water table (Cannell, 2012a, Macphail, 2012).

During the last glacial maximum, sea levels in Vestfold were at least 155 m above present (Sauer et al., 2011). Kaupang, for example, which is c. 15 km directly south west of Gokstad, had a sea level of 158 m a.s.l. during the marine regression, whereas at Holmestrand to the north, sea levels were up to 190 m a.s.l. (Sørensen et al., 2007). Isostatic rebound is slower than eustatic rises after the glacial melting, which results in the land remaining below rising sea levels during, and for a period after, de-glaciation. Marine sediments were deposited over large areas of the landscape, creating islands and inlets far inland, as shown in figure 6.3. Sea levels initially fell at the rate of between 25 to 48 mm per year, however this has decreased to the current levels of 3 mm a year according to Sørensen (Sørensen et al., 2007), or perhaps 2 mm per year according to Olesen (2000). The marine sediments are silty to silty clay, with interspersed layers of sand. These occasionally contained shells fragments, which are perhaps indicative of higher energy events and/or current changes in an otherwise low energy coastal landscape, eventually progressing toward estuarine, intertidal conditions (Macphail et al., 2014, Schneidhofer et al., 2016). Where preserved, the upmost centimetres of the marine deposits consist of fine to coarse sand material, relating to the emergence of the area from the sea. The land the mound is constructed upon slopes gently south, 9.7-11 m a.s.l., therefore the emergence from the sea can be dated to around 700 BC, although this date contains a margin of error (Sørensen et al., 2007).

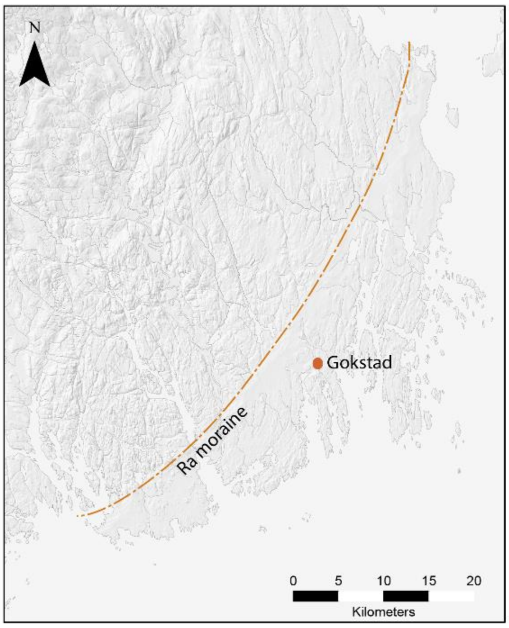


Figure 6. 2. The Ra moraine in Vestfold, Norway. Map source: Author/ Norwegian Mapping Authority 2016.

Located on the seaward side of the Gokstad Mound, the Heimdalsjordet is at 3-6 m a.s.l, dating the emergence from the sea to c. AD 400-900 according to Sørensen et al. (2007), although as this does not quite match dating evidence from the site, the sea level retreat clearly requires some minor local adjustment. The land immediately surrounding Gokstad is today a flat plain between exposed, steeply graded bedrock hills, the majority under 100 m a.s.l. seaward of the Ra. The land has been levelled significantly by modern land use, from a gently undulating landscape intersected by small, entrenched streams, to a highly managed and drained landscape. From magnetometer data, it is clear the area north of the Gokstad Mound was originally intersected by four dendric low-order streams, which predominantly flow north to south (Schneidhofer et al., 2016). Two streams merged just north of the mound. These, and the stream course south of the mound toward Gokstad, are now channelized as part of a dense drainage system to cope with the natural wetness of the area.

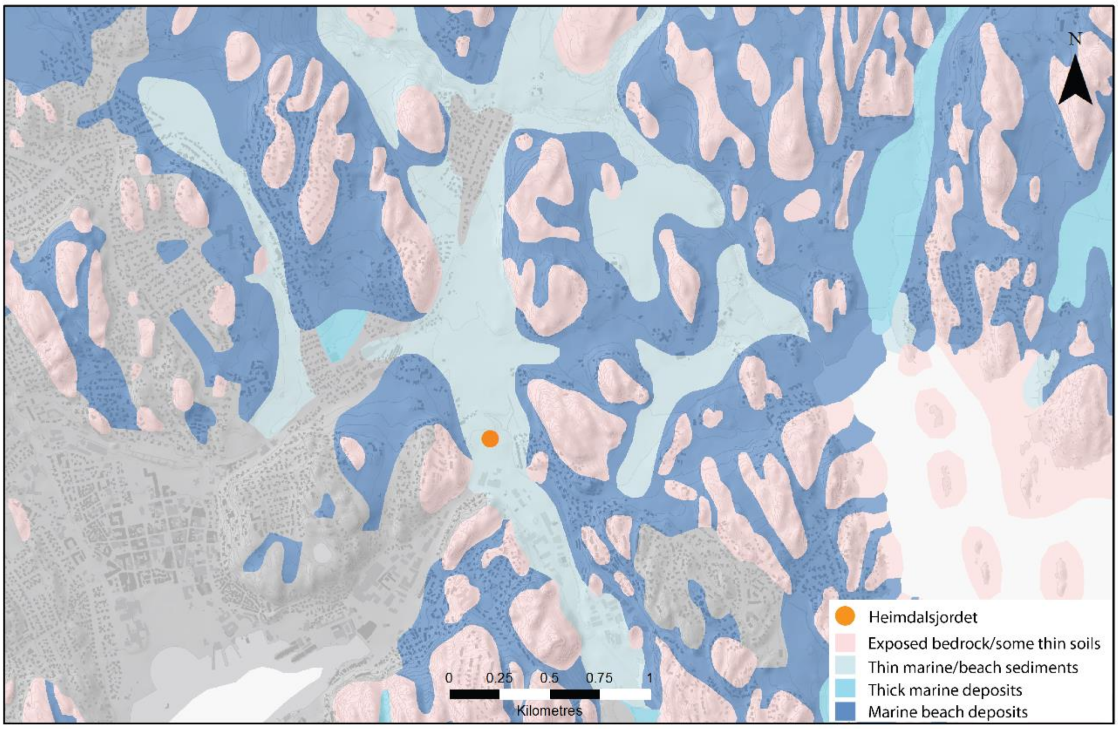


Figure 6. 3. Surface deposit map of the landscape surrounding Gokstad/Heimdalsjordet. Map Source: Author/Geological Survey of Norway/Norwegian Mapping Authority 2016.

6.2.2 The soils

During the Iron Age the shoreline continued to retreat, and the upper sediments developed into the gleyed soils still active today. The area, indeed much of the land seaward of the Ra, is characterised by stagnosols, gleysols and albeluvisols. These are all hydromorphic soils, where the soil processes are dominated by surface or groundwater waterlogging, and as a result can lead to localised peat formation (White, 2006). The marine sediments hinder drainage, and under Gokstad this is exacerbated by the impervious, glacially sourced till below the gleyed marine sediments, readily creating seasonal or permanent waterlogged conditions. This could have hindered the productivity of the land for cereal farming in the low lying areas, although it is more than suited to pasture, and sedge-grassland has been proposed for the area based upon the micromorphology evidence from preserved turfs in the Gokstad Mound (Macphail et al., 2014). The beach and colluvial deposits near exposed bedrock rises are better drained, not only by the degree of slope but the sands and silts that compose the upper layers. However, the soil cover is thin, often leading to the development of arenosols which easily become parched (Solbakken et al., 2006).

Soil mapping large areas is obviously an enormous task. In Norway it is the responsibility of NIBIO, formerly the Norwegian Forest and Landscape Institute (Norsk Institutt for Skog og Landskap).

The data represented in the WRB maps (figure 6.4) is designed as a guide, rather than absolute. They are an excellent starting point, although it must be recalled small variations are not displayed, and the WRB group level 1 is the lowest level of classification (Solbakken et al., 2006). It must also be noted that the WRB system is young, and has changed terminology and guidelines over the years, most recently in 2006 and 2014.

The distinct properties of gleyed (gleysol) soils are caused by groundwater saturation, as opposed to the hindered drainage of precipitation in albeluvisols and stagnosols. The luvic stagnosol under and surrounding the Gokstad mound is characterised by gleyed subsoil features, such as iron nodules and ocherous mottling that increases with depth, as well as a massive structure (no structure). The soils evidenced in cores from the Gokstad Mound showed strong gleyed characteristics and pale mottles consistent with stagnosols. The implication is that both high groundwater and a tendency for surface water are enduring features of the soil. The detail given here is motivated by the fact that the soil processes can and do effect the interpretation of any geochemical data produced.

Table 6. 1. Soil types in the Gokstad area. Information from WRB-definitions (F.A.O., 1998, F.A.O., 2006, F.A.O, 2015) and Birkeland (1999). Additional data from http://kilden.skogoglandskap.no/

Soil type	Processes	Appearance	Common types in Gokstad area	Areas found
Albeluvisol[1]	Typified by the leaching of clay from the A horizon to the Bt (illuvial). This leaves coatings on peds and grains, and in pore spaces.	Often gleyed characteristics. Develops an E horizon, pale soil between the A and B horizon that can extend in 'tongues' (along cracks etc.) in the B horizon.	Endostagnic and Epistagnic (indicates depth of frequent saturation, source is precipitation). Often with *siltic*. Profile e.g. A→Eb→Bt→C	Most frequently found on silty clays or clay silts, occasionally on coarser material. Found only on gentle to moderate gradients.
Gleysol	Groundwater saturation causes reducing conditions. Fe (and Mn) is mobilised and redeposited around area of the water table fluctuations, as ironpan nodules or concretions round roots or in pores/cracks.	Grey blue to grey green, from the reduced iron (Fe^{2+}). Fe (and Mn) concentrations, red-brown to red-yellow in the intermittent saturated zone.	Halpic and Mollic gleysols (depends upon organic content of A horizon). Profile e.g. A(h)→Bg→Cg	On level to gentle gradients, esp. water courses/bodies, where groundwater is high. Where water table is perched over impervious layer. Features are pH/Eh dependant.
Stagnosol	Flooding and surface water	Diagnostic characteristic: mottling below saturated	Luvic Stagnosol, leaching of clay down	On level to gentle slopes, areas prone

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[1] This classification is no longer used by the WRB, it was replaced by Retisols in 2014 (F.A.O. 2015). It reflects the time of soil classification by NIBIO, and is kept as the classification relates to previous guidelines.

	causes temporary reducing conditions, similar to gleysol, but not groundwater related.	zone being one Munsell hue lighter than matrix (i.e. pale spots).	profile. Often with *siltic*, due to silt content. Haplic Stagnosol (ruptic), a typical stagnosol with a lithological discontinuity within 100 cm of the soil surface. In this case, sandy loam in areas to the north of the arenosol.	to surface water flooding.
Arenosol	Self-draining.	A young, sandy soil, self-draining, with little profile development. Texture is loamy fine sand or coarser in a layer, 30 cm or thicker, within 100 cm of the soil surface.	Haplic Arenosol: A typical arenosol with no other qualifiers.	The south/south eastern area of the Heimdalsjordet site, where the former sand bank is located.
Regosol		Weakly developed and poorly consolidated soils	Anthropic Regnosol[2]. A regosol of anthropogenic origin.	In the area labelled 'modern landscaping' on the legend of figure 6.4.
Cambisol		A young soil with little to moderate profile development, which has a *cambic* horizon within 50 cm of the surface, i.e. a horizon that has lost its original rock structure in at least half of the fine earth fraction.	Endostagnic Cambisol (dystric). A cambisol with a stagnic horizon between 50 cm and 100 cm of the surface. Dystric indicates the soil has a base saturation of less than 50% between 20 and 100 cm from the surface.	Area to the south east of the Heimdalsjordet site.

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[2] This is from NIBIO, however this classification cannot be found in; F.A.O. (2006). However, it is to be found in pre-2006 F.A.O. documents such as Deckers et al. (2003). Therefore, as previously, the reader is advised this classification reflects the timing of NIBIO's soil mapping, and is kept as it adheres to the *then* current guidelines.

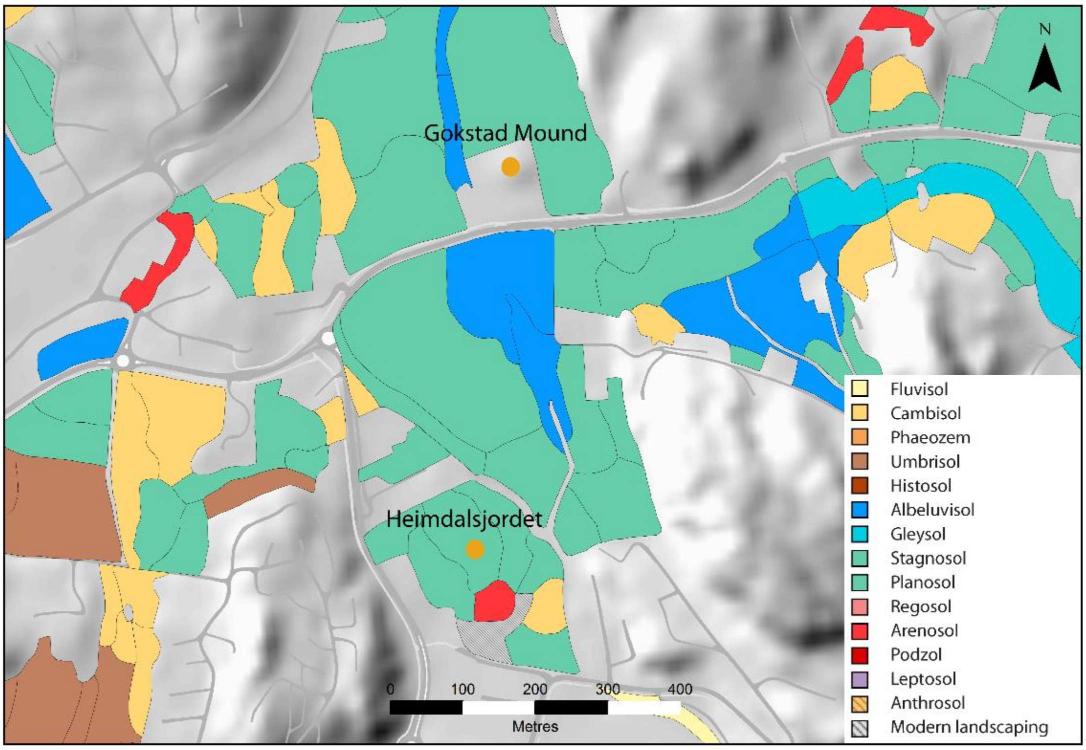

Figure 6. 4. Map of soil types in the area surrounding the Gokstad area, classified using the World Reference Base for Soil Resources (WRB). Note the differing soil type (albeluvisol) surrounding the stream course north and south of the mound, and the dominance of stagnosols in the landscape, and the area of arenosol at the Gokstad settlement site. Map Source: Kilden (NIBIO)/Author/ Norwegian Mapping Authority 2016.

6.3 The Viking Age Archaeology of Gokstad

6.3.1 The Gokstad Mound

This monument, measuring roughly 43x48 m, and some 5 m in height, is one of Norway's largest burial mounds. Excavated by Nicolay Nicolaysen in 1880, it was revealed to contain the well preserved remains of a Viking ship with a burial chamber. The Gokstad ship now sits in the Viking Ship Museum in Oslo, beside the Oseberg and Tune ships as the best preserved Viking Age ships known today. Now we view it with our cultural eye, and divorced from all original intentions and contexts, but time does not seem to have muted the intended message of status, and of cultural and material wealth. It is majestic, and impressive to see, as is the inventory of grave goods excavated with the ship, including sleds, smaller boats, camping equipment, shields, furniture, a peacock, several horses and harness fittings, dogs, textiles, and fragments of the interred (Nicolaysen, 1882). The grave had unequivocally been disturbed, as indicated by the cutting of the ship's side and burial chamber, and the disturbance in the grave goods. As part of the GOREV project, the mound was cored to record the construction sequence of the mound, and locate the later trench that disturbed the burial (Cannell, 2012a). As no personal weaponry was found, it appears these were removed in the robbery, and to define how and when this occurred was essential to place the event in a cultural and political context. Dendrochronology placed this event in the latter half of the tenth century, and the burial itself somewhere around the year AD 900 (Bill and Daly, 2012).

Figure 6. 5. The Gokstad Mound in its modern, partly reconstructed form, taken looking south toward the Heimdalsjordet settlement site, located just beyond the trees in the right background. Photo: Author/GOREV/MCH.

After the 1880 excavation, the mound was left open, until efforts eventually had the gaping hole in the middle refilled in the 1920's. Still, as mentioned before, even in its reconstructed and eroded state, the mound visually seizes the landscape, set mid-valley at the logical topographical thoroughfare (figure 6.5). At the time of its construction, the beck that flowed near its western flank would have continued south some few hundred meters, to the settlement and the sea. The trading settlement existed before the mound was built, and it is impossible to consider them unconnected; both are placed with a respective direct line of sight, and ships berthed or drawn up on the coast would have read the cultural and political landscape. This included the mound, the small cemetery near the trading post arching up the western slope, possibly heading toward larger farms set upon the hill crest. It is a design and language orientated to both the wider landscape and the immediate sheltered coastline. The shallow coastline beside the trading settlement would have offered some shelter from coastal storms, as the islands of Vesterøya and Østerøya lie between it and the sea, which in turn also limit visibility to the Oslo Fjord. The trading site becomes the focus of the text below and the remainder of the chapter.

6.3.2 The trading site

The idea that the area around the trading site was of archaeological importance was garnered by GOREV from referencing place-name evidence, topography, and not least, previous archaeological excavation, as named above. In 1993, two trenches were dug, stripping off the topsoil to expose the subsoil and negative archaeological features. The evaluation was connected to road improvement plans, and it was decided the proposed corridor would not be pursued. The 1993 evaluation exposed negative features and discovered finds such as knives typologically dated to the Viking Age, as well as a concentration of slag (Gansum and Garpestad, 1995). Earlier archaeological investigation includes the excavation of a boat grave in 1944, and the Freberg excavation 400m east of the Gokstad Mound in 1956 (Hinsch, 1945, Skjelsvik, 1958). Therefore, prior to the GPR survey, there was knowledge that the area contained burial monuments and possible settlement from the Viking Age

Commissioned by the GOREV project, the wider geophysical landscape survey by ZAMG ArcheoProspections© was carried out in collaboration with the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro), the Vienna Institute for Archaeological Science (VIAS), its Norwegian partner organization NIKU (Norwegian Institute for Cultural Heritage Research) and supported by the archaeology team of Vestfold County administration (VFK), and encompassed near 500,000 m^2 of land, centred on the Gokstad Mound (Nau et al., 2015). The initial GPR interpretations form the basis for the excavation and additional prospection discussed in this chapter. However, the reader is advised the final interpretations, which primarily added to the burial area north of the Heimdalsjordet settlement, are not included in the illustrations within this chapter (see figure 6.6).

The surveys were conducted over several campaigns in 2011 and 2012, and detailed both the archaeological and geomorphological landscape (Nau et al., 2015, Schneidhofer et al., 2016). The trading site received most attention, as its existence just 15 km from contemporary Kaupang challenged assumptions of regional political and economic control and international trade in Viking Age Norway (Bill and Rødsrud, in press).

Figure 6. 6. Map of the Heimdalsjordet trading site from the GPR data interpretations as of 2012. The burial mound ditches are seen as circular forms to the north east, whereas the settlement is to the south and west. Note the extensive drainage ditch network over the site. Map source: Author/Norwegian Mapping Authority/GOREV.

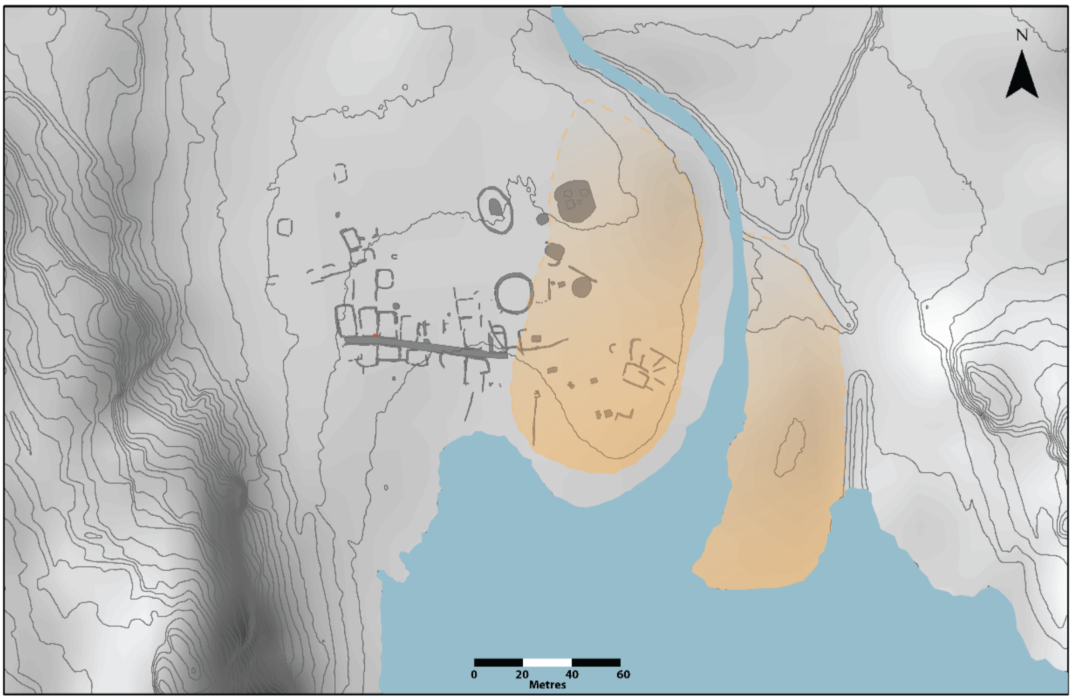

Figure 6. 7. A coarse map of the sand bar area (orange) as it exists today, and an estimate of the relative sea level and the river course passing by the east of the site. The data is from coring on the site by the author and GPR data from reports (Nau et al., 2015, Schneidhofer et al., 2016). Note that the landscape and elevation is based upon LiDAR data, and does not represent previous landscape form. Map source: Author/GOREV/Norwegian Mapping Authority 2016.

That it was a trading site with international reach in terms of imported objects, and also the location for working the imported raw and processed materials, was soon apparent. A campaign of metal detecting over the site quickly began to accumulate Arabic coins, metalworking waste and weights. The metal detecting campaign was continued intermittently during the two seasons of excavation in 2012 and 2013. In addition, a grid with 10 m spacing was set out for topsoil sieving 1 m^2 sections of topsoil for artefacts. These results are returned to in the section 6.7 of this chapter.

6.4 The site specific approach

6.4.1 Site specific aims and objectives

The site at Heimdalsjordet was selected as it provided an ideal site to test the main research aims, and integrate methods within a larger research project. The clear advantage from working closely with a larger project was evident at Avaldsnes, in the form of debate, support, shared resources and access to a far wider range of information sources from the same excavation and site than would otherwise be possible. The main research aim outlined in chapter 1 is as follows:

The overall aim is to assess the potential of integrated geochemical sampling and data using portable XRF within archaeological excavation and prospection to better interpret use of space and the range of activities in Viking Age settlements.

Due to the extensive, high-resolution GPR data available and the low proportion of the site to be excavated, in fitting with the aims and objectives, a combined prospection and excavation informed sampling approach was developed. Specifically for Heimdalsjordet, an additional aim was to test whether three dimensional geochemical data from coring could be used to improve interpretations on the use of space when secondary deposits were the primary source of information. The parcel ditches, discussed in detail below, dominate the preserved archaeology, the site being highly truncated by modern land use. This is not an uncommon situation, where negative features and backfill are all that remains of an archaeological site. At Heimdalsjordet, the remaining backfills in the ditches appeared to stem from the occupation phases of the site, and therefore they were a viable source for archaeological interpretation.

6.4.2 The parcel ditches

The most immediate feature of the Heimdalsjordet site, visible from the GPR data and confirmed by excavation, was that the site as it appears today, is defined by ditches. All ditches were truncated by modern ploughing, and varied in surviving depth. The deepest preserved were in the areas of parcels 1 and 2, located toward the western edge of the site (figure 6.8). Here the soils are gleyed silty clay, as detailed above, and also where the site is fairly level. A thoroughfare was visible in the GPR data as a W-E orientated reflective surface, fading to the east as the ground rises to the sand bar area (figure 6.7). This rise begins just west of parcel 6, and continues on past parcels 9-14. This area was referred to as the 'labyrinth' during excavation due to the number of intercutting ditches, and the term is also used here on occasions. Drainage conditions are obviously improved over the sandy substrate, and also more vulnerable to plough erosion. This has perhaps been slightly countered by the possibility that the labyrinth area was a focus of settlement, and where the greatest build-up of occupation deposits occurred. The parcel ditches investigated to the eastern side of the site were shallower, which could be a product of the lesser need for drainage, and more certainly, by plough erosion.

The structure of the site by ditches is what remains today. Considering other comparable sites such as Ribe, Denmark, where ditches defined boundaries, the parcels were also separated by fencing (Feveile, 2008). The plots probably stretched back from the thoroughfare further than the parcel ditches along it, making it likely that the ditches were not the only form of division. It can also be seen in the GPR data that some ditches are shared, whilst others are not, implying the land division was not solely reinforced by the ditches. Whilst many are too deep to be wall ditches, they could define building plots within a larger plot defined by fencing, the traces of which have not survived.

To the north of the thoroughfare and parcel ditches, a mound cemetery has been identified. Modern ploughing has also reduced these to little more than shallow negative features in the subsoil. The boat grave investigated by GOREV was discovered by a metal detector investigating a strong signal just under the plough soil, which was revealed to be a sword hilt (figure 6.8). The remainder of the grave was excavated, but is not considered further here (Bill and Rødsrud, 2013).

The parcel ditches varied in width and depth, as did the enclosed areas within them. Most are rectangular or sub-rectangular, the longest being 14.5 m x 6.7 m, smaller parcels measuring, for example, 10 m x 5.5 m. Several are cut by later ditches, suggesting re-cutting or several phases of occupation on the site. They are concentrated and orientated around the thoroughfare, however to the north there are isolated, smaller parcels. These are most likely parts of plots that extended back from the thoroughfare, or beside roads now ploughed away or simply undetected by the GPR survey. The function of the parcel ditches was not solely for drainage, although the vulnerability of the site to surface flooding from impeded drainage and the coast, flooding from spring tides and storms was also a risk. Parcel ditches also formed boundaries, sub-dividing the land into lots. Together with other forms of boundary, such as fences, these form political, economic and social boundaries for the occupants. This is further discussed in section 6.8 and chapter 8.

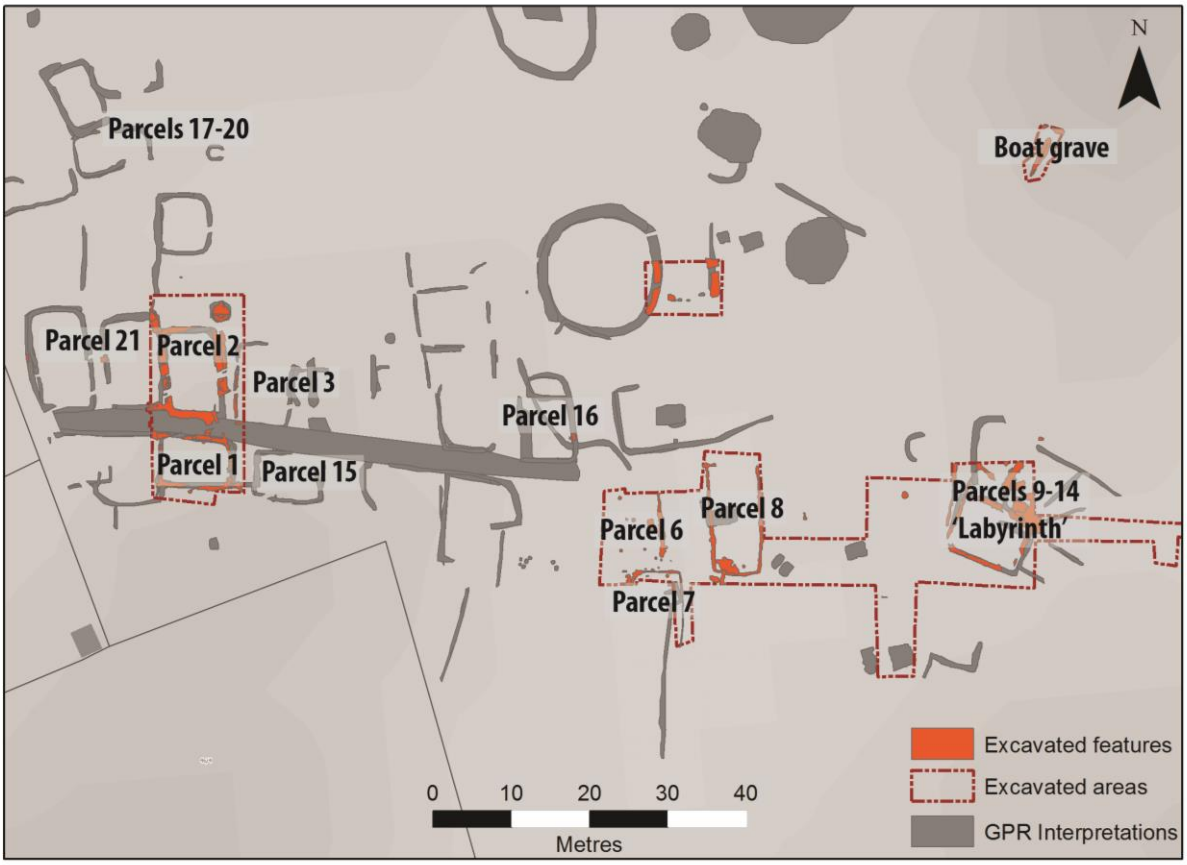

Figure 6. 8. The parcel ditches at Gokstad as identified via GPR and excavation. Those labelled are referred to in the text. Map Source: Author/GOREV/Norwegian Mapping Authority 2016.

The parcel ditches investigated by coring and excavation were in-filled by a combination of factors: settlement waste, flooding and natural erosion. As outlined in the introduction (section 1.4), these are secondary deposits composed of mixed, redeposited sediments. Additionally, it must be stressed that modern disturbance from drainage ditches was an acute issue. Modern drainage ditches, both older hand-dug trenches and more recent systematic machine cut ditches crossed the entire site, cutting archaeological features (see figure 6.6). As these were, in general, near perpendicular to the parcel ditch orientation, most ditches were cut several times by drainage ditches along their length. This limited the selection of coring locations, and can obviously lead to localised oxidising conditions where the drainage ditch cuts the archaeology, and more universally lowering the water table in the hydromorphic soils. This can be detrimental to preservation conditions in archaeological contexts, and represents another threat to the archaeological site.

The following is a brief summary of site specific methods, as chapter 4 is intended to explicitly detail methodological decisions and technical information.

6.4.3 Coring strategy

The first phase of coring coincided with the first season of excavation on the site by GOREV. Core transects were taken to a depth of 1-2.35 m perpendicular to the 3 m contour to investigate the Viking Age shore line and associated human activity. Further cores were taken along the sand bar area to understand the landscape formation processes. It became clear from the GPR data, cores and consultation with the prior landowner, that the former course of the stream running thorough the site had been in-filled after the stream was piped (Bill and Rødsrud, 2013). This inhibited coring the area of the sand bar suspected to be the Viking Age shoreline, just south east of the labyrinth parcels (see figure 6.8). Sufficient cores were taken, however, to understand site formation, identify possible disturbance in the area suspected to be the Viking Age shoreline, and sub-samples were sent for micromorphology analysis.

From the area mechanically stripped of topsoil for the excavation, cores were taken from the exposed surface into the visible parcel ditches. The cores were not taken until sections of the parcel ditches had been excavated, to ensure the potential and suitability of the features. The sites were selected to be representative of the ditches composing the parcel, and where possible, close to sections to be recorded during the excavation. Drainage ditches limited locations, as did the fact that some sections had already been excavated.

During the second season of excavation, due to the initial success of the method, the next stage of the research was begun. Using the GPR data, locations were selected and surveyed using a total station theodolite where the GPR data indicated a possible parcel feature in an unexcavated area. Cores were then taken, and without exception, an archaeological feature similar to the excavated parcel ditches was identified in the cores. In total, four parcel ditches were cored in this manner. The sample density was greater in these parcels as they were not limited by already excavated sections, and experience suggested as the deposits were varied, more samples were needed to ensure cores were representative. Further cores were also taken from the area excavated in the second excavation season (2013), in a similar manner and with similar limitations as the previous season.

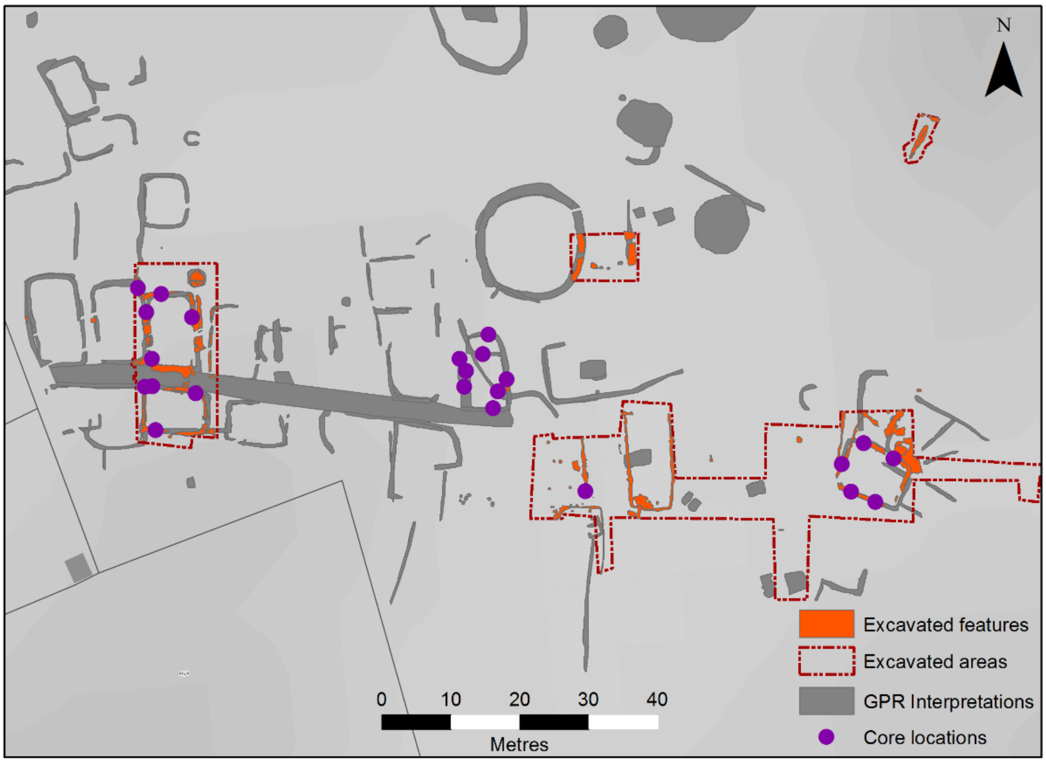

Figure 6. 9. The location of cores taken in parcel ditches and used for geochemical analysis. Map source: Author/ GOREV/Norwegian Mapping Authority 2016.

Near the end of the first season of excavation, a burnt clay feature within a charcoal and ash layer was uncovered but not excavated. This was located in parcel 21 beside the thoroughfare. Samples were taken from the surface at c. 20 cm intervals, as stated in chapter 4, section 4.2. The samples were processed as indicated under laboratory methods in chapter 4, section 4.3.

6.4.4 Selection of sample locations

The cores taken from the excavated areas focused on the parcel ditch areas that were excavated, sampled and recorded in detail. The intention was to obtain cores and subsequent sample data that could be verified by or compared to, the excavation record. This would strengthen interpretations of the geochemical and coring data, which could then be applied to cores taken outside the excavation area. Cores taken using the GPR data to select sample locations had to be limited due to time constraints, and therefore it was deemed best to concentrate on a few parcels and increase the sample density rather than have one or two samples from each potential parcel ditch visible in the GPR data. Parcel 15, just south of the thoroughfare was sampled as this appeared to be a smaller plot, orientated along rather than perpendicular to the thoroughfare. From the GPR data, the ditch on the western side appeared connected to the adjacent parcel, in a similar manner to the parcels interconnecting through the thoroughfare, probably for drainage purposes. The parcel ditches here show signs of re-cutting either within the existing form or along a slightly different orientation. These cores were sampled and analysed, and the core descriptions can be found in Appendix 2. However, the pXRF data was lost due to an error in data handling. To compensate, additional cores were taken in parcels 17-20, but unfortunately this area proved to be too truncated and disturbed for analysis.

6.4.5 Establishing background

Contrary to general practice, or wisdom one might say, in archaeological geochemistry, this study does not place great weight on background values being divinely neutral. Whilst Middleton (1996, 2004) suggested an off-site horizon be found that is of similar age and properties to the measured archaeological horizon, and free from anthropogenic influence, should then be measured for background values, finding such an elusive trove whilst living in the modern era and working in intensity cultivated land, is near impossible. Therefore, in substitute and with the intention they be used as a rough guide, a core from the Viking Age shore line (c. 3 m a.s.l.) was subsampled on all major horizons. This produced some broad geochemical parameters for the marine sourced sediments which form the soil's parent material. In addition, as the cores include subsoil sections, these provide the most relevant comparison material for the anthropogenic layers, as they represent the local conditions. Naturally, issues such as leaching and disturbance can have affected these sub-soil samples.

6.4.6 Statistical analysis

The intent is to use the statistical analysis to extract what is a product of soil processes and composition, and what is potentially archaeological. As pXRF is a total technique, measuring everything in the sample, before we can be confident there is anything archaeologically significant about the results; the soil itself has to be understood.

All data was calibrated as outlined in chapter 4. The data from cores was then classed according to stratigraphic horizon, under three broad categories of topsoil (T), subsoil (S) and archaeology/anthropogenic (A). Categories S and T were also grouped as non-archaeological (N). In addition, based upon interpretations from excavation records and observations in cores supplemented by micromorphology data (Macphail et al., 2014), archaeological horizons were classed into early (E) or late (L) phases of occupation. The creation of subgroups within the geochemical data set was to allow parametric testing of groups to validate interpretations. The data set consisted of 374 readings. Eighteen elements were selected for parametric testing, being those elements that could be calibrated, and produced significant results (over LOD set to 2 σ), and from previous experience and published research could be interpreted as a result of past anthropogenic activity (as detailed for the Avaldsnes data set, chapter 5). Before proceeding to PCA, a one tailed ANOVA test with A/N as a dependant variable was performed to test the significance of the variation. The result (F 5.187, .000 significance value) confirmed there was significant variation between the archaeological and non-archaeological soils in terms of measured geochemical values. Whilst some elements had a normal distribution, others, particularly metals such as Cu, Pb and Ag, were skewed. Pearson's correlation (two tailed) was used; however, this assumes a normal distribution of the data. To compensate, in tandem, bootstrapping was performed on all data, and separately on the topsoil only data set. This was done as the lower sample number (*n*=54) meant that there was a degree of uncertainty in whether the PCA results for this data set were significant (see below). Bootstrapping does not assume normal distribution, and can be used to test the robustness of correlations identified via other statistical tests.

All data was then standardised (Zscore) prior to PCA analysis. The test is sensitive to outliers/extreme values, which are reduced via standardisation. As with the Avaldsnes data set, Varimax rotation was selected. This was selected as the data has a few dominant component loadings, such as soil structure, and some far smaller, which include zero values, for example Sn and Ag. Varimax rotation maximises the variation by rotating the axis after extraction, which can ease interpretation (Abdi, 2003, Abdi and Williams, 2010), although a non-rotated data set is also simultaneously produced and therefore also presented in Appendix 2.

Initially, all data, without a dependent variable, was tested both in standardised and non-standardised form. These produced broadly similar results, and therefore further testing was done on the standardised data set alone. All data discussed here is either presented below or in Appendix 2 under PCA results. The standardised data set was then tested in classified groups (T, A, S, see above) in order to discern leaching into the subsoil, modern contamination of topsoil and archaeological horizons and how effectively PCA could isolate soil processes. The number of components considered significant was determined by scree plot (Abdi and Williams, 2010), although in all cases all eigenvalues over 0.8 were extracted. Further geostatistical analysis to relate localised enhancement of the interpreted factors/principal components was not done as the data was unsuitable.

6.5 Results

6.5.1 Principal component analysis

The 374 readings from pXRF analysis on the cores was divided into 231 readings deemed to be from archaeological contexts (A), and 143 from non-archaeological contexts, which were further sub-divided into topsoil (T) and subsoil (S).

Table 6. 2. Results for Varimax rotated PCA analysis for all standardised data from cores (*n=374*). The 'Z' indicates Z score value.

	Principal Component					
	1	2	3	4	5	6
Influence (%)	25.3	16.4	16.3	10.4	6.1	5.4
ZSn	-.059	.217	.032	.011	.076	.926
ZAg	-.001	.038	.017	.034	.942	.086
ZSr	.197	-.066	-.153	.760	-.065	.028
ZRb	.716	-.135	.178	.148	.008	-.102
ZPb	-.116	.950	.009	.016	-.007	.112
ZZn	-.093	.421	.425	.013	.331	-.222
ZCu	-.142	.945	.015	.016	.017	.123
ZFe	.056	.110	.899	-.069	.035	.021
ZMn	-.097	-.161	.772	.275	-.190	.072
ZCr	.478	.088	.714	-.149	.162	-.042
ZV	.467	.081	.795	-.228	.094	-.001
ZTi	.878	-.159	.195	-.034	.009	-.062
ZCa	.093	.028	.070	.858	.084	.009
ZK	.920	-.157	.132	-.003	-.026	-.028
ZAl	.930	-.073	.118	.071	.033	.025
ZP	-.546	.316	.032	.558	.049	-.093
ZSi	.793	-.213	-.276	.237	-.073	.076
ZS	-.291	.808	.063	-.005	.059	.061
Interpretation	Clay / Soil Matrix	Non-ferrous metalworking	Sesquioxides/ Hydromorphic processes	Organic waste	Silver	Tin

Within Table 6. 2 are highlighted results, which form the basis for the interpretations shown. All values over ±0.5, thus account for over ±50% of the elemental variance, are included. The greatest weight is placed upon the higher figures. Tables 6.3 to 6.5 below show the results from the same data set, separated into stratigraphic components. Note that the data quantity for topsoil (*n=54*) and subsoil (*n=89*) is lower than for the archaeological data (*n= 231*), and thus the variable (*p*) to observations (*n*) ratio is low.

Table 6. 3. Results for Varimax rotated PCA analysis for standardised data from cores, archaeological layers only (*n=231*). The 'Z' indicates Z score value.

	Principal Component					
	1	2	3	4	5	6
Influence (%)	24.7	17.6	16.6	9.7	6.3	5.5
ZSn	-.055	.206	.037	-.005	.074	.936
ZAg	-.003	.039	.034	.011	.926	.084
ZSr	.299	-.104	-.108	.718	-.107	-.011
ZRb	.678	-.155	.137	.137	-.017	-.104
ZPb	-.148	.950	.007	-.013	-.022	.112
ZZn	-.212	.458	.344	.122	.330	-.186
ZCu	-.183	.945	.005	-.016	.000	.124
ZFe	-.054	.134	.895	-.046	.021	.018
ZMn	-.197	-.170	.736	.268	-.232	.067
ZCr	.442	.120	.766	-.082	.218	-.049
ZV	.385	.115	.850	-.142	.125	.013
ZTi	.864	-.159	.189	-.024	.038	-.081
ZCa	.046	.030	.062	.874	.098	.014
ZK	.913	-.170	.049	.001	-.028	-.018
ZAl	.923	-.066	.075	.100	.032	.043
ZP	-.570	.318	.015	.529	.048	-.067
ZSi	.767	-.228	-.342	.208	-.093	.086
ZS	-.222	.893	.132	-.012	.088	.077
Interpretation	Clay / Soil Matrix	Non-ferrous metalworking	Sesquioxides/ Hydromorphic processes	Organic waste	Silver	Tin

In order to verify that PCA on each of the data sets would produce valid results for interpretation, a Kaiser-Meyer-Olkin measure of sampling adequacy was performed on both the standardised data set as a whole, and the topsoil only data set. The results were similar, with .726 for the whole data set, and .717 for the topsoil only. Results between .6 and 1 are seen as a suggesting the variance within the data set is not random chance, but significant and suitable for PCA. In addition, the bootstrap correlation data was integrated into interpretation to verify correlations were not a product of the data skew in certain variables.

Table 6. 4. Results for Varimax rotated PCA analysis for standardised data from cores, topsoil layers only (*n=54*). The 'Z' indicates Z score value.

	Principal Component					
	1	2	3	4	5	6
Influence (%)	19.5	16.7	16.4	14.7	9.6	8.8
ZSn	.262	.092	-.141	.049	.039	.871
ZSr	.101	.124	.081	.839	-.127	.126
ZRb	.029	.159	.103	.810	.069	-.448
ZPb	.037	-.306	-.726	.015	.283	.340
ZZn	.349	-.115	.016	.036	.814	.065
ZCu	.229	-.272	-.754	-.032	.280	.380
ZFe	.875	-.021	.227	.107	.206	.097
ZMn	.165	.183	.801	.345	.155	.235
ZCr	.918	.129	-.006	.171	-.004	.119
ZV	.912	.226	-.125	-.132	.048	.099
ZTi	.550	.566	.274	.262	-.003	.058
ZCa	.341	.435	.639	-.164	-.213	-.046
ZK	.218	.592	.511	.275	-.138	-.373
ZAl	.325	.882	.242	.008	-.067	-.008
ZP	.031	-.097	.004	.876	-.007	.093
ZSi	-.055	.922	.246	.028	-.156	.095
ZS	.103	.104	.277	.122	-.786	-.003
Interpretation	Sesquioxides/ Hydromorphic processes	Clay/Soil matrix	Disturbed archaeology Fertilisers		Zinc (fertiliser/ disturbed archaeology)	Tin (disturbed archaeology)

Table 6. 5. Results for Varimax rotated PCA analysis for standardised data from cores, subsoil layers only (*n=89*). The 'Z' indicates Z score value.

	Principal Component					
	1	2	3	4	5	6
Influence (%)	23.1	17.2	15.1	11.4	9.5	6.4
ZSn	-.003	-.119	.078	.101	.044	.944
ZSr	.308	-.137	.747	-.064	.290	-.089
ZRb	.713	.150	-.025	-.149	-.442	-.182
ZPb	-.012	.192	.147	.886	-.012	.001
ZZn	-.019	.150	-.769	-.008	.338	-.235
ZCu	.034	.050	-.215	.906	-.028	.134
ZFe	-.136	.896	-.074	.060	-.022	-.036
ZMn	-.005	.749	.327	.386	-.106	-.092
ZCr	.253	.728	-.278	-.013	.149	-.083
ZV	.340	.778	-.382	.089	-.012	-.052
ZTi	.878	.084	.243	.068	-.184	-.083
ZCa	.360	-.061	.852	-.003	.197	.003
ZK	.839	.275	.183	-.110	-.314	-.046
ZAl	.912	.037	.059	.052	-.019	.084
ZP	-.327	-.180	.210	.122	.761	.096
ZSi	.737	-.296	.393	.157	.042	.198
ZS	-.212	.318	-.053	-.264	.659	-.047
Interpretation	Clay/soil Matrix	Sesquioxides/ Hydromorphic processes	Leaching	Leaching	Organic matter, reducing conditions	Tin (leaching?)

6.5.2 Interpretation of the PCA results

The data here is treated differently to the previously case study, as the sampling method allows and requires an alternative angle. Prior to unpicking the tables above, a few broad definitions are perhaps helpful. Here we are focusing on the soil's fine earth fraction, less than 2 mm, which is composed of sand, silt and clay, and organic matter in various states of decomposition. Chemical exchanges are dominated by the finest of the fine within soils. Imagining soil as an organism is one way of visualising the composition and complexity, which is here adapted from Tan (1998). The finer matter, the clay and humus, collectively compose the soil plasma, the part under 2 µm. The larger fraction of the soil is the skeleton grains, which support the overall structure, but are relatively immobile. Serving as a medium of exchange and supply is the soil solution, the blood in this imperfect analogy, gathering, transporting, redistributing and removing nutrients. The skeleton grains will be weathered into plasma over time, if conditions allow. The plasma is more mobile within the soil profile, via the soil solution. Within the plasma, we find colloids. A colloid is a specific size; between 0.2 µm and 5 nm, and it is here most exchanges take place due to their charge and vast surface area. There are many types of inorganic and organic colloid, but simply put, within the organic fraction, composed of carbohydrates, amino acids, proteins, lipids, nucleic acids, lignin and humic compounds formed by the soil's decomposition of organic matter, the functional groups of these compounds form the medium of exchange. The inorganic colloids are formed of layered clays, sesquioxides and other mineral forms (Tan, 1998). Sesquioxides have a specific ratio of oxygen (O) to aluminium (Al), iron (Fe), manganese (Mn) and titanium (Ti), and are ordered crystalline forms in the range a few nanometres, but disordered on larger scales (White, 2006). Layered clays are classified by their Si:Al ratio and form, and types include those with ratios that dictate properties such as their ability to expand and contract. The types of clay within a soil matrix are a product of parent material, climate in all its variables, and age. Some clay types have sheets of magnesium (Mg) and potassium (K) within the lattice (White, 2006). The formation of the layers and the substitutions within, combined with the soil's pH, on a broad level, control the electrostatic charge, and thus the soil's exchange capacity. Within this process, weathered or decomposed additions to the soil are retained as ions, primary and secondary minerals or as larger inclusions. Many of the elements retained in cation or anion form, are utilised by plants, and if plants decompose in situ, they are then recycled. This is what we are measuring; the how, why and in what form anthropogenic enhancements have remained in the soil in patterns we can interpret *above* soil processes alone.

In tables 6.2 to 6.5, the correlation of Fe, chromium (Cr) and vanadium (V) combining in a principal component is interpreted as the soil's sesquioxide component and clay matrix. In all but the topsoil, Mn also has an affinity with these elements. Vanadium is common, albeit in far lower proportions, in Fe (hydr)oxides, as in soils the soluble H_2VO_{4-} readily sorbs onto Mn, Al and Fe oxides, and thus often correlates with Fe. Where phosphorous (P) content is high, this can reduce V sorption, as phosphate can out compete V in anion exchange and sorption in soils (Larsson, 2014). How V is retained in soils is pH and redox dependent, however, here it seems to favourably adsorb to Fe (hydr)oxides, and this correlation holds for every soil horizon. Iron, Al and Mn (hydr)oxides do seem to control V sorption in soils (Larsson, 2014), as does pH to some degree (Gäbler et al., 2009). Mangenese and Fe are affected by cycles of reducing and oxidation in soils, which results in a leaching or redistribution of the these elements as they become soluble and are redeposited locally or more widely in oxidising conditions such as root channels, voids or as the water table fluctuates (Birkeland, 1999). Sesquioxides, or amorphous clay minerals, are common in tropical conditions, where weathering is rapid (Tan, 1994), but also, to a lesser extent, in acidic soils where clays are leached of their Si content. In these conditions, Al, Fe, and often Mn, form metal oxides, typically Al_2O_3, Fe_2O_3, Mn_2O, although other forms occur and proportions vary (Mayer et al., 2001). In reducing conditions, Mn_2O is reduced to the cation Mn^{2+}, which is in turn rapidly seized by Fe (hydr)oxides. Therefore they remain correlated, as this sorption tends to remain stable until very low pH levels (He et al., 2010). In the ploughed, aerated and relatively drained topsoil, Mn does not correlate with Fe, probably because of the lack of reducing conditions. This could also be the large uptake by plants, as Mn is generally found in far lower amounts compared to Fe (typically Fe 2-6%, Mn 0.03-0.1%), and is an essential plant nutrient (Brady and Weil, 1999). In these conditions, Cr forms a part of the factor as Mn is a nurtrural oxidant, and is strongly retained in soils (Covelo et al., 2007, Ma and Hooda, 2010). Titanium, which correlates with Fe in the topsoil, also readily forms the metal oxide TiO_2, although this is not strictly speaking a sesquioxide (De Vos and Tarvainen, 2006a).

The combination of silicon (Si) and Al is immediately recognisable as inherited minerals and layered clays, which in all horizons correlate with K and Ti. As Ti is solely from minerogenic inputs and has no known biological function, this factor represents the soil's geogenic mineral components (Kylander et al., 2011). Interesting, in all but the topsoil rubidium (Rb) also forms this factor. Measured in proportions generally between 70 to 160 ppm, Rb, in the form of Rb^+, is assumed to be isomorphic substitutions in the clay lattice or a weathering product from K-Rb rich mica and feldspars. As Rb has similar atomic radii to K, it is a common substitution in the clay lattice, and is also found in similar quantities as those measured as a weathering product in southern Norway (De Vos and Tarvainen, 2006b).

In the topsoil, Rb and strontium (Sr) correlate with P in principal component 4, whereas Ca and K correlate in principal component 3. This is assumed to be a combination of plough erosion bringing archaeological material into the topsoil, and modern additions from atmospheric inputs and artificial fertilisers adding to the organic and mineral components in the soil. Common micronutrients in fertilisers include copper (Cu), Fe, Mn, molybdenum (Mo) and zinc (Zn), as well as P (Brady and Weil, 1999). This could also explain factor 5 in the topsoil as Zn alone. Unfortunately, the type and use of modern fertilizers on the site is not known, but certain fertilizers are a source of accumulating Zn, and of course other elements utilised by plants (Stacey et al., 2010). This hole in knowledge does limit the detail of topsoil interpretation. To this must be added that in the topsoil data, P does correlate with Sr, but not Rb in the bootstrap test data. Calcium (Ca) and K do correlate. Therefore the correlation between P and Rb could be a product of the skew in the data (skewness P is 4.449 for topsoil only).

Just as the topsoil samples are from directly over the archaeology, samples for the subsoil are largely taken within 15 cm of an archaeological deposit above, and therefore the principal components 3 and 4 in table 6.5 are possibly leaching and precipitation of metals and alkaline earth metals from archaeological contexts. Raising the eye from the site to a more general level, Ca and Sr commonly correlate. The similar atomic radii of Sr and Ca mean the less abundant Sr is a common substitution for Ca in rocks and minerals, and is easily weathered into solution in the mildly acidic conditions at Heimdalsjordet. For Ca, the mean and standard deviation (SD) of observations in the topsoil and subsoil differs from the archaeological contexts. For subsoil, the mean is 8,899.3 ppm and the SD 1,692.7 ppm, whereas for topsoil the mean is 8836.6 ppm with a SD of 1052.7 ppm. The SD is less for topsoil, despite the similar averages. In the archaeological contexts, the figures are 10,612.6 ppm for the mean and 3,527.7 ppm for the SD. Despite the issue of comparing one data set with a larger number of observations to another with less, it does appear that the topsoil has least variation, whereas the archaeology is generally enhanced in Ca. For Sr, all horizons have a SD between 32 and 37 ppm, and the mean is slightly higher in the archaeology (183.6 ppm) compared to the topsoil (174.8 ppm) and the subsoil (158.6 ppm). These figures are close to the regional Sr levels (De Vos and Tarvainen, 2006a), but it is possible Ca and Sr represent more than one input. The fact that Sr and Ca do not correlate in the topsoil by any test undertaken can perhaps be attributed to modern land use practices to reduce acidification, although the exact modern additions to the land are unknown at present.

That they do correlate in the subsoil and archaeological contexts is perhaps another issue. The affinity of Ca and Sr due to their similar atomic radii in clay lattices and geological formations mean that from the geogenic inputs, they will correlate, even though Sr is far less plentiful than Ca. Calcium is enhanced in the archaeological contexts due to the additional inputs of Ca rich material, namely bone material and ash. This does not strongly correlate with P, the other main input from bone material, as P is present in virtually all other organic materials. However, they do correlate somewhat in the archaeological contexts. In the moderately acidic conditions at Gokstad, where burnt bone is leached and weathered and still present but unburnt bone has decomposed, the Ca and P released into the soil solution is retained in different forms and by different mechanisms. For calcium, commonly the cation Ca^+ is adsorbed onto clay surfaces and humic compounds, or leached into solution and lost to the soil (Brady and Weil, 1999). In occupation contexts, ash is also a source of Ca. Mechanical and chemical weathering in these conditions will remove all traces over time (Courty et al., 1989, Canti, 2003), however rare exceptions can occur if the deposit form allows, by creating a more neutral microenvironment that reduces chemical loss, such as in urban 'dark earth' contexts (Courty et al., 1989). Phosphorous, as part of anion exchange, in acidic conditions can form insoluble compounds with sesquioxides (Brady and Weil, 1999). In the archaeological data set, besides the correlation with Ca, i.e. bone and other organic human waste, it has no other correlation. Therefore bone and similar organic material from anthropogenic activity is the most likely source.

The final principal component(s) in each of the tables 6.2-6.5 are dominated by a single element; tin (Sn) or silver (Ag), and in one case, Zn. The data is no longer being reduced by PCA. Appendix 2 contains scree plots associated with each of the horizon data sets, and these final factors are at or beyond the 'elbow', where the curve levels off and the differential influence between principal components becomes small. In this case, these account for well under 10% of the variation. Therefore undue weight will not be laid upon this data, although it deserves a mention as it is repeated in each of the data sets.

Firstly Sn. Tin behaves differently to the other metals commonly exploited by past human populations. In natural conditions, Sn is either in the form of Sn^{2+} or Sn^{4+}, the latter being iron-loving, the prior even more picky. Tin forms few minerals, cassiterite (SnO_2) being the dominant form, although minerals with Cu and sulphur (S) also occur (Kabata-Pendias, 2010:337-338). Silver has several mineral forms with other elements; however, in naturally occurring minerals form, silver is often argentite, Ag_2S, or native silver, Ag. Silver has the strongest affinities to S and chlorine (Cl), although in these organic and slightly acidic soils, S is comparatively abundant, whereas Cl is only detected in close proximity to bone material. With S, in organic or inorganic forms, Ag forms strong bonds, which can and do out-compete many other common metal cations, such as Cu^+ and Pb^+, attracted to colloid surfaces (Evans and Barabash, 2010). The principal component with Ag alone as a dominant influence can therefore be interpreted as a product of the low proportion of silver within the samples, its concentration in a few specific contexts, and its strong retention in these conditions through colloidal adsorption with S. Similarly, Sn is found in low to medium concentrations in few contexts, and is commonly found in soils, either as a cation, or in mineral form with O.

As mentioned previously, S is fairly abundant. Sulphur is generally associated with wetter conditions, reducing environments and the organic soil fraction; however, it is also in mineral form in complexes with metal ions (see below). Sulphur is found in plant material, marine-sourced sediments and geological formations, although in soil it is usually in organic forms. Within the organic fraction it is fairly stable, but once released/weathered as ions, it is easily leached (White, 2006). In reducing conditions, bacteria release S into the soil matrix in anion form, although in Fe and sesquioxide rich soils, such as Heimdalsjordet, sulphate can be adsorbed and retained (Tan, 1994, Tan, 1998).

Returning to the data tables, as mentioned previously, Ag_2S is a common form of silver. Sulphur does not correlate well with Ag, because of the difference in abundance and the universally anthropogenic source for Ag, whereas S will be, to some degree, also naturally occurring. In the data presented, sulphur correlates differently in the topsoil, archaeology and subsoil layers. Indeed in the topsoil, it does not correlate with much at all, although the bootstrap testing weakly correlated it with the clay matrix minerals Al, K, Si as well as Mn and Ca. In the archaeological horizons, S forms a principal component with lead (Pb) and Cu. In the subsoil, it correlates with phosphorous. The most common form of S in soils is the bacterially formed pyrite (FeS_2), although other mineral forms are known, such as the previously mentioned Ag_2S, and other Fe bearing mineral forms (Mees and Stoops, 2010, Kabata-Pendias, 2010). In the site conditions, S is likely to form stable sulphides with other metallic ions, such as Cu^{2+}. Lead also has an affinity for S, and these forms for both Cu and Pb are fairly insoluble and unavailable for plant uptake (Hough, 2010). If the soil drains, some forms of metallic sulphides become oxidised and more soluble (Kabata-Pendias, 2010), which explains the presence of Cu and Pb in the upper subsoil horizons as leached. Together, this implies that the principal component in the archaeological contexts where Pb, Cu and S correlate is a result of organic and metal inputs from anthropogenic activity being subject to intermittent reducing conditions since deposition. This is highly plausible in stagnosols and gleysols. Many of the concentrations of non-ferrous metals are in contexts with gleyed characteristics, including primary and secondary Fe mottles and coatings. In the next section, these concentrations are located and described from an archaeological perspective.

To focus now on what can be taken from the data as potentially archaeological, weight will be placed on the data in table 6.3. Soil processes dominate, but here the task is to discriminate the anthropogenic enhancement within and above this. The combinations of Pb, Cu and S, probably from sulphide ores, impurities in refined metals and/or organic inputs, are all at levels far above background data (De Vos and Tarvainen, 2006b). These are interpreted as evidence for non-ferrous metalworking, without making the assumption this is the only source of enhancement. In the core data, these elements, as well as Ag and Sn, appear in concentrations on the horizontal and vertical planes. They do not correlate well in the PCA analysis as they are present in different concentrations, and retained and mobilised by different soil processes, entered the soil in different forms, and plural forms probably exist at present; however, they are highly likely all to represent metalworking. Human settlement increases organic inputs, which has caused the enhanced P and S. The enhancement of Ca and to a lesser extent Sr above the levels from modern land-use and geogenic inputs is attributed to human activity, including but not exclusively, bone material.

6.5.3 Results by phase

The phase results are only considered in terms of descriptive statistics on the calibrated data. The cut off between the early (E) and late (L) phase is based upon elemental values and excavation records, and is imperfect in that the cores do not necessarily represent the same features and layers that were recorded during excavation. It also involves certain assumptions created during the excavation, that the first phase of the site has less anthropogenic inputs.

Table 6. 6. Descriptive statistics for the early phase from the geochemical core data. All data is in ppm, with the exception of N (no. of samples).

Early	Sn	Sr	Rb	Pb	Zn	Cu
N	74	74	74	74	74	74
Mean	1.25	180.20	120.60	18.12	68.33	34.82
Std. Deviation	9.60	27.94	18.39	13.53	13.25	24.92
Minimum	0.00	97.50	87.39	0.00	41.09	0.00
Maximum	82.14	232.88	159.61	82.41	106.48	153.68
Sum	92.22	13334.95	8924.45	1340.81	5056.53	2576.60

Early	Fe	Mn	Cr	V	Ti	Ca
N	75	74	74	74	74	74
Mean	29160.93	434.53	62.44	95.04	4072.55	10044.08
Std. Deviation	9400.40	110.97	15.00	24.65	636.26	1977.42
Minimum	14780.01	245.82	22.99	40.51	2855.89	5524.63
Maximum	51015.38	780.08	93.43	146.01	5357.52	16128.53
Sum	2187069.55	32155.24	4620.74	7033.27	301368.92	743261.98

Early	K	Al	P	Si	S	
N	74	74	74	74	74	
Mean	22098.40	41906.06	1178.92	217368.45	250.63	
Std. Deviation	3470.77	12365.77	712.97	46507.46	118.95	
Minimum	16373.45	11727.10	244.27	76784.06	59.21	
Maximum	28805.02	72881.84	3724.08	306133.19	544.19	
Sum	1635281.83	3101048.60	87240.07	16085264.94	18546.38	

Of note, when considering the differences between the phases, is that the mean and standard deviation (SD) for the elements extracted as anthropogenic from PCA analysis. Calcium is only slightly enhanced in late phase (table 6.7) compared to the early (table 6.6), yet the SD is over twice that of the early phase. For P, both the mean and SD increase markedly. From the low sum and mean, it is clear the non-ferrous metals are far rarer in the early phase. As these phase divisions are using stratigraphic context boundaries, this can be interpreted as that non-ferrous metalworking, almost exclusively, is a later phase phenomenon. Silver can be seen as a minor contribution to the evidence of non-ferrous metalworking in the parcel ditch backfills. Elements associated with the soil matrix, such as Si and Rb, decrease slightly in the later phase as proportionately the archaeological sediments are more organic and thus marginally less minerogenic.

Table 6. 7. Descriptive statistics for the late phase from the geochemical core data. All data is in ppm, with the exception of N (no. of samples).

Late	Sn	Ag	Sr	Rb	Pb	Zn
N	116	116	116	116	116	116
Mean	21.06	0.73	187.49	108.50	179.63	79.99
Std. Deviation	105.88	3.88	35.60	18.73	750.68	24.10
Minimum	0.00	0.00	85.90	54.04	7.13	31.85
Maximum	1084.34	34.38	301.70	161.87	6473.32	171.13
Sum	2443.46	75.01	21748.62	12586.04	20836.61	9278.39

Late	Cu	Fe	Mn	Cr	V	Ti
N	116	116	116	116	116	116
Mean	209.17	28178.06	476.39	53.63	79.06	3316.50
Std. Deviation	691.91	15189.37	356.05	13.85	25.34	690.34
Minimum	0.00	11428.09	165.96	25.11	23.11	1256.08
Maximum	5518.56	111544.87	2628.87	95.90	169.44	4776.58
Sum	24263.89	3296833.46	55260.74	6220.72	9171.48	384714.02

Late	Ca	K	Al	P	Si	S
N	116	116	116	116	116	116
Mean	10988.05	18246.16	32388.65	2458.77	192956.70	380.22
Std. Deviation	4347.23	3040.72	8870.68	2023.61	38807.27	376.95
Minimum	5634.79	8323.58	13111.33	364.43	64049.50	45.62
Maximum	48975.61	25323.64	53223.59	12559.64	291212.77	3003.90
Sum	1274614.09	2116555.00	3757083.65	285217.19	22382977.23	44105.89

In the next section, selected areas of the site will be examined via the coring data, to apply the statistical results where possible to the horizontal and vertical archaeological stratigraphy. To reiterate, the focus will be on the PCA results shown in table 6.3.

6.6 The geochemical stratigraphy by core and area

For this section, the reader is referred to figures 6.8 and 6.9 for the general layout of the site, which will be illustrated more specifically on an area by area basis below. Appendix 2 contains all core descriptions and stratigraphy. As an advisory note, in the figures with the core illustrations, the context numbers are labelled in a consequent manner on a core by core basis. The first four digits is the core number, followed by the context number. The contexts are numbered from top to bottom; therefore 7938/1 is the upmost context in core 7938. Within the figures are also the regression scores from the PCA analysis. These scores are constructed from the Zscore data using the principal components. Each regression score is a standardised score for the data at that sample point, for each principal component. The scores are positive and negative, and between -3 and +9 in this case. A negative score means this point/sample had less than average influence on the principal component, and a positive score means it had a more than average influence. Thus, the higher the score, the more concentrated the geochemical causes of each principal component are in that sample/context. It also follows that principal component regression scores with the greater value range have more extreme values, and thus are more influenced by localised concentrations. This is particularly the case for the anthropogenic factors.

6.6.1 Parcel 1

Beginning in the west of the site, parcel 1 was partially excavated in 2012 (figure 6.10). The thoroughfare borders to the longer northern edge of the rectangular ditch system, implying the parcel is orientated parallel to rather than perpendicular to the roadway. The form of the northern ditch appears to follow the subtle curve of the road, whereas the southern ditch follows the very gentle contours, implying the road is perhaps older than the ditch arrangement. The southern ditch system also extends into further parcel ditch systems to the east and west. Excavation also revealed linked ditches across the thoroughfare, implying a complex, interdependent drainage system as well as a system for demarcation. During the excavation, four cores were taken from the surface after it had been mechanically stripped of topsoil. Two cores were taken c. 1 m apart to verify how abrupt stratigraphic changes were on the site. Each core from parcel 1 is considered below.

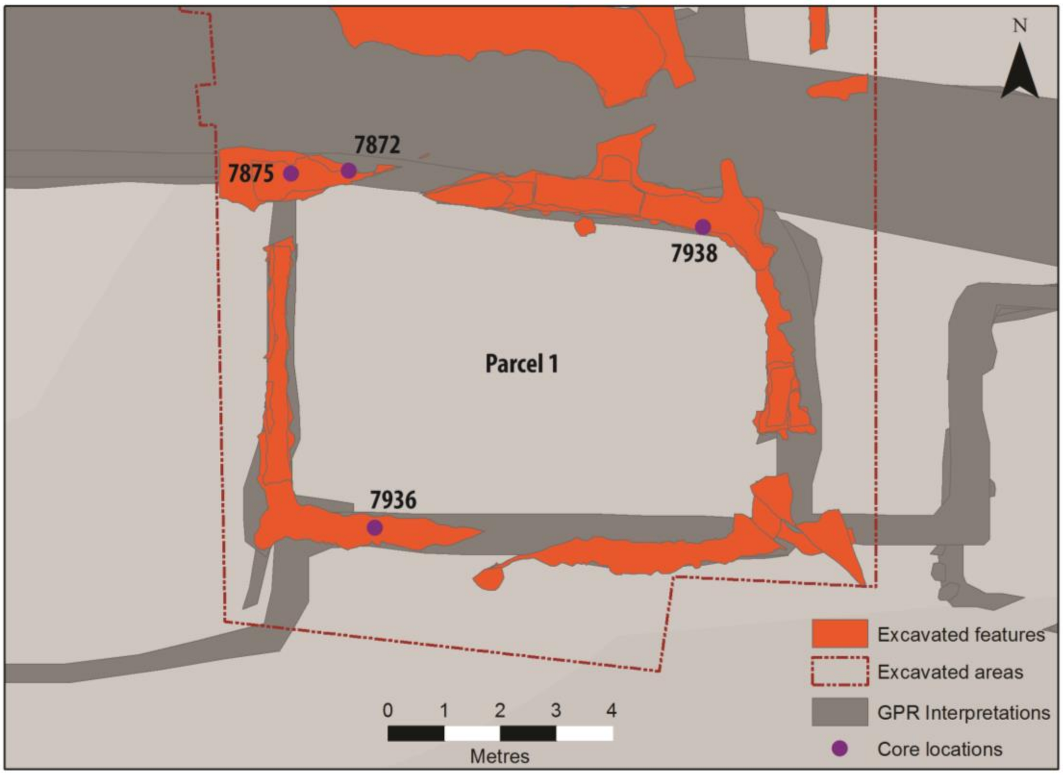

Figure 6. 10. The parcel ditches identified via GPR and excavation for parcel 1 at Heimdalsjordet. The core locations are marked and labelled. Map source: Author/GOREV/Norwegian Mapping Authority 2016.

Core 7875

The core is located in the north western corner of the parcel ditch, immediately south of the thoroughfare. Five stratigraphic contexts were observed in the core, which was a total of 35 cm in depth. The lower contexts (7875-4/5) were identified as a possible stakehole with backfill. The core did not reach undisturbed subsoil. The lower levels were clay-silt with a low proportion of woodchips, a laminated structure with in-filled and iron coated fine to medium root channels and burrows. In common with other parcel ditches, this is interpreted as the earliest phase of the site, with less intense anthropogenic activity. This is returned to in section 6.8.

Context 7875/3 showed proportionally greater anthropogenic material, including burnt bone fragments, fine charcoal flecks within the humic, silty loam matrix. Secondary iron staining was also visible. Above this, context 7875/2 is interpreted as flood waters re-depositing anthropogenic material and beach sand in fine, defined layers. There is also evidence of water reworking and re-depositing settlement material in the upmost context, 7875/1, and the flood inputs of fine sands have caused the increase in the soil processes factor (figure 6.11), and the decrease in soil matrix, as the proportion of clay lowers. The upper three contexts show a far greater degree of settlement influence, with an increase in anthropogenic material such as charcoal and burnt bone, and higher organic material from waste/occupation remains. This is seen in the increasing of the organic waste component.

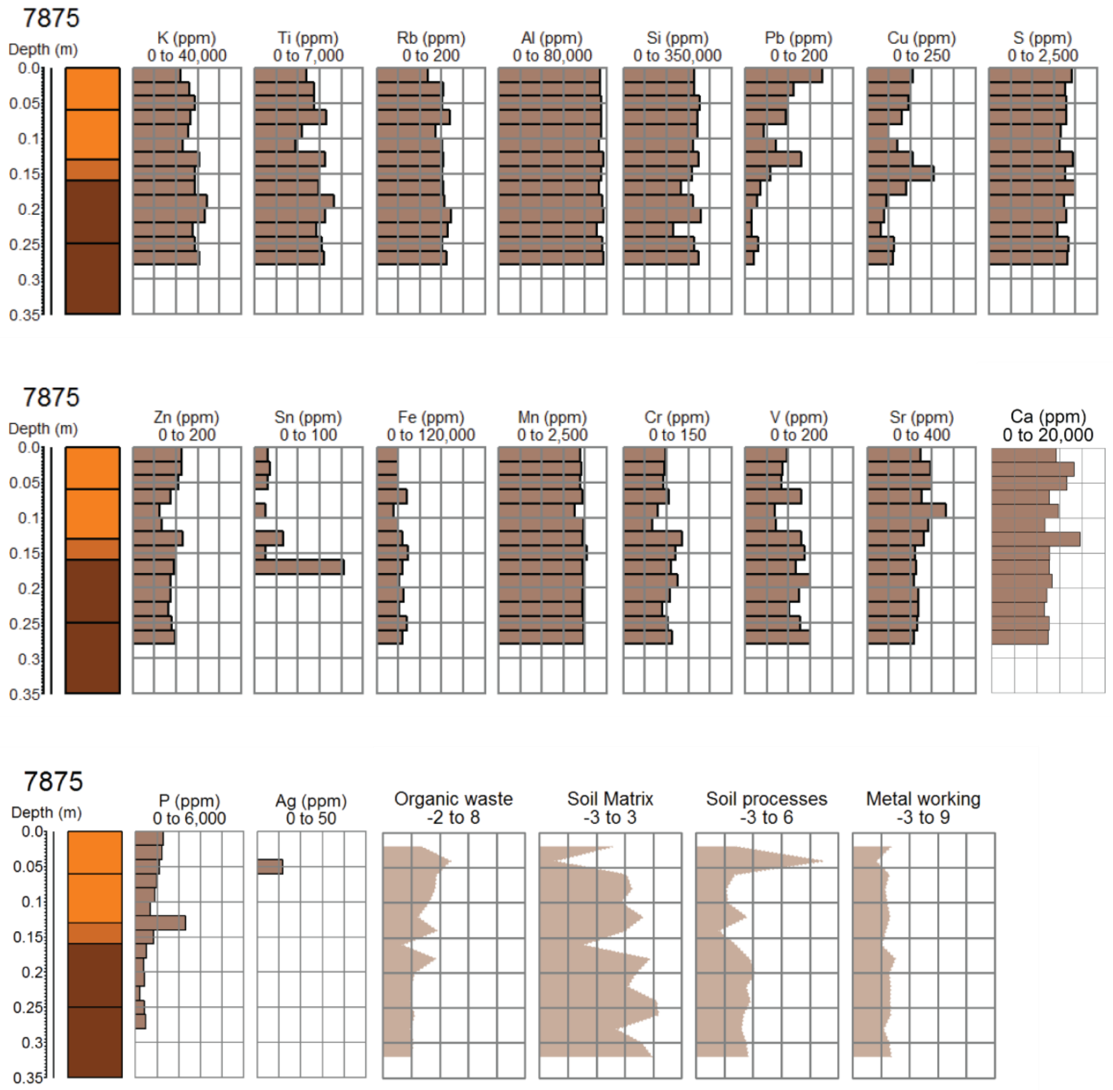

Figure 6.11. Core 7875, stratigraphy and geochemistry. The final four graphs are the interpreted results from PCA for the archaeological contexts only.

Geochemical data

Context 7875/1, at 0-6 cm, has low level metalworking waste either dumped, or considering the fluvial reworking of the context, washed in from the immediate surroundings. This is indicated by higher levels of Pb, (up to 136 ppm at 4 cm), Cu (up to 161 ppm at 4 cm), Zn (up to 97 ppm at 2 cm), with very low levels of Ag at 6 cm (9.52 ppm). This appears intermixed with redeposited settlement waste, including bone, suggested by elevated Ca, and high P levels (7,696 ppm at 4 cm). Although the section photographed in figure 6.13 is some 50 cm distant from the core, there are some contextual similarities, and the upmost context clearly has a higher organic and anthropogenic content.

Figure 6.12. Photo Cf34662_288. Section 9094, ditch 3701. Scale is 40 cm. Photo: GOREV/ MCH

Context 7875/2 is also consistent with a flood sourced redeposit of in-washed sediment and lesser amounts of anthropogenic material; levels of Ca and P are notably lower and decrease toward the base of the context, metalworking traces are less consistent and lower. Context 7875/3 is a 2-3 cm layer of highly organic silty loam, which was tentatively interpreted as cess or other highly organic waste from examining the core. Chemical traces support the interpretation of organic waste, with high levels of P and Ca, although the source cannot be specified further. Contexts 7875/4 and 7875/5 contain lower levels of metals on the whole, with P and Ca levels gradually falling toward background levels with depth. Fe and V increase slightly compared to the upper contexts, fitting the observed secondary iron coatings.

In summary, the upper two contexts show flood deposits reworking and in-washing waste from metalworking and settlement, whereas context 7875/3 is a dump of organic material, which is sharply defined. Lower contexts suggest less intense human activity, and the abrupt division between contexts 7875/3 and 7875/4 could imply re-cutting or cleaning out the ditch.

Core 7872

Located 1 m east from core 7875, this core is also in parcel ditch 1, beside the thoroughfare. This core was taken to see how varied the deposits were over short distances. Contexts 7872/1 and 7872/2 composed the upper 10 cm of the core, are humic silts with higher organic contents. Context 7872/1 contained in-washed lenses of pale silts, interpreted as in-washed after precipitation, as well as weathered burnt bone fragments, charcoal and a burnt hazelnut shell. Context 7872/2 had a higher proportion of fine gravels, rare burnt bone, one ashy slag droplet, and fine burnt clay fragments within the humic silt matrix. Bioturbation was evident in the form of burrows, voids and root channels. Below, context 7872/3 was a gleyed clay silt, with increasingly large iron mottles toward base. The upper boundary contained a coarser lens of silty loam. Layer 7872/4 appears as undisturbed Bg1 (subsoil), implying the ditch here is considerably shallower than core 7875.

Geochemical data

Non-ferrous metalworking evidence is present in contexts 7872/1 and 7872/2, the levels falling only slightly toward the lower interface of context 7872/2 (figure 6.13). Silver is not present, Pb, Cu, Zn and Sn are in fairly typical proportions for the site, with Pb up to 103.76 ppm, Cu up to 135.88 ppm, Zn up to 96.87 ppm and Sn up to 34.19 ppm. The levels fall in context 7872/3, with the exception of Zn, which is above 70 ppm into the upper subsoil context (7872/4). From the subsoil data set taken south of parcel one, Zn at 72.03 ppm was measured at 82 cm depth in the lower subsoil (core 2524), and in the same core, at 131 cm in the Cg layer, the measured level of Zn was 80.04 ppm. This suggests Zn is naturally present in the clay silt matrix at these levels, and marine sourced. Therefore the Zn enhancement in the anthropogenic layers, is moderate in this core, and possibly within the soil’s natural variation.

In similarity to metalworking, organic waste/bone enhancement is seen in the upper two contexts, the levels lowering in context 7872/3 for Ca and Sr. P levels are more varied. Background P levels are c. 700 pm, whereas measured values in contexts 7872/2 peak at 2,483.83 ppm. Levels remain enhanced throughout context 7872/3, peaking at 1,924.11 ppm. Again, the sharp contrast between the upper and lower core strata in terms of anthropogenic inclusions could represent a re-cutting of the ditch.

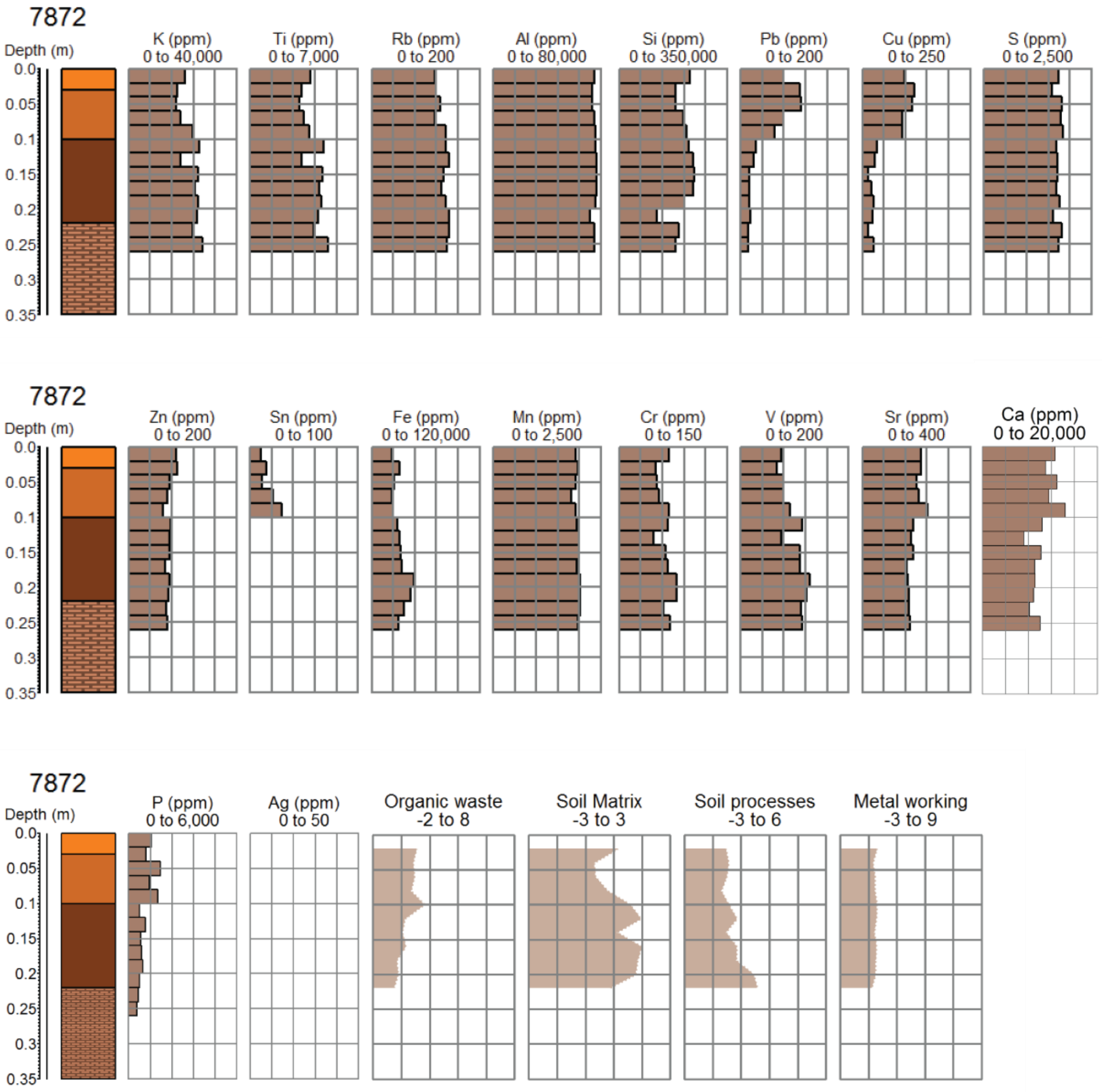

Figure 6.13. Core 7872, stratigraphy and geochemistry. The final four graphs are the interpreted results from PCA for the archaeological contexts only.

Core 7938

Five stratigraphic layers were observed in core 7938. The upmost layer, 7938/1, was 10 cm thick, and consisted of mixed sands, humic matter and grey silts. The layer was heterogeneous, intermixed and clearly from in-washed material gradually and more rapidly accumulating after precipitation/flooding events. Layer 7938/2 deserves particular attention. The matrix is heterogeneous, humic clay silt with a compact, platy structure. Within the 7 cm thick layer were large, common charcoal pieces, burnt clay, vitreous ashy red slag, burnt pebbles, very fine burnt bone, a pale clay mortar-like material (unidentified further), and small to medium wood chips. This suggests hearth/industrial material mixed with other waste. At 13 cm in depth, a bright yellow object (1-2 cm long, thin plate) was sampled and separately analysed, and appeared to be a pyrite coated copper alloy and silver object. Two far smaller fragments from the same location were not analysed. This suggests metalworking waste. Also within the matrix were rounded clasts of gleyed clay, similar to the local Bg subsoil. In figure 6.14, the scale values for P, Ca, S and Pb have been increased as this core has far higher measured values for these elements. This is also shown in the peaks for principal components 2 and 4 in this layer, with a corresponding fall in factor 1, indicating the context is dominated by anthropogenic inputs rather than local subsoils.

Context 7938/3 is silty clay with frequent fine ferrous mottles. The anthropogenic inclusions decrease with depth, suggesting this is a slowly accumulating layer, with the fine slag and bone only present near the upper interface, whilst the few charcoal flecks are present throughout. The lower interface is both very sharp, and uneven, which is tentatively interpreted as possible ditch re-cutting. Below, context 7938/4 is gleyed clay silt with frequent iron mottles, which increase in size and frequency toward the lower interface, together with fine sand which is consistent with this being the base of a ditch cut for drainage (figure 6.14). Layer 7938/5 is the upper Bg1. This suggests that the ditch was initially open, and fairly free from in-washed or dumped anthropogenic waste, although slow silting did occur. The period of time this represents is impossible to define. Layer 7839/4 accumulated, followed by layer 7938/3, which shows increasing anthropogenic inputs. The ditch continued to fill, and was re-dug. Layer 7938/2 then accrued, as anthropogenic waste. This shift, from low level human occupation waste to high, suggests a change in the nature of the settlement, and intensity. Context 7938/2 clearly contains hearth and metalworking waste, suggesting a smithy and possible domestic activity within the parcelled area, or at least very close by.

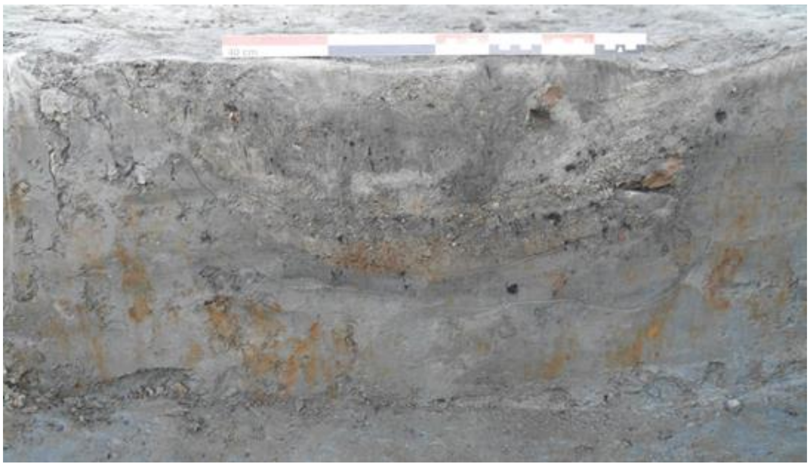

Figure 6.14. Photo Cf34662_297. Section 9241, ditch 3701. The section is located 2.4 m west of core 7938. Scale is 40 cm. Photo: GOREV/ MCH.

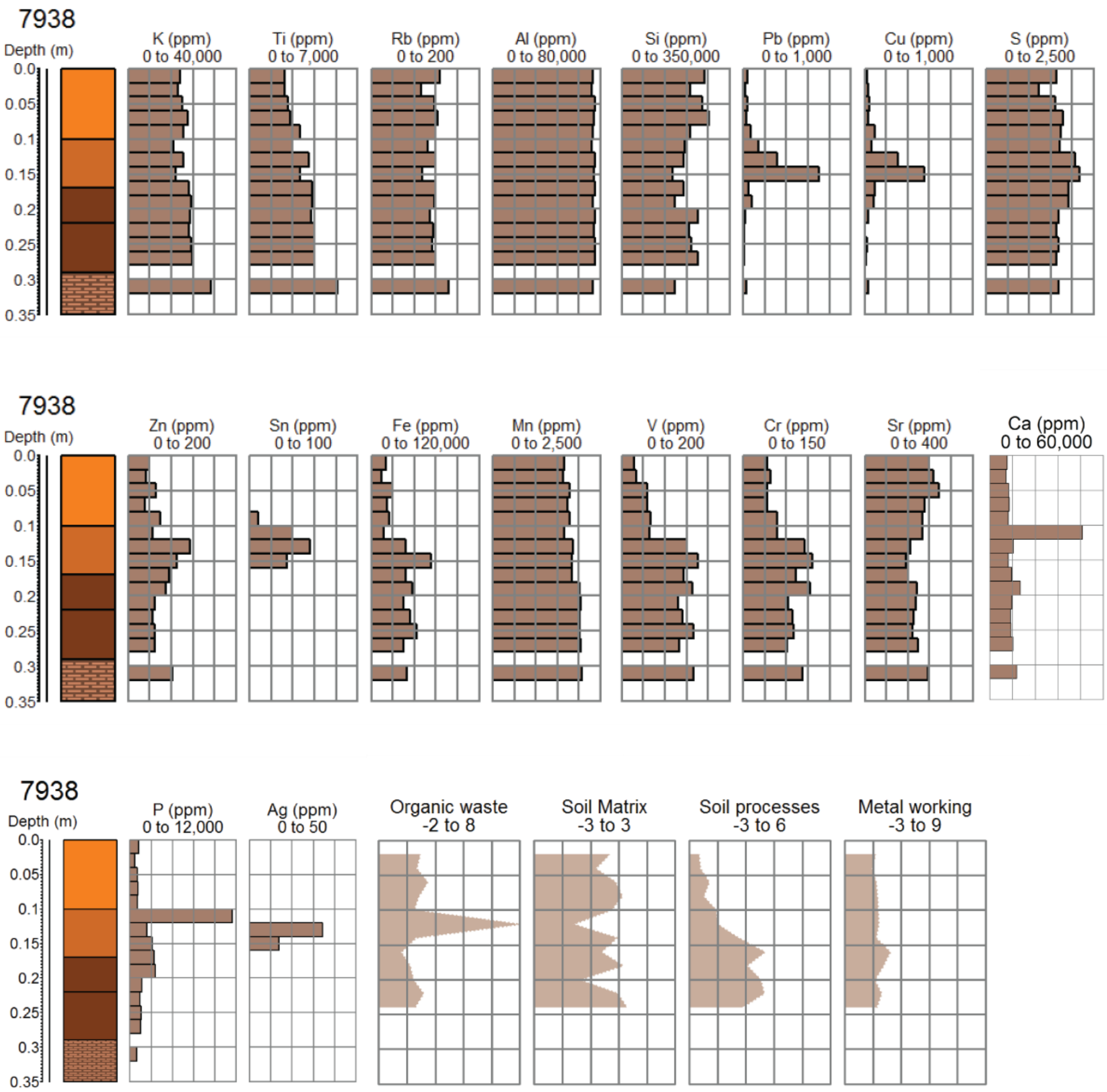

Figure 6.15. Core 7938, stratigraphy and geochemistry. The final four graphs are the interpreted results from PCA for the archaeological contexts only.

Geochemical data

Unsurprisingly, the measured values for metalworking (Pb, Cu, Zn, Sn and Ag), as well as P, Ca and Sr, are consistently highest in context 7938/2. They peak at 14-16cm, toward the base of the context, where P reaches 16,285.1 ppm (0.16%), Ca at 12 cm is 48,975.61 ppm (4.8%), Ag is low at 27.78 ppm, but as it is rarely present, this is significant (figure 6.16). Lead reaches 660.49 ppm, Cu 619.85 ppm, Zn 122.76 ppm, and Sn, which again is rarely present, measures 66.06 ppm. The high Ca values, in light of the slag and burnt materials, could well be ash and bone if the microenvironment of the context retained traces of ash (see section 6.5). For comparison, a burnt bone fragment within the soil matrix at the base of this context, without sample preparation, was measured in situ and measured 111,343 ppm, or 11% Ca, and P measured

68,671.6 ppm, or 6.8%. Interestingly, the analysis also contained unusually high levels of Zn (521.92 ppm), Sn (103.78 ppm), and relatively high levels of Pb (584.73 ppm), and Cu (482.14 ppm). Whether this is the bone structure absorbing metals traces from the surrounding matrix or that the bone has been utilised in the metal processing is hard to distinguish, and must be considered in relation to techniques employed at the time.

Context 7938/3, in contrast, has fluctuating but low levels of Zn and Pb closer to background levels, and no Ag or Sn was recorded. Copper falls from 104.37 ppm to 34.78 ppm from the top to the base of the context. However, Ca and P remain enhanced throughout context 7938/3, with P up to 4,000.15 ppm and Ca 14,550.8 ppm. This implies that metalworking waste was not directly accumulating in this section of the parcel ditch at the time, but there was certainly occupation waste present and accruing. Layer 7938/4 has near background levels of metals and Ca, whilst P remains slightly enhanced, implying some low intensity human inputs immediately after the ditches were cut.

Core 7936

This section of the parcel ditch, located on the southern edge, was unexcavated; therefore there is little comparative data available. This core was subsampled after in situ analysis, for comparison of the data (see chapter 4 for comparison of direct core measurement to subsampled data). The core was 35 cm long, and the base of the parcel ditch was not reached. Five layers were identified.

Geochemical data

With the exception of P, all other elements used here to identify anthropogenic activities were far lower than the cores on the north side of the parcel, beside the thoroughfare (figure 6.16). To generalise, values are highest at the top of the core, and fall steadily toward background values at the base of the core, implying that the interpretation that the lowest context, 7936/5, has little anthropogenic inputs, and therefore very near the base of the ditch, is correct.

The upper context, 7936/1, measured P at 5,714 ppm at 2 cm, however by the base of the same context, the measured value was 764.75 ppm. Ca values are also enhanced in the context, measuring 11,492 ppm at 6 cm. Tin is not present in the core, although Cu is enhanced in the upper context, at 223.29 ppm. The peak of Fe in the upper context could be due to Fe fragments, which were very occasionally observed, or more likely, a Fe mottle or coating was measured. As Si and Ti also decline at this point this is the most likely explanation. What is clear from the geochemical data, it that only the upmost few centimetres of the core have notably higher anthropogenic inputs.

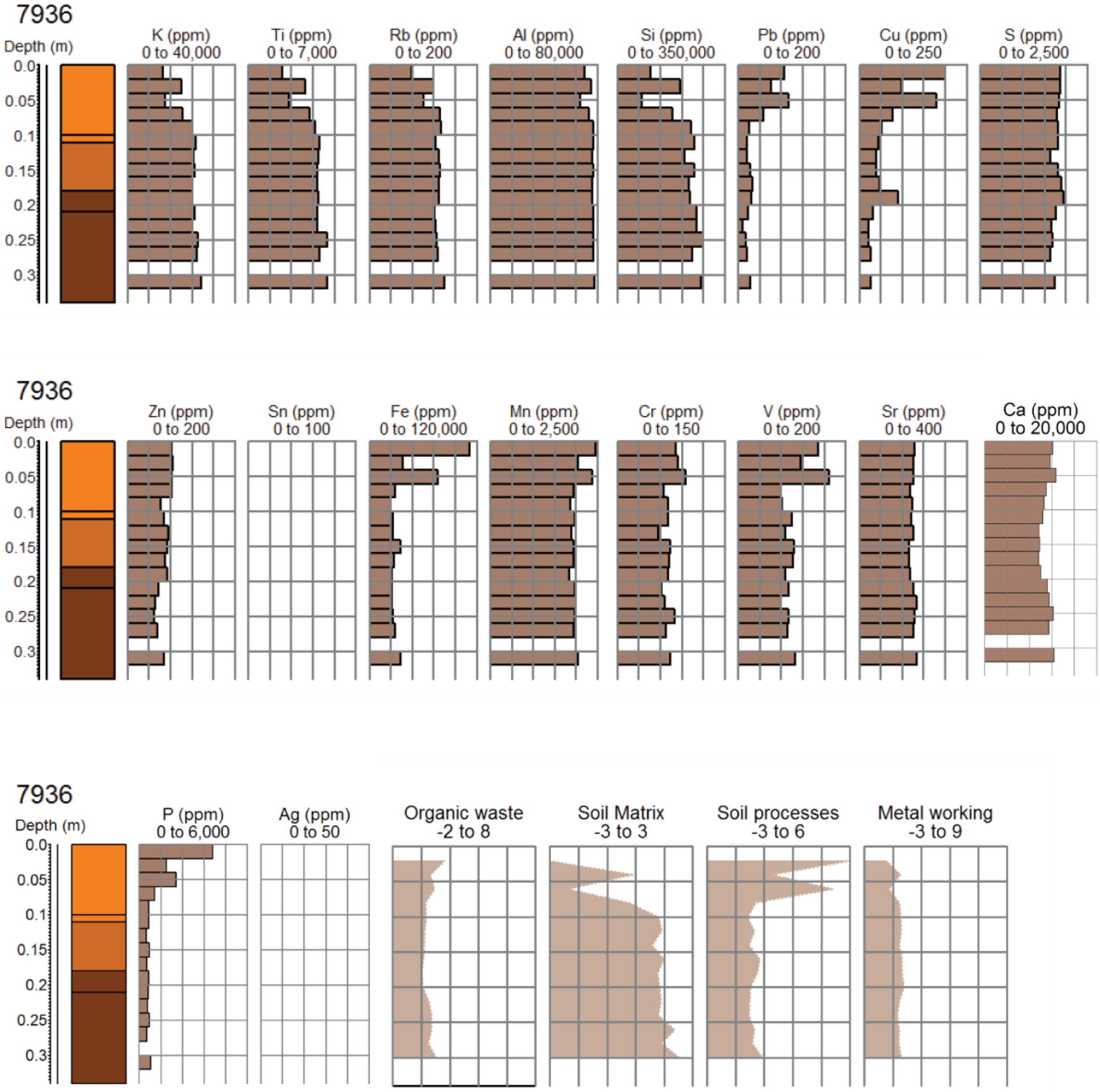

Figure 6.16. Core 7936, stratigraphy and geochemistry. The final four graphs are the interpreted results from PCA for the archaeological contexts only.

Interpretation of parcel 1

The contexts change over short distances, as do the depths of the ditches, meaning extrapolating out from one core is flawed. Interpretation must be on generalities, and there are general similarities in the cores near the thoroughfare. The upper contexts are rich in metalworking and organic waste, and affected by in-washing or flooding in the form of silting and higher energy sand rich deposits. Fine sand and silt sediments from flooding cause a peak in the soil processes component, and a corresponding decrease in the soil matrix factor. Flooding has reworked and washed-in some of the material found in the parcel ditches. Three cores show clear indications, from sharp interfaces and abrupt changes in stratigraphy and intensity of occupation, for the ditches being re-dug. Whether this was a repeated phenomenon is difficult to conclude, but it occurred at least once. In contrast, the core on the south side of the parcel ditch does not show the same degree of waste material accumulating; however, it was also affected by flooding in context 7937/2. The base of this context could also indicate re-cutting of the ditch, in a similar stratigraphic location to the other cores from parcel 1, although flood deposits have partly obscured this. Tentatively then, it appears the whole ditch was re-dug, and only the later phases can be associated with metalworking and intense occupation waste.

6.6.2 Parcels 2 and 21

Above, parcel 1 was interpreted in some detail to give a general impression of the commonalities and variation within the core data. Space is not unlimited; therefore not every parcel and core will be subject to the same scrutiny. All cores are, of course, presented in Appendix 2, and the following text will consider each sampled parcel in turn, on a more general level.

The larger, N-S orientated parcel 2 abutted the thoroughfare on its southern edge, extending back some 11.8 m, the width some 8.7 m (see figure 6.17). The enclosed parcel could well be part of a larger plot, stretching back from the road, and the area cored merely a division within this for a building foundation or similar. The parcel was cut on the eastern side by a later parallel ditch. This could represent a re-cutting of the parcel, once older ditches were either silted up, to meet additional drainage purposes, or to redefine the parcel at a slightly greater width. Additionally, the parcel ditch has two extensions that continued beyond the limits of excavation. One extension continued N from the western side of the parcel, whilst a second, also on the western side, continued parallel to and beside the thoroughfare. This second section was only partly excavated, stopping at a feature interpreted as a possible oven. This feature was sampled, and the results presented within this section. These two extensions are located in parcel 21, which shares a common ditch course with parcel 2.

Additionally, immediately north-east of the parcel was a large circular feature, which upon partial excavation was interpreted as a well, near 2.2 m in diameter. This well did not form part of this data set, however provided additional comparative data.

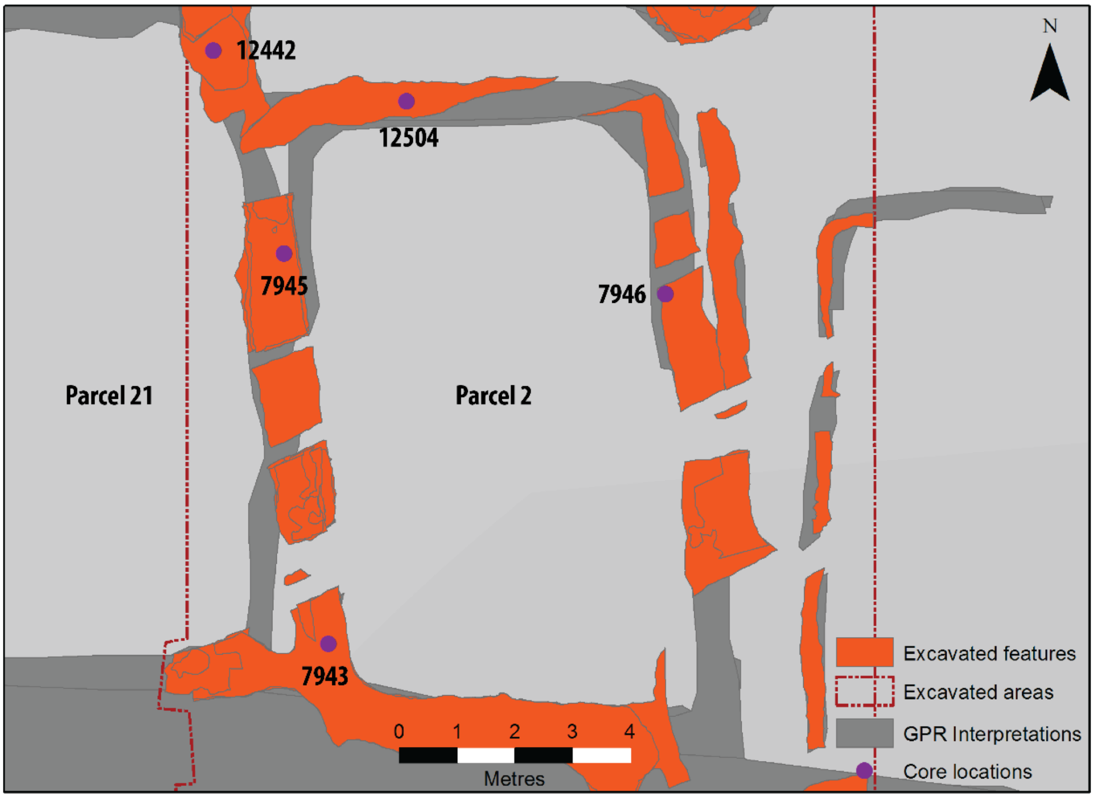

Figure 6.17. The parcel ditches identified via GPR and excavation for parcel 2 and 21. The core locations are marked and labelled. Map source: Author/GOREV/Norwegian Mapping Authority 2016

Core 7943

This core was taken in the southern part of the parcel ditch, close to the thoroughfare. Five contexts were identified in the 35 cm long core, with the interface at 29 cm possibly representing the base of the ditch cut, however the final context was too dry upon analysis for confident interpretation. Sections cut and recorded nearby (sections 10502 and 104898) have similar depths, increasingly the likelihood that the core represents all preserved archaeological stratigraphy.

The upper context, 7943/1 was 7 cm thick, and more porous than the other parcel ditch backfills in similar cores, and with a texture more reminiscent of topsoil than other cored contexts. The sharp lower interface led to a context with in-washed and disturbed anthropogenic material. The context below was similar in anthropogenic inputs; however, it was compact and sharply defined as a dump. The lowest context has decreasing anthropogenic inclusions, as with other cores.

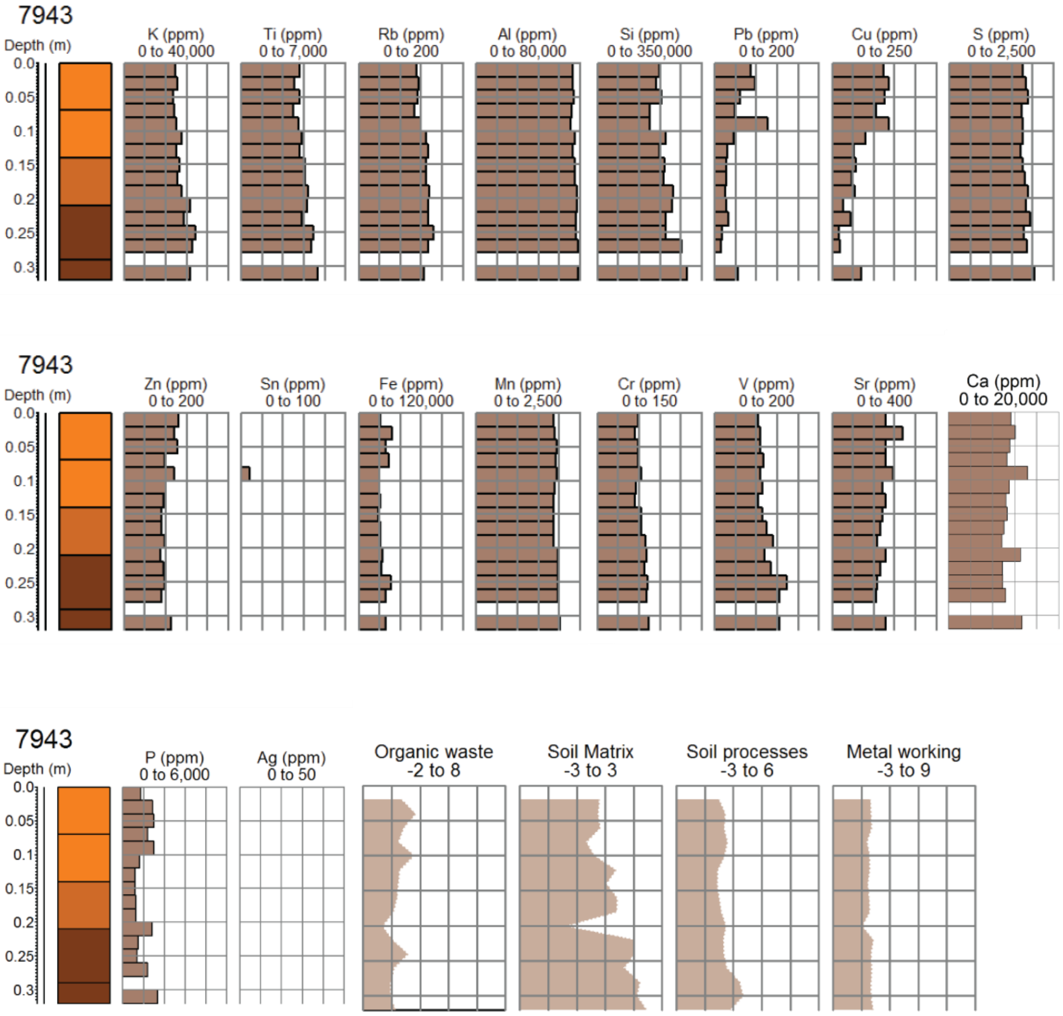

Figure 6.18. Core 7943, stratigraphy and geochemistry. The final four graphs are the interpreted results from PCA for the archaeological contexts only.

Geochemical data

A similar pattern can be observed to the cores taken across the thoroughfare. Organic waste increases throughout, and only the upper contexts contain metalworking waste (figure 6.18). Strontium and P values increase accordingly, as do Pb and Cu. The stratigraphy has accumulated through dumping, in-washing and slow accumulation, displaying increasingly intense occupation inputs.

Cores 7945 and 7946

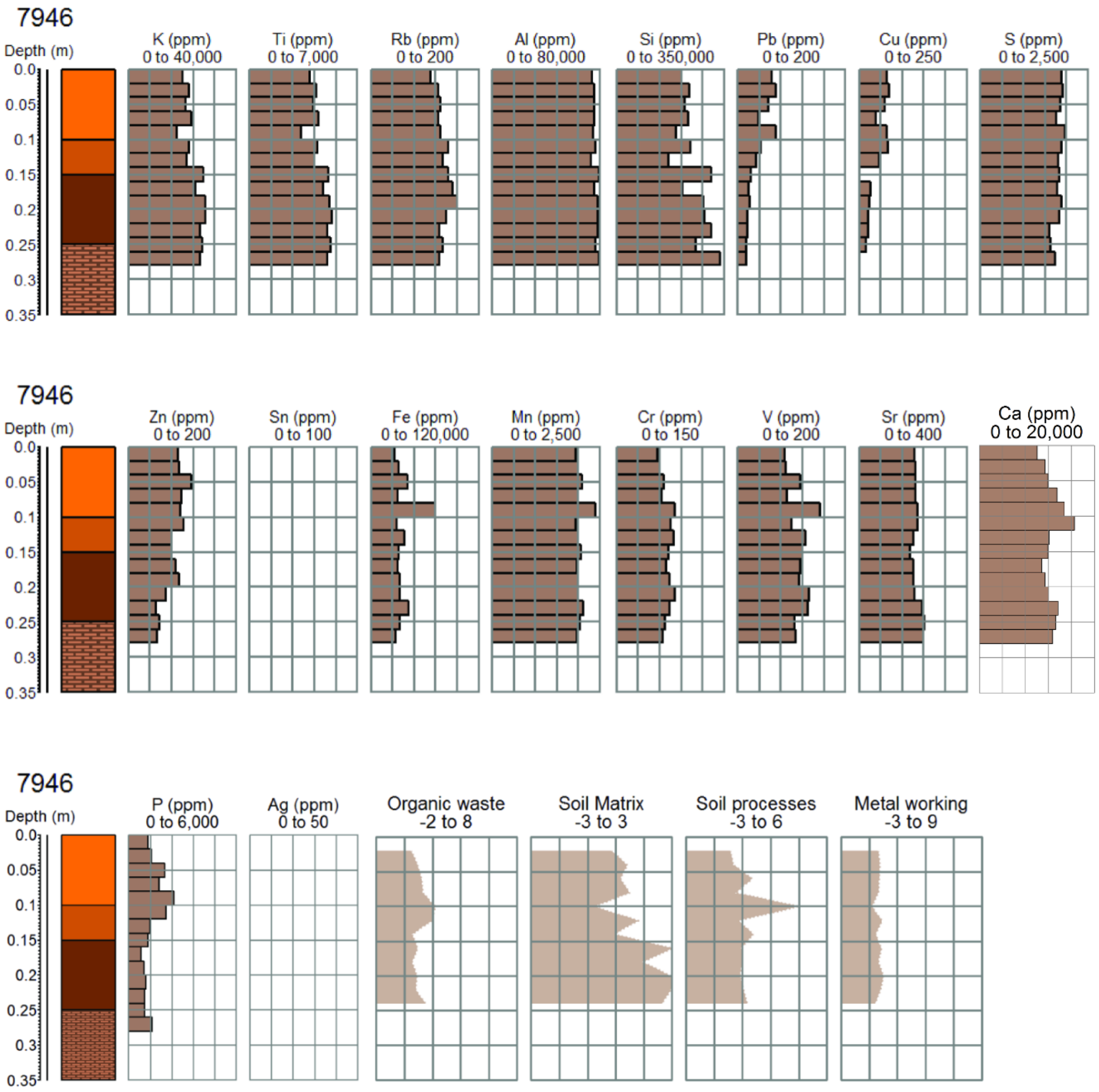

Figure 6.19. Core 7946, stratigraphy and geochemistry. The final four graphs are the interpreted results from PCA for the archaeological contexts only.

These cores are presented together as they are highly similar in geochemical results and overall stratigraphy. Core 7495 (illustrated in Appendix 2), has the lowest levels of P, Pb, and Cu for this parcel. The core contained clear evidence for re-cutting in the form of an abrupt sloping boundary, and the upper contexts again contained evidence of silting and in-washing of sediment from lower energy events. The material appeared to be both from dumps of material, and gradual accumulation.

Core 7946, illustrated in figure 6.19, has higher levels of organic waste. In light of the general trend in the previously illustrated cores that soil processes increase with in-washed material, as the organic waste and soil processes peak in the same context, it appears some of this organic material has accumulated from nearby rather than being dumped. Levels for metalworking are similar to other cores, if not a little lower.

Cores 12442 and 12504

These cores have a slightly different pattern. The upper context in 12504 (see Appendix 2) is a heterogeneous mix of in-filling and accumulation, including coarser sand grains and gravels, with a lower anthropogenic influence. The second context is possibly a mixed dump or rapid accumulation of waste from human activity. The geochemical levels are comparatively low.

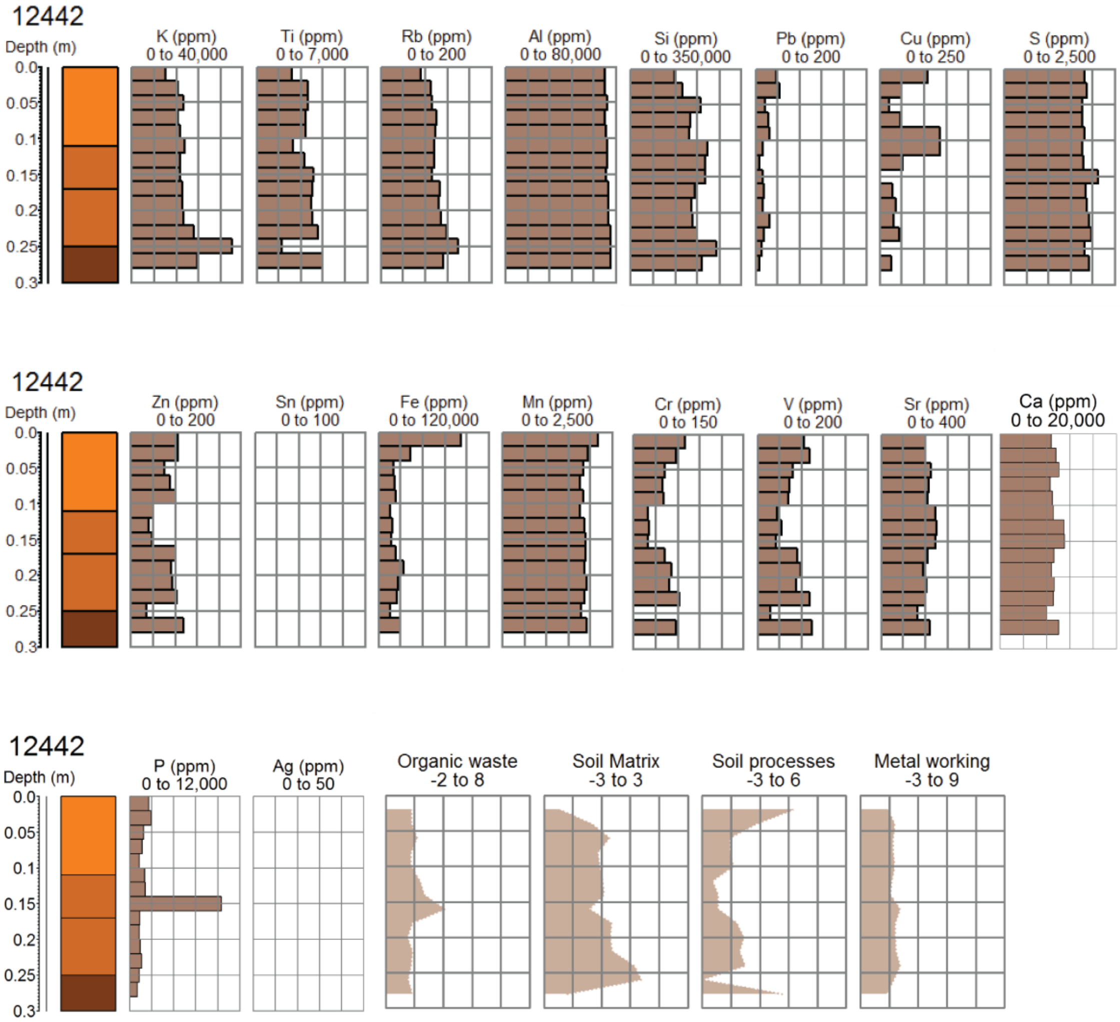

Figure 6.20. Core 12442, stratigraphy and geochemistry. The final four graphs are the interpreted results from PCA for the archaeological contexts only. Do note the different scale for P.

Core 12442, in parcel 21, had two distinct upper contexts (figure 6.20). The upper contains four very fine metal fragments, which were possibly silver or copper alloy, clustered together with burnt clay and charcoal in the upmost 5 cm of the context. In the lower 6-11 cm, there was a dump that included a charred seed, charcoal, burnt bone and a small sandstone fragment with a vitreous coating. The geochemistry also shows a sharp increase in Cu in the centre of the context, and there are notable increases in Cr, V, and Fe toward the top. These elements are associated with soil processes, rather than metalworking per-se. This suggests that either the metalworking waste is local or insubstantial compared to overall trends, or the metalworking input affects the mobility and form of Fe and associated minerals.

The context below, with greatly elevated P (note scale difference in figure 6.20), was a layered mix of coarser grained in-washed and silting deposits and organic lenses, possibility presenting repeated wet conditions over a period of time. The layering continues into the third context, however the matrix is finer, and the layers less clear, lower energy, more disturbed and slightly less anthropogenic.

6.6.3 Parcel 6

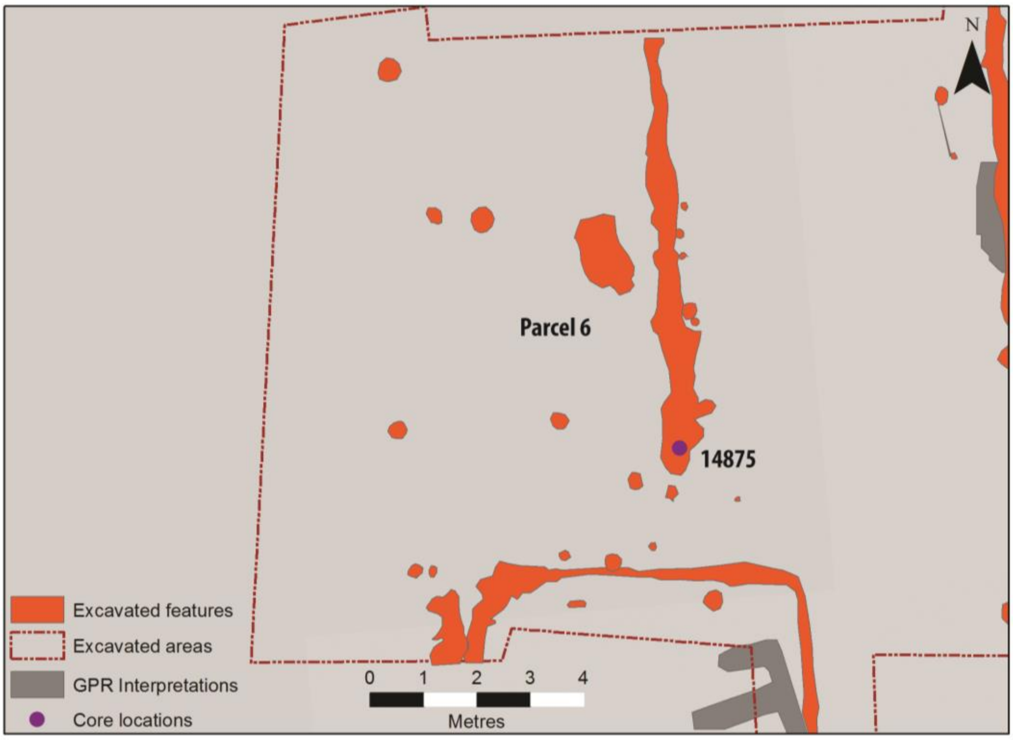

Figure 6. 21. The parcel ditches identified via GPR and excavation for 6. The core locations are marked and labelled. Map source: Author/GOREV/Norwegian Mapping Authority 2016

The parcel ditch is located on the sand bar area, where the ground rises slightly and the upper strata becomes laminated and layered sorted sand. The soils are fast draining arenosols, creating markedly different preservation conditions to the lower lying hydromorphic clay silt soils. Only one section of the parcel ditch remains, and the varied width exposed in plan suggests this is the base of a highly truncated feature. The visible backfill of the feature was sandy silt, with a few fine charcoal flecks. Only one core was taken here, to verify that the deposits were similar from one parcel ditch to the next. There were broad similarities to cores in the labyrinth area (see parcels 9-14, below), but here only a few centimetres remained. These contained moderately elevated P and Cu, for example, although there was some evidence of leaching into the upper substrate. This, of course, is unsurprising in the coarser grained, faster draining soil in the sand bar area. As one core cannot represent a parcel, no detailed interpretation of this parcel is possible, and the geochemical data is used only to contribute toward the overall data set. Therefore the data was included to improve the overall understanding of the site, rather than the individual parcel.

6.6.4 Parcels 9 to 14

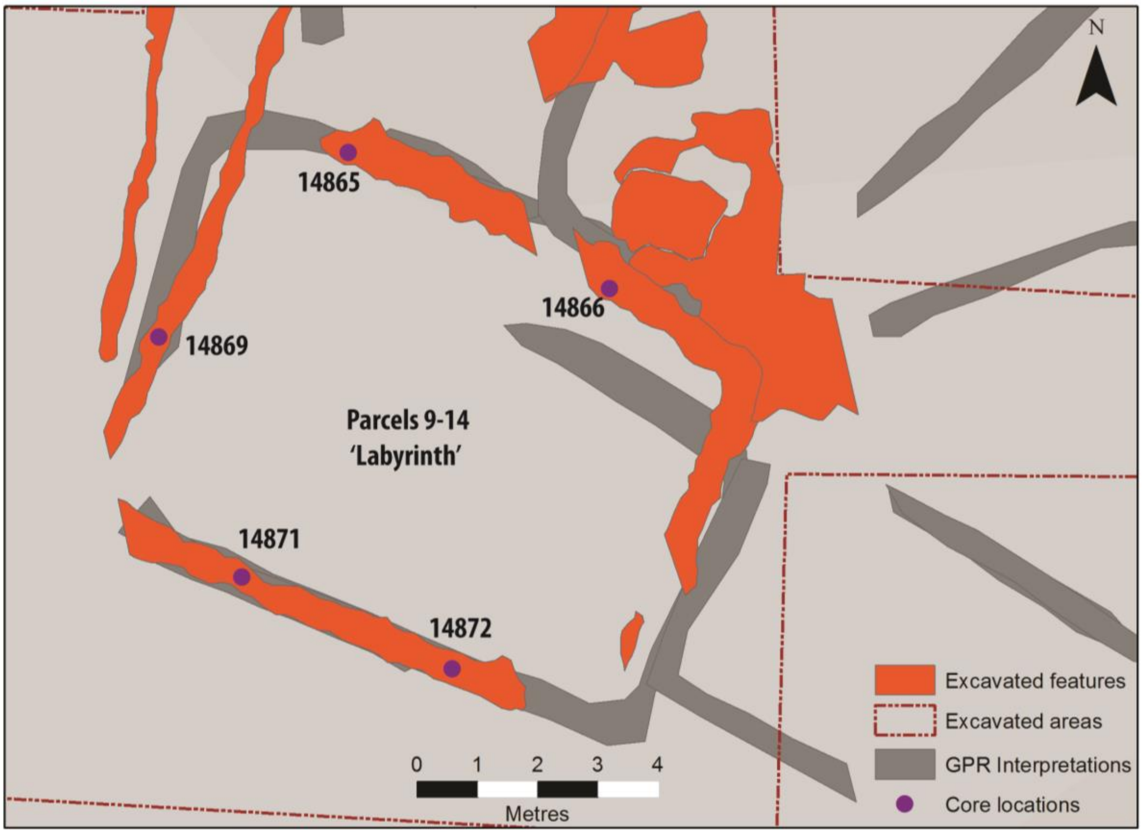

Figure 6. 22. The parcel ditches identified via GPR and excavation for parcels 9-14. The core locations are marked and labelled. Map source: Author/GOREV/Norwegian Mapping Authority 2016

Also located on the sand bar, this parcel complex marks the eastern-most parcelled area. As the land rises slightly over the sand bar, the thoroughfare in the GPR data vanishes. However, by projecting along and beyond its course, it is heading toward this cluster of parcel ditches and whatever once stood there. There is no discernible front or back to the plot, only that the road leads to it from the west, and to the east a possible harbour area was identified. From the north eastern corner of the parcel, a preserved archaeological context spread north and east, and thickened over the sloping ground down toward the harbour and former river mouth. Overlapping cores 13866 and 13867 confirmed a thickening occupation and colluvial deposit over the slope toward the former river course (cores described in Appendix 2). Within the parcel, there is no geochemical data available from core 14866, and therefore the summary below refers to the four other cores named in figure 6.22.

Cores 14869 and 14671 are shallower than the other cores, with 16 and 18 cm of archaeological contexts preserved, respectively. As can be seen from figure 6.22, there are multiple ditches, suggesting the parcel has been recut, each time re-orientating or expanding the parcel slightly, and it appears that core 14869 is in a parcel ditch that is stratigraphically later. The lower contexts for cores 14869 and 14871 are very similar, being silty clay with intense, clustered ferrous mottles and coatings in channels and voids. Organic inputs dominate the archaeological contexts, with Cu levels being broadly comparable to other parcels, slightly under the mean (105.3 ppm), although the Pb levels are well below the mean (84.49 ppm) at 21.64 ppm or less. In contrast, the P values for the upper context are almost exclusively above the mean (1,759.56 ppm), and up to 4,710.24 ppm. This is reflected in the PCA results, with the principal component representing organic waste enhanced here (figure 6.23).

Similarly, core 14865 has below mean levels of Cu and Pb. The core possibly did not reach the base of the ditch, although below 24 cm there was little anthropogenic impact in the ditch sediment backfill. There also appears to be some geochemical change in deposits which was not observed in the core stratigraphy. Around 6 cm, Mn, P and Ca increase markedly. The P levels are the highest measured on the site, the maximum being 12,559.64 ppm at 6 cm depth (see figure 6.23). Calcium, and subsequently Sr also peak in this core, although higher values are recorded in core 7938 near a burnt bone or hearth waste. Burnt bone was also observed in core 14865. Core 14872 continues this trend, although with slightly lower P levels.

It is worth noting that the south west corner of the ditch complex is cut by a drainage ditch; there is no known opening in the parcel. Where activity was focused cannot be asserted as geochemical data is not available for core 14866. The occupation layer preserved here, and the geochemical data from cores 14865, 14869 and 14871 suggest intense organic inputs. There is no reason to believe preservation more favourable in this parcel compared to the more western parcels; in fact the opposite is the case. The 'labyrinth' is located on a high point in the terrain, on sandy soils that are easily eroded by the plough, and naturally have a lesser propensity for the retention and preservation of organic material. Therefore the enhancement is assumed to be real and archaeological, rather than a product of modern conditions.

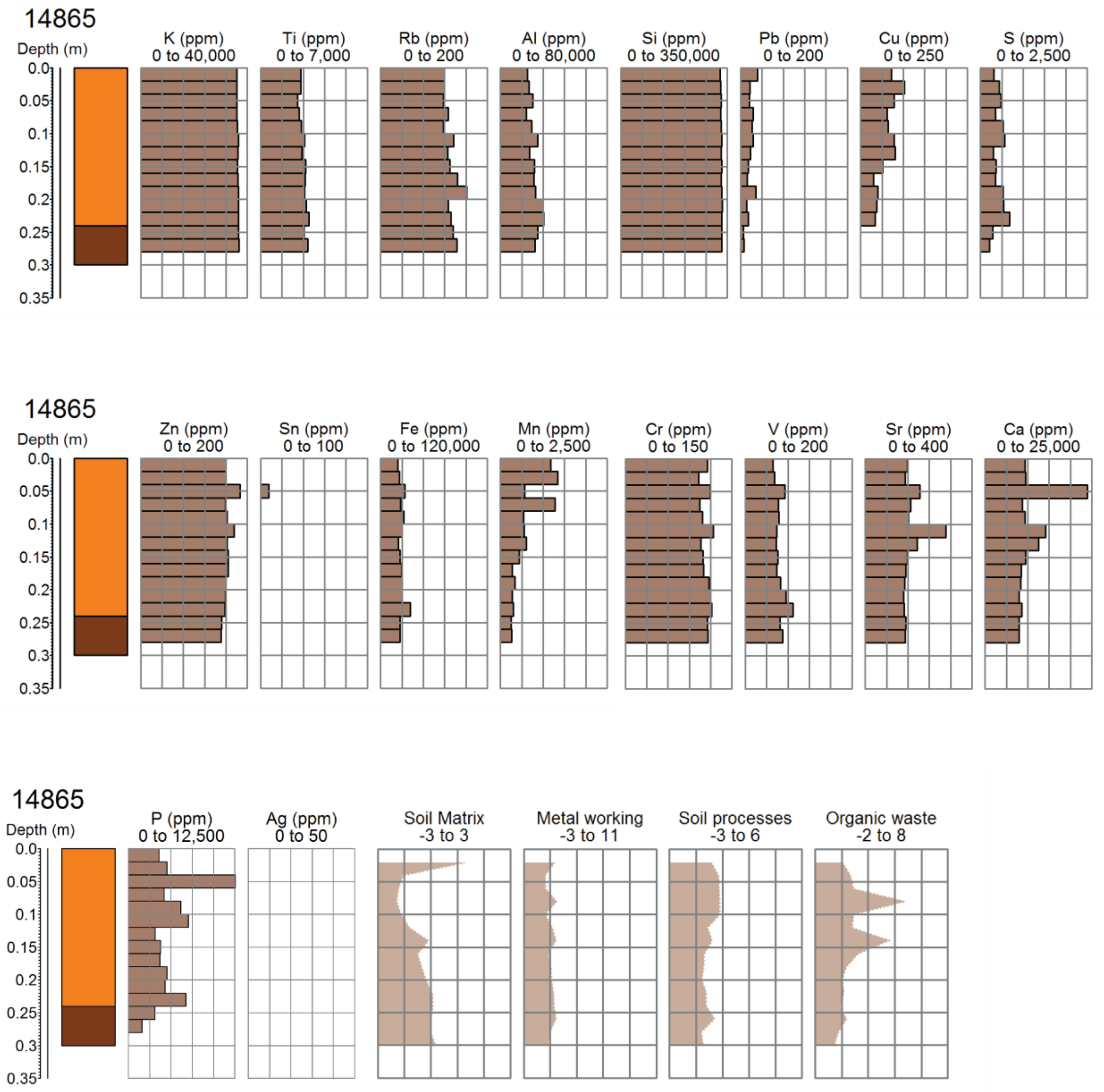

Figure 6. 23. Core 14865, stratigraphy and geochemistry. The final four graphs are the interpreted results from PCA for the archaeological contexts only. Do note the different scale for P and Ca.

6.6.5 Parcel 16

This parcel was not excavated, save for a small area of less than 1 m^2 which was exposed and recorded during topsoil sieving. All cores were taken from the topsoil, as described in chapter 4. Preservation here was poor; most surviving archaeological layers are 10 cm or less in thickness and being rapidly truncated further by the plough, as testified by the generally higher metal values in the lower plough soil than the archaeological contexts. The parcelled area clearly is multi-phase, the dimensions either expanded or contracted at one time, plus the additional curling ditch that crosses diagonally over the parcel should pre- or post- date the occupation of the parcelled area. Despite the fact that in figure 6.24 it appears that some ditches cut, or overlie, others, this is purely a product of ArcMap 10.2 software creating outlines around polygons. As these are GPR interpretations only, the relative sequence is unknown.

Firstly, the diagonal ditch, which core 14821 targeted, was found to be preserved as an 11 cm thick sediment with few signs of anthropogenic inputs, although the structure was clearly disturbed. A sand lens present was probably in-washed after a precipitation event or flooding, which split the core. Levels for non-ferrous metalworking were low in the archaeological layers; that said, more unusually, there was Sn and levels of Pb and Cu above the mean in the topsoil of the core. This point is returned to below.

Moving to the northern end of the parcel, levels for non-ferrous metalworking were higher in the topsoil to 14807 than in the preserved archaeology. The reverse is true of 14809. Overall, the P levels are higher in 14807, but again, the difference is slight. Therefore suggesting which is the elder remains impossible. Logically, as the cumulative knowledge from the cores and the other data sources (see section 6.7) suggest the site became more intensely used and occupied, it would be rational to think of the parcel expanding, thus the smaller parcel represented by core 14809 being the older, but that cannot be confirmed.

High levels of P were found in core 14823 (figure 6.26), as well as above average levels of non-ferrous metals within the archaeological layers. The preservation was a little better on the east side of the parcel compared to the west. The three cores on the western side, 14813, 14815 and 14819, were more truncated, leaving 8 cm of archaeological deposits in core 14813, 10 cm in 14815 and 4 cm in 14819. Core 14815 contained fine laminations of clay silt, again suggesting gradual accumulation was the norm, whilst the upper part of the context, with low but sharp and parallel increases in Sn, Cu and Pb suggest waste dumping. As the ditch is 10 cm deep at core 14815, the gap in the parcel circumference where it is not visible in the GPR data could simply be a product of preservation, a further indication that the site is close to be eroded away.

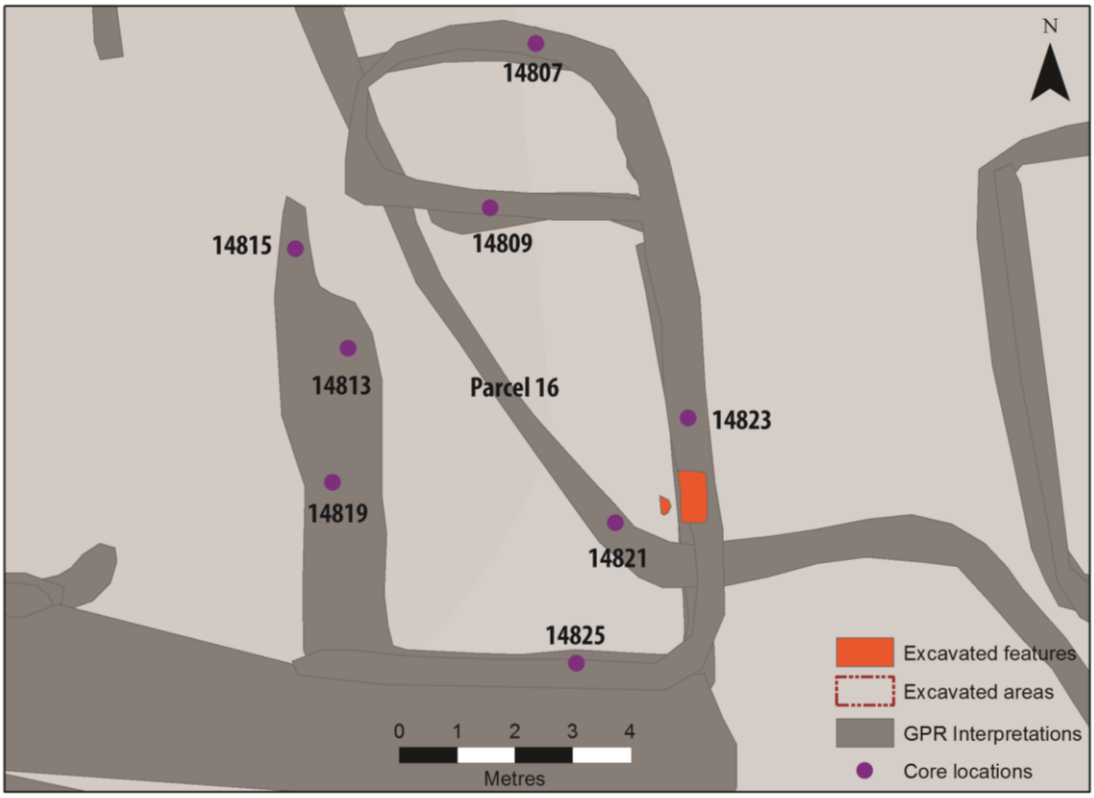

Figure 6. 24. The parcel ditches identified via GPR and excavation for parcel 6. The core locations are marked and labelled. Map source: Author/GOREV/Norwegian Mapping Authority 2016.

Core 14825 is a little extraordinary, and will be considered in a little more detail. To begin, in figure 6.27, the scales for Cu and Pb are far greater than in the other core diagrams, and P is also increased. Measured values of Pb, Cu, Sn, Zn, P and S are all well above the mean. Silver was also found in low amounts. In the 10 cm of preserved archaeology, non-ferrous metals are abundant. Observed in the core were very fine sand lenses, burnt bone, burnt clay, charcoal and inclusions of pale silty clay, intrusive from a different sediment. The geochemistry and the little information gleaned from the core suggest the layers in the core are comparable to the oven type feature found in parcel 21, which is considered in section 6.6.6.

The majority of cores from parcel 16 display some above mean levels of non-ferrous metals and the elevated values in the topsoil suggest this metalworking detected in core 14825 is being drawn into the plough layers. That core 14821 has low levels of metals compared to the other cores could indicate the diagonal ditch crossing the parcel is the older feature, with the rectangular parcel supplanting the earlier ditch alignment. The earlier feature does not appear to align to the road either, again suggesting an earlier date and phase.

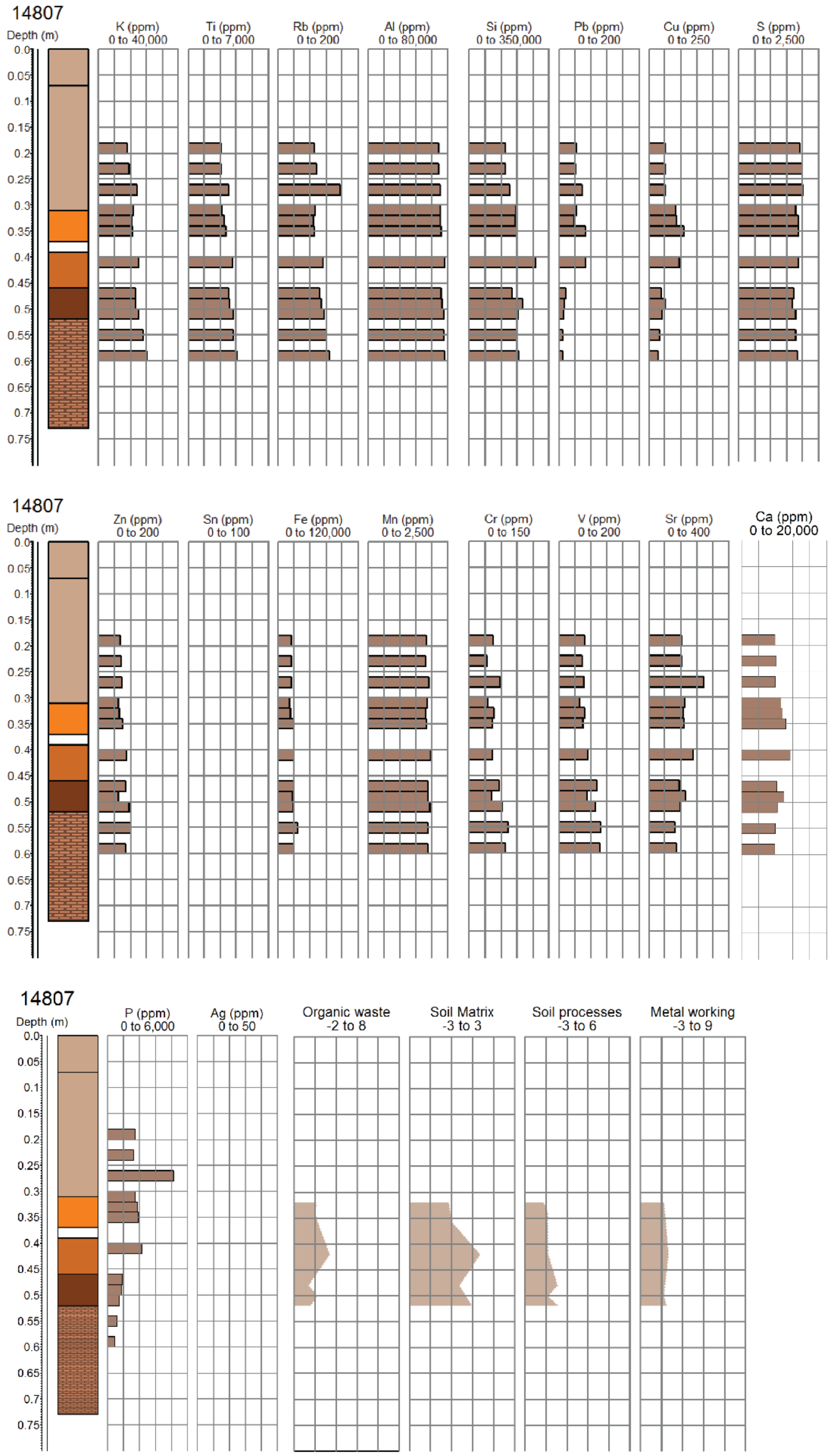

Figure 6. 25. Core 14807, stratigraphy and geochemistry. The final four graphs are the interpreted results from PCA for the archaeological contexts only.

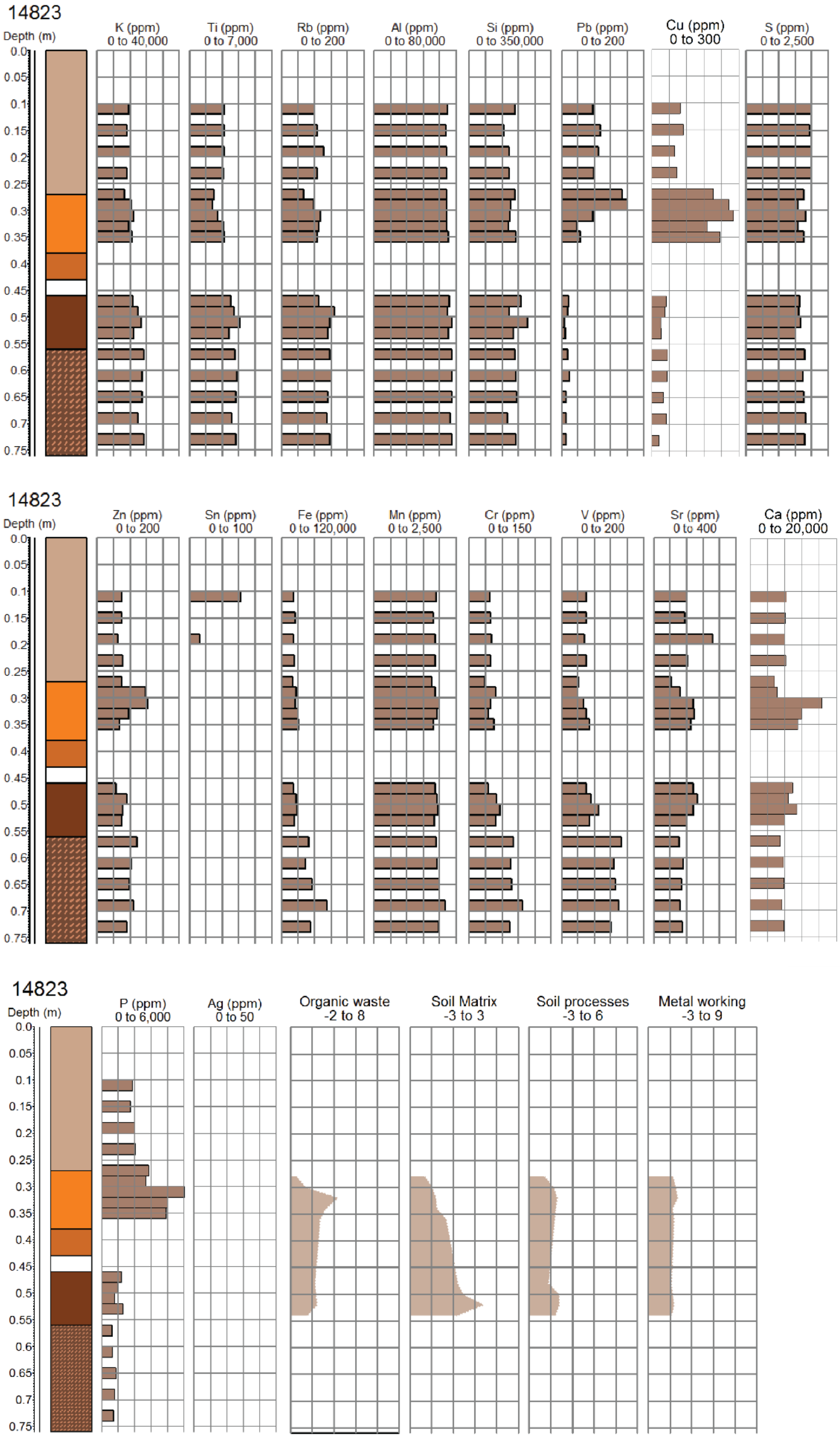

Figure 6. 26. Core 14823, stratigraphy and geochemistry. The final four graphs are the interpreted results from PCA for the archaeological contexts only.

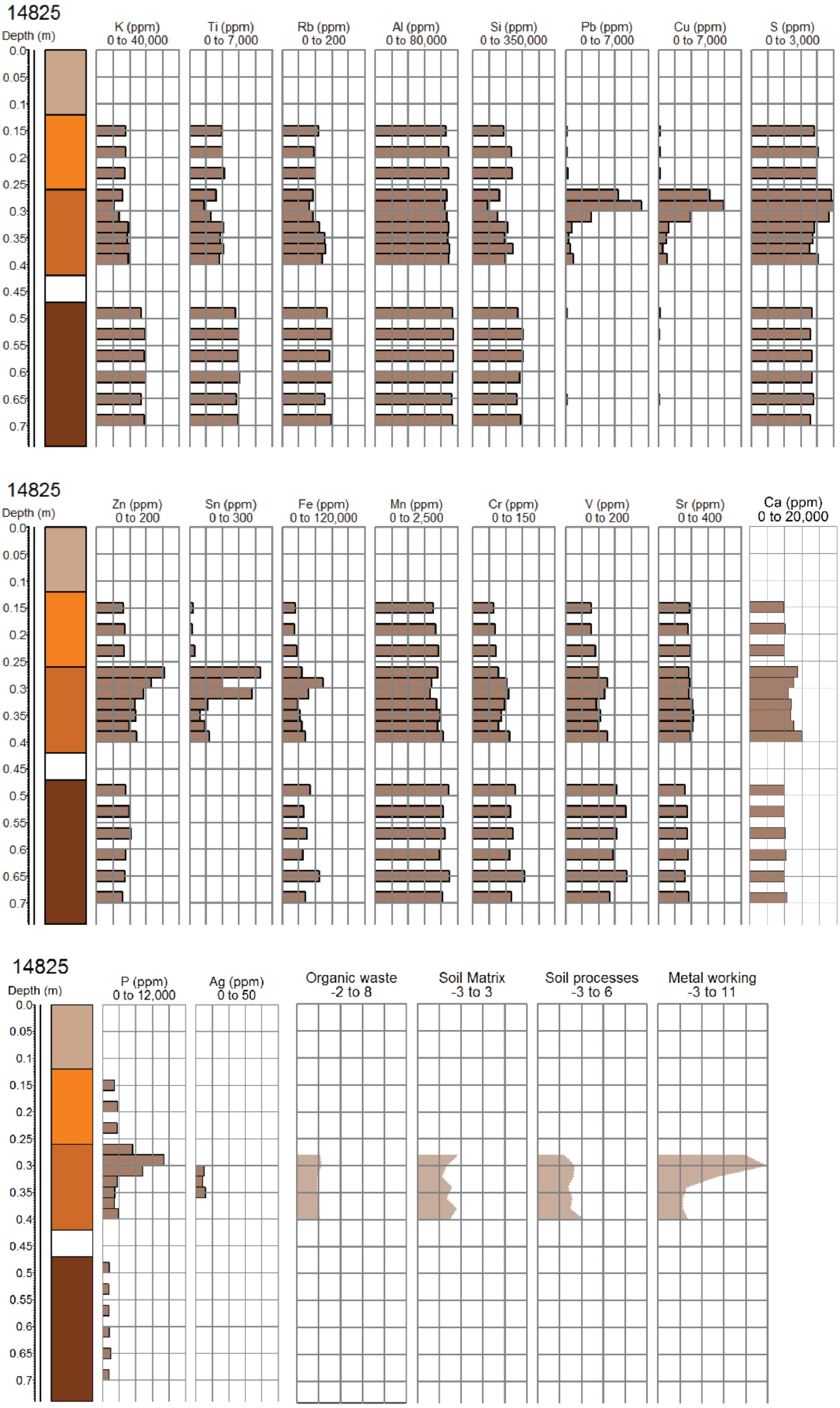

Figure 6. 27. Core 14825, stratigraphy and geochemistry. The final four graphs are the interpreted results from PCA for the archaeological contexts only.

6.6.6. Other sampled areas

This section details additional areas that were sampled, however the data was not included in the statistical analysis, or used to provide weight to interpretations of the parcel ditches.

Parcel 3

This parcel was cored in a similar manner to parcel 16. The cores were described and analysed, however the pXRF data was unfortunately lost, together with the data for core 14866. The appendix therefore contains core descriptions of these cores (see Appendix 2), however the lack of chemical data limits the use of the data set. Whilst there is no indication of metalworking, and the ditches were shallower with backfills that appeared less effected by intense anthropogenic inputs, these observations cannot carry equal weight in overall interpretations.

Parcels 17-20

This area was cored at a later date to the others, in an attempt to expand the potential range of activities represented, and see if different areas of the site were indeed used for different purposes over the active settlement of the site. However, cores taken in these three parcels revealed highly truncated deposits. In many cases, but a few centimetres remained of the parcel backfills. Other cores appeared disturbed by drainage ditches, to the extent that the stratigraphy was upturned. Therefore the few available sample points were not deemed to be representative enough of each parcel, and the data were not used for statistical analysis. Core descriptions of selected cores from this area can be found in Appendix 2.

Oven feature in parcel 21

Feature 12263 was exposed in plan in the final few days of the 2012 excavation campaign. This feature was located within the cut of a parcel ditch beside the thoroughfare. It was speculated to be the remains of a small oven for heating crucibles, although all that remained was a heat-effected clay base. Surrounding this was packed clay and a charcoal rich layer with burnt clay fragments. It was attempted to set out a near regular 20 cm grid over the contexts associated with the feature, however stones within the contexts meant the eventual grid was imperfect. Therefore the sample locations were dictated by opportunity, and the area covered was defined by the limits of excavation rather than the extent of the layer. They are not ideal, but the coverage of the relevant contexts was deemed sufficient to warrant analysis in order to help interpretations of the feature's purpose. The samples were taken and analysed as described in chapter 4.

Figure 6. 28. Photograph of feature 12263 after sampling and partial excavation: Interpreted as a possible oven, in parcel ditch 21. Scale is 30 cm. Photo: GOREV/MCH.

The feature was not excavated further than figure 6.28 indicates, due to time constraints, and once the field campaign ended for 2012, it was covered and backfilled.

The data produced from the 20 samples was not included in statistical analysis with the pXRF core data, as the samples were not comparable in terms of collection, analytical error and representativeness. As there are only 20 samples, they are not suitable for the majority of average based statistical testing. Instead, the data was considered spatially to evaluate the interpretation it was an oven for non-ferrous metalworking. Immediately apparent was the high levels of non-ferrous metals, including Ag, which in some samples were higher than those seen from the coring data. For example, core 14825, context 14825/2 had 6,473 ppm Pb, and core 7938, context 7938/2 had 11,556 ppm Pb; the highest values measured in the cores. The samples around the oven had two measured Pb values over 8,000 ppm. Such high values, the measured part of the sample containing 0.6-1.1% Pb, are the exception, and they are indicative of the type of waste remaining. Whilst a direct correlation cannot be made been measured values and the intensity or duration of previous activities, such high values indicate selected areas of the site do contain high levels of waste from non-ferrous metalworking. Furthering this, the patterning of the elements and the contextual information do not suggest a dump of mixed material, but the remains of in situ working.

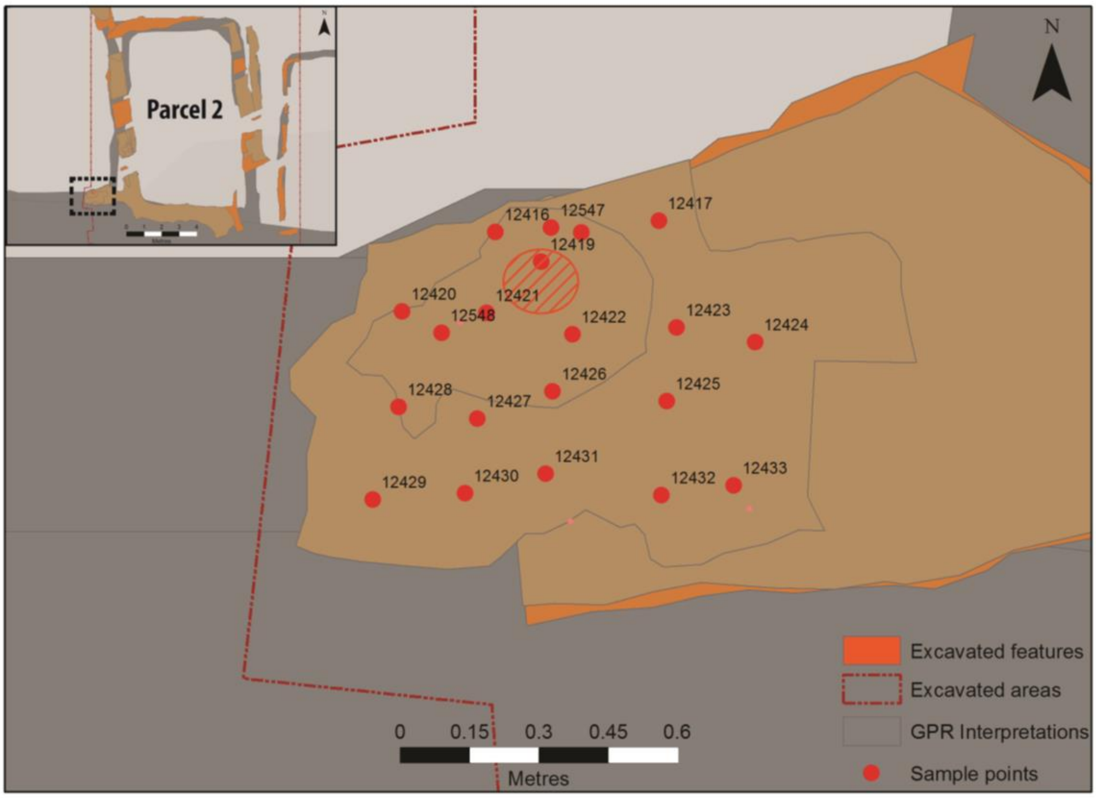

Figure 6. 29. Samples taken in the 'oven' area, feature 12263, located in parcel ditch 21. The rough form of the oven is shown in hatched orange. Map source: Author/GOREV/ Norwegian Mapping Authority 2016.

Kriging and Cokriging using ArcGIS 10.2 Geospatial Analyst were used to create a predictive model based upon the sample points, as contextually they were deemed comparable. Cokriging is used where one dominant element is assumed to be correlated with elements of lower concentrations, and the dominant element is used to reinforce and predict the distribution of the lesser elements. Here, Pb dominates, with Ag and Sn in far lower amounts. Interestingly, however, when kriging alone (ordinary, simple) is used per element, the predictive model is highly similar to the one presented in figure 6.30. The measured values for elements commonly associated with non-ferrous metalworking, and identified through the PCA analysis on the cores, produce distinct, and similar, spatial patterning. In contrast, when spatially analysed in the same manner, P and Ca show a random distribution, indicating the sources of these elements were not used and deposited in the same manner. This suggests that the distribution of elements associated with non-ferrous metalworking, Pb, Ag, Cu, Zn and Sn, can be attributed to the use of the oven for metalworking. Furthering this, S, which has a strong affinity with metals such as Ag and Pb for retention in the soil, has a very similar distribution. This fits well with the correlation noted in the core data between non-ferrous metals and S. The concentration of all the named elements to the east of the burnt clay oven, could represent the focus of the smiths' work, with the halos of decreasing amounts of metal from this area suggesting habitual use of the same area as a work focus. It must, however, be stressed that the area to the north was not available for sampling, and therefore the working pattern - as interpreted from the data - remains speculative.

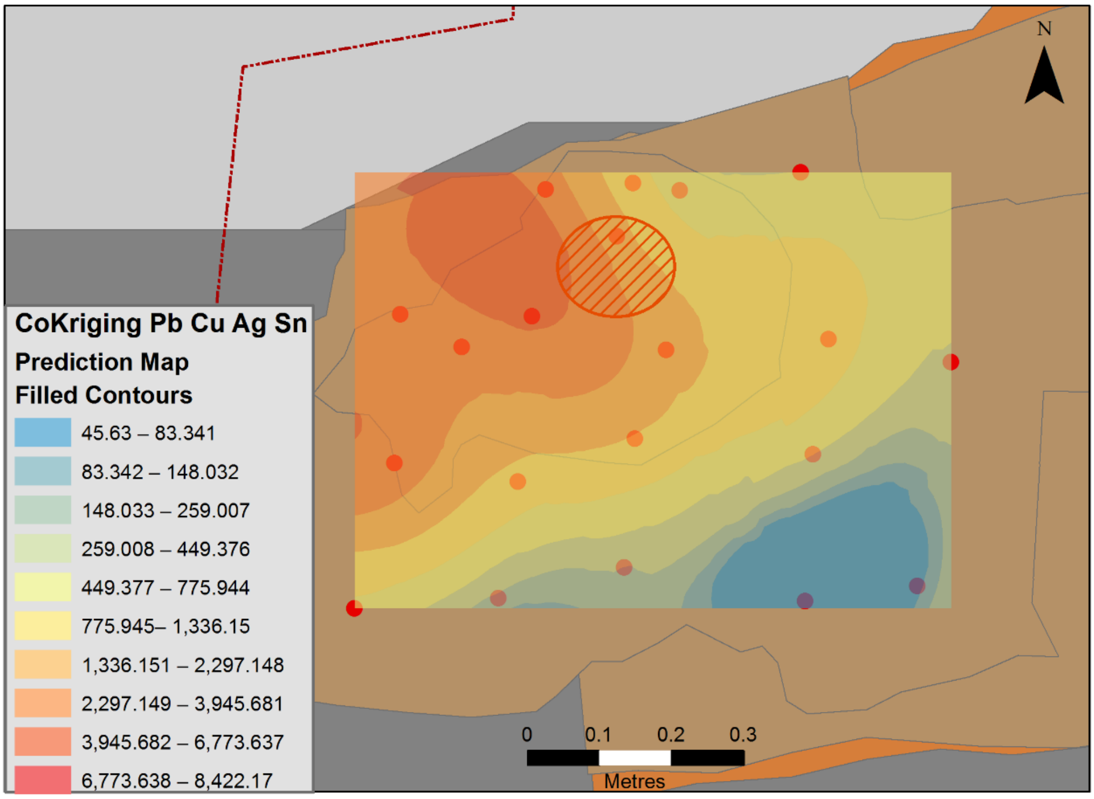

Figure 6.30. Co-kriging to form a predictive model of non-ferrous metals Pb, Cu, Ag and Sn from samples taken near the oven feature 12263. The rough form of the oven is shown in hatched orange. Map source: Author/GOREV/Norwegian Mapping Authority 2016.

6.7 Integration of other data sources

6.7.1. Absolute and relative chronologies

Whilst considering the cores, the assumption that the archaeological layers measured represent the activities that occurred there, is sufficient to form a platform for interpretation. Moving onto time and phase, and the assumption that the deposits are in chronological order, in light of the widespread evidence for ditches being re-dug, this requires some further data. From the excavation, 40 ^{14}C dates have been undertaken to improve the chronological resolution of the preserved phases. The number was necessary to compensate for the rather flat calibration curve in this period, and to abate fears over stratigraphic integrity. The INTCAL 13[1] calibration curve

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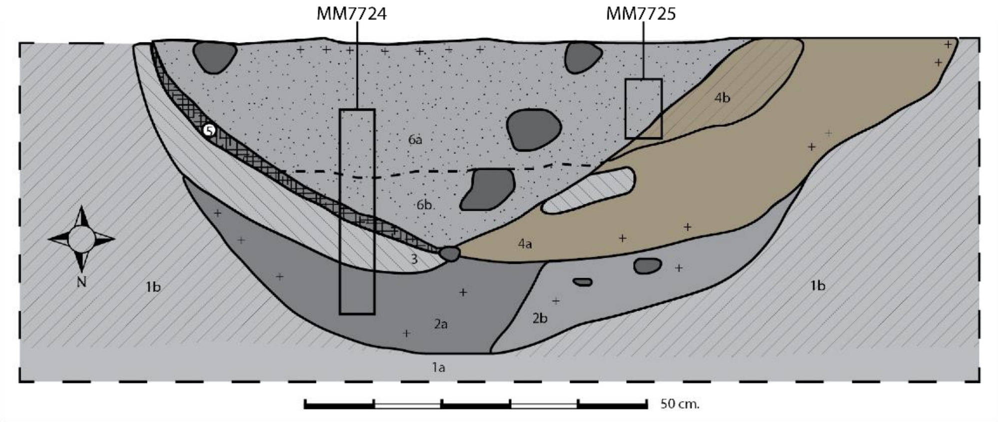
[1] http://www.radiocarbon.org/IntCal13.htm. Accessed 30/11/16.

between AD 775 and 875 is stubbornly level, which inconveniently corresponds to the preserved main occupation phase of the site.

Parcel 2, section 7473, south facing



Layer	Material dated	Calibrated date (3 sigma/95%)
1a Subsoil Bg1, below modern water table. Compact clay silt, gley features.	Not dated	Not dated
1b Subsoil Bg1, above modern water table, slightly oxidated clay silt.		
2a Grey, gleyed compact clay silt. Early phase ditch backfill. Rare wood chippings and charcoal		
2b As 2a, with lighter/less organic matrix.	Corylus avellana (hazel, nut fragment). From seiving layer, unknown stratigraphy.	C58682/135=770-900/920-940 A.D. C58682/153=720-740/765-895 A.D.
3 Re-deposited subsoil material, slump.		
4a Clay silt, compact, Fe mottled, re-worked and re-deposited subsoil. Anthropogenic inclusions.	Corylus avellana	C58685/152= 770-900/925-945 A.D.
4b As 4a, but intense Fe mottling, possibly a wetting front.		
5 Charcoal lens/slump		
6a/b Clay silt with lenses of in-washed silt and fine sand. Few large stones. Charcoal.	6a: Hordeum (barley) Hordeum Corylus avellana 6b: Picea (spruce)	C58682/150A= 895-925/940-1020 A.D. C58682/150B= 775-790/800-980 A.D. C58682/131= 670-780/790-810 A.D. C58682/151= 775-790/800-980 A.D.

Figure 6. 31. Section 7473, parcel 2, with the micromorphology sample points (MM), layer descriptions and dating material. Adapted from figure 21, Rødsrud (2014).

The stratigraphic integrity, according to ^{14}C dates, appears reliable at first glance. However, the date ranges are both too wide to confirm this, and potentially even contradictory (see figure 6.32). Simply by looking at figure 6.31, one can begin to imagine a recut between the boundaries of contexts 2 and 4, which slightly widened the ditch. Context 3, with its dished bottom, is perhaps the older phase. Layer 2, dating from AD 720 to 940, is representative of the earlier phase found in near all cores. Across the site, the first phase is present in the form of less intense anthropogenic inputs at the base of each ditch. Whilst within the realms of possibility, it is unlikely that in every cored and excavated section an even earlier phase has been completely removed, therefore this early phase is assumed to be from the first use of the site. The most likely date range for the early phase of the site is the very late 700's to early 800's, based upon wider finds evidence. The later phases, from radiocarbon dates alone, cannot be distinguished. They all fall within the same two hundred year period, from the mid-8th to the mid-10th centuries. It appears the settlement fell out of use in the latter half of the 10th century. A tighter chronology may be unachievable, even with the aid of relative chronologies.

Items such as beads already established in relative chronological systems, such as Callmer (1977), provide date ranges, as do dirhams and other coinage. On the site as a whole, the majority of the 59 beads date to the later part of the settlement period, the second half of the 9th century and onward. Provenance is for the most part Middle Eastern, including Byzantine glass tube beads and cornelian and rock crystal beads from Caucasus, the Indian sub-continent or Iran. For the low quality, white glass beads, production *may* have been local; however substantial production waste has not been found (Bill and Rødsrud, in press). This could well be due to the strong bias in the finds material toward non-ferrous metals due to the collection method.

Of the coins, the earliest is an Umyyard dirham, minted in AD 710-11 under Caliph Walid AL-N in Wasit, now modern day Iraq. The youngest coins are minted in the first quarter of the 10th century, and are sourced from Afghanistan, Armenia, Uzebekistan, Iran, Iraq and Syria (Bill and Rødsrud, in press). Of the 174 coin fragments found, only three are possibly European. Another artefact type hailing from the East is weights. Many of the 147 found are of lead or copper alloy, with or without iron as a core. The types recorded originate in the Middle East, but they were eventually also produced in Scandinavia (Bill and Rødsrud, in press).

Production waste, such as slags and crucible fragments are of course more local, and demonstrate metal working was occurring on the site. The metals used, and possibly even the fabric for the crucibles were imported (Pedersen, 2016). The source of the metals is a topic for future study, and is not considered here. Small amounts of bullion, hacksilver and ingots were found on the site. Items of jewellery did include some insular fragments, and local products include iron and whetstones (Bill and Rødsrud, in press).

It is clear from the provenance of the objects that the site looked east; goods from the Middle East were being brought to Heimdalsjordet and Gokstad, worked, finished, and/or traded on. This happened over a period of well over one hundred years using the coins, beads and radiocarbon dates as a chronological baseline (Rødsrud, 2014). If we can trust the dates from the lowest stratigraphy, and that the finds from both excavation and topsoil sieving and metal detecting are sufficiently representative, the plots contained generations of occupation and industry. From the four parcels studied here, there appears to be no drastic shift in the use of the plots during their occupation, and the finds distribution (figure 6.32) is too coarse to discuss finds on plot level. From the in situ finds, there are for example, crucible fragments and copper alloy production waste was found in parcel 1 beside the thoroughfare, and gold wire, lead and copper production waste as well as crucible fragments were found in parcel 2. The majority of finds were closer to the road, however, a higher proportion of ditches facing the road were dug compared to the rear of the parcels.

6.7.2. Micromorphology

Micromorphology analysis was conducted by Dr. Richard I. Macphail of University College London for the GOREV project. The results broadly confirm the geochemical data presented here and the excavation records. For example, the first phase of the site, as represented by parcel 2, was characterised by some byre waste, grazing, and low impact activity (Macphail et al., 2014). In addition, the geomorphological setting for the settlement was also detailed, such as the presence of inter-tidal mudflats in the sand bar phase, the complex development of the clay silt substrate, and the land use of the area during the construction of the Gokstad Mound (Macphail, 2012, Macphail et al., 2013, Macphail, 2013, Macphail et al., 2014, Macphail et al., 2016b). Constructed around AD 900, the turves preserved within the mound suggested a landscape dominated by grazing and wet-land pasture, and assuming the turves were local, this provides additional background for the settlement context (Macphail, 2012). Within the parcel ditches, the main occupation phases were characterised by latrine waste, burnt settlement waste from hearths and ovens, burnt and unburnt bones - including fish bones, charcoal and phytoliths. This is occupation waste, as expected. The thoroughfare, whilst difficult to see with the naked eye, did contain organic fragments and phytoliths reminiscent of other trackways. Sediments were covered by dumps, or by high tides and flood washing in sediments, confirming the site's vulnerability. Also confirmed were the high P values and larger amount of charred and uncharred grain in the labyrinth area compared to parcels 1 and 2 (Macphail et al., 2014).

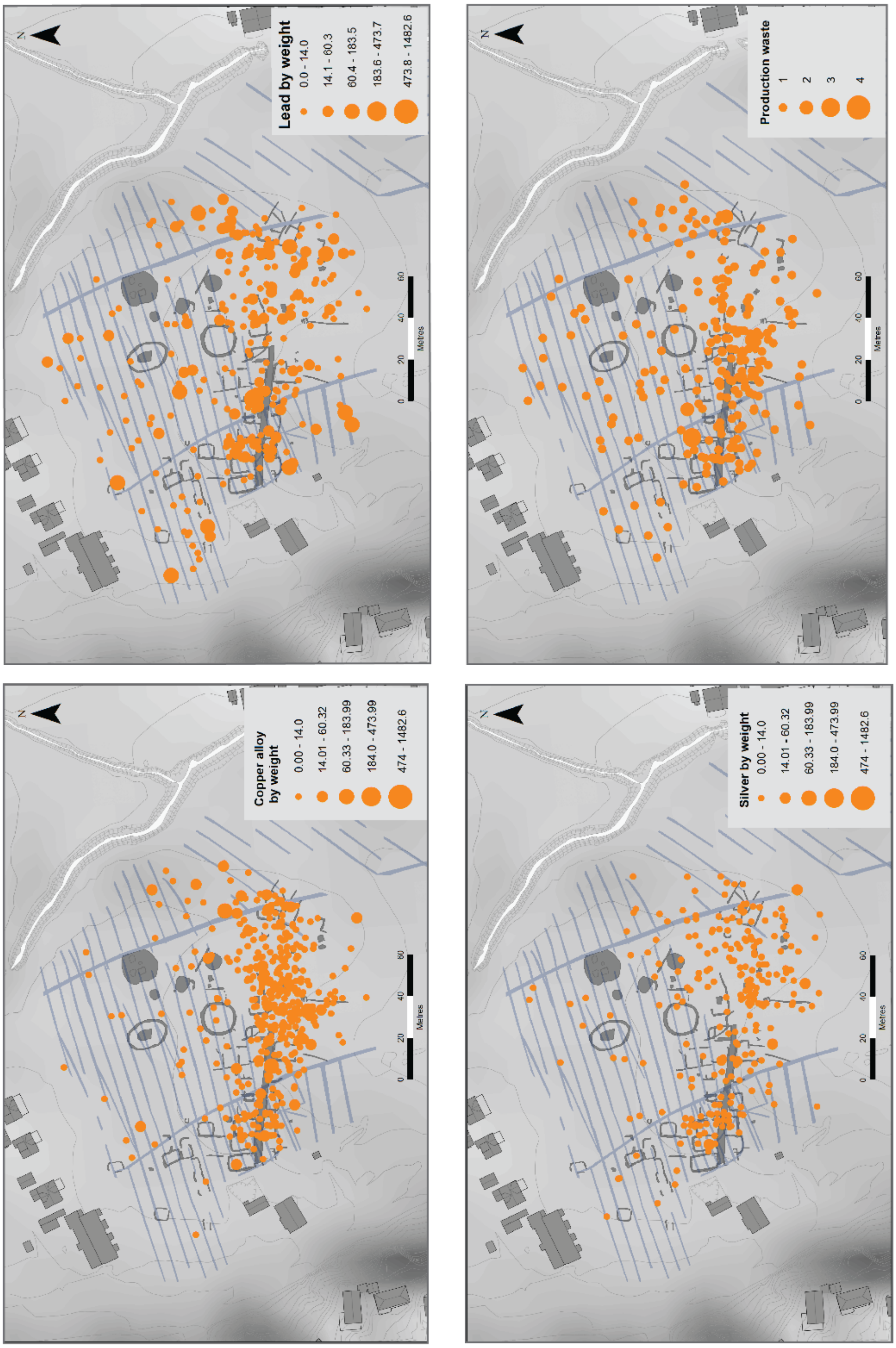


Figure 6. 32. The finds distribution for (clockwise from top left) copper alloy, lead, production waste and silver. Silver, Copper alloys and lead are by weight in grams, production waste is by number of fragments. The data is from GOREV, and is sourced from metal detecting, excavation and topsoil sieving. Map Source: Author/GOREV/Norwegian Mapping Authority 2016.

6.7.3. Artefact distribution

As stated previously, the artefact distribution is biased toward non-ferrous metals, and the durable inorganic objects. Therefore the artefact distribution maps are purely a product of that, and the limited excavation. In addition, as some of the finds material is from metal detecting, undiagnostic pieces are not necessarily from the Viking Age occupation. This applies particularly to lead objects, as they were more frequently nondescript. Even so, they confirm the primacy of the road as a focus for activity, and that metalworking was not concentrated in one parcel alone. The distribution pattern for each of the categories in figure 6.32 is remarkably similar. The prime difference is how many finds are located north of the thoroughfare and into the burial area of the site.

6.8 Discussion

6.8.1 A summary of results

In summary, four of the parcel ditch areas that were cored were used for geochemical analysis. This data set was subjected to PCA to differentiate between past anthropogenic inputs, past and present soil processes, and the soil matrix. The results suggest the parcel ditch backfills are enhanced by organic waste including P and Ca rich material, which is interpreted as bone and other organic waste. This enhancement is general; although there are sharp peaks in enhancement, such as in core 14865, which are interpreted as rubbish dumps.

In addition to the organic waste enhancement, there are more localised enhancements characterised by raised levels of Cu and Pb, and to a lesser extent Sn and Ag. Zinc appears in background and subsoil samples, and is tentatively interpreted as marine sourced (De Vos and Tarvainen, 2006). Anthropogenic inputs in the parcel ditch backfills are modestly enhanced over background levels of Zn, and are interpreted as human inputs without a clear source. Zinc has been associated with bone material and general human occupation (Ottaway and Matthews, 1988, Entwistle et al., 1998). It is clear from the high concentrations and the spatial patterning, that in all likelihood the feature sampled and excavated in parcel ditch 21 is the base of an oven for non-ferrous metalworking. The levels present for C, Pb and Ag suggest that in parcel ditch 16, core 14825, a comparable oven was located in a similar situation. As parcel ditch 16 is unexcavated, this cannot be confirmed.

Within each parcel, excluding parcels 9-14 were the road is not present, there is some spatial patterning relating to the relative enhancement. It appears the areas of greatest relative enhancement are nearest the thoroughfare. There also appears to be a greater amount of waste focused around the road, which holds for both phases. This is assuming measured values correlate with intensity, which is generally seen to be the case. Many other geochemical studies also correlate greatest enhancement with intensity. This is not unproblematic, as the nature of the inputs must also influence values, which are discussed in section 6.8.2, below.

This spatial variation is more distinct for the later phase. At least two phases have been identified within the parcel ditches, both in the geochemical data, the excavation data and the micromorphology (Macphail et al., 2014, Rødsrud, 2014). In light of the re-cutting and truncation of the ditches, stratigraphic integrity and phasing is discussed below.

Therefore the initial subjects in the discussion are firstly; the intensity of activity compared to measured values; the limitations of this data set in terms of differentiating between sources and thus activities in these challenging deposits and via geochemistry; and multi-scale interpretation of three dimensional geochemical data sets.

The remainder of the discussion touches on themes such as the form of the parcel ditches, the use of space within the trading site over time, and questioning if we are any closer to understanding the overall form of the settlement.

6.8.2 Relating values to inputs

It is fairly logical for us to assume the more that is put in, the more remains as traces to be measured. This, however, is an assumption that does not always hold for all elements in all soil conditions when considering the amount of time that has passed between the input and the measured values (Wilson et al., 2008). As an example, in acidic soils Ca is easily leached (Ottaway and Matthews, 1988, Brady and Weil, 1999), which has in part resulted in the lack of unburnt bone on the site. Therefore we cannot assume that the amount of Ca correlates perfectly to inputs from bone or any other potential source. Another major constitute of bone, P, can quickly become stable in inorganic mineral form in these conditions, especially with Fe and Al oxides (Bethell and Máté, 1989, Linderholm, 2007), but as stated previously, P can be from multiple sources. Therefore we cannot really equate any of these values directly with inputs in any quantitative proportion. What we *can* assume is intra-site comparability when the environmental conditions are more or less constant. From this, phases and/or intensity of inputs can be equated to settlement pattern or density.

Therefore intensity, and by extension phase and change, can be measured in stratigraphic accumulation on an element grouping basis. Comparable studies, such as Wells et al. (2000), equate measured values with intensity of activity and thus input. They equated high P values with middening, and high Hg and Pb values with craft production areas. Another example would be the kailyard in pre-industrial rural Scottish houses was where organic waste was stored before being distributed as manure. Entwistle et al (1998) identify the highest measured values of certain biophile elements as the kailyard, as this is where the most intense organic inputs were, therefore enhancement is correlated with input. Both Aston et al. (1998a) and Cook and Heizer (1965) attempted to equate the waste produced by humans and domestic species to the potential for detecting sites by relative enhancement, but both stopped short of equating measured values to physical input by direct correlation. They both consider it to be the proportional relative enhancement of groups of elements that suggest activity occurrence or focus and intensity. On an element by element basis, the measured values are both connected to inputs, preservation and soil conditions over time. Once again this is a reason why inter-site comparison is not possible on a value to value basis. Wilson et al. (2009) demonstrated this was true even if sites were geologically and culturally comparable.

Therefore, for the Heimdalsjordet site, even using the crude broad strokes of the descriptive statistics shown in tables 6.6 and 6.7, together with the stratigraphic enhancement shown in the core figures, the late phase is markedly different from the early. This is both in terms of inputs volume, and the activity range represented. The issue with this statement is time. None of the data presented here allows a time frame per phase to be estimated. Intensity can either be by duration, or intensity, the resulting volume is the same. Unfortunately, this is a limitation of the data set, which is only exacerbated by the truncated and secondary nature of the deposits. This is detailed in the next section.

6.8.3 Compromised stratigraphy and attrition

Truncation by modern or past activity is common in archaeological stratigraphy, and the hiatus in the sequence cannot always be filled by proxy information. Secondary deposits, or sediments formed by a deliberate act, are those which include material from another act (Harris, 1989). As stated in chapter 3 (section 3.6), this is rather a linguistic fuzzy logic in some circumstances, as a dump of material possibly represents a deliberate act, but the activity represented in the dumped material is no longer where it was deliberately created. In terms of geochemistry and the use of space, however, this distinction can be vital. The contrast is quite plain in this data set between what can be deduced from the spatial-geochemical data relating to primary oven feature 12263, where it is speculatively possible to suggest where smiths' had focused their work, and the far less specific interpretations from the parcel ditch backfills. In essence, it is utilising the only sources available. Through this, it exposes a limitation, which is the subject of section 6.8.4 and continued in chapter 8 on a more general level.

The GPR survey of Heimdalsjordet mapped the settlement far better than current commonplace excavation or evaluation strategies could have done (Stamnes, 2016). The GPR survey was able to detect insubstantial but archaeologically significant features, particularly the data acquired using the 16 channel MIRA (MÅLA imaging radar array, central frequency 400 MHz) (Nau et al., 2015: 19). This was clearest after coring parcels 17-20. These cores were not used as part of the geochemical data set. Here, cores showed clear signs of recent disturbance, including upturned stratigraphy. The trenches dug over the site in 1993 by Vestfold Municipality (Gansum and Garpestad, 1995) are poorly surveyed in due to limited contemporary technology, and it is entirely possible the disturbance recorded over the eastern section of parcels 17-20 represents these trenches. In one core (14325, see Appendix 2), a few centimetres (2-3 cm) of possible in situ parcel ditch was covered by c. 10 cm of redeposited archaeology and subsoil, a shallower than average topsoil above. If the trenches were re-excavated today, those remaining 2-3 cm could easily be removed by over-zealous mechanical stripping, something which in the author’s experience regularly occurs in evaluation and excavation conditions. Remaining in parcels 17-20, in the best preserved parcel ditch observed in a core, there was only 5 cm of clear archaeological backfill remaining in-situ in this area. In addition, whilst the surveying of the trenches in 1993 is perhaps poorly geographically referenced, in some areas they recorded surface features which can correspond to features seen in the GPR data, however, in the intervening 18 years, these features have reduced in width, implying attrition by the plough. That, together with the apparent damage causing by mechanically digging trenches, means that these features are now very shallow, captured by the GPR data, but in all likelihood, soon to disappear from the archaeological record entirely. It is very likely this observation and reality also holds for other features on the site. The excavation of parcels 6 and 7 also revealed ditches with but a few centimetres remaining. Without a clear and immediate change in land use policy on the site, it is highly likely the GPR data collected in 2011 and 2012 represents the best documentation of the site’s layout and extent that will ever be obtainable.

6.8.4 Dealing with generalisations in three dimensions

Returning to secondary contexts from cores, in dealing with samples from more than one horizon and having the vertical and horizontal planes as part of the geochemical data set, it becomes apparent that interpretations cannot be made purely on archaeological terms. The natural variation has to be explained in conjunction with the archaeological (Oonk et al., 2009a). The closer you look and the smaller the scale, from site, to feature, to context, the more complicated the picture becomes. This is because generalisations falter and the patterns we seek become either obscured or clarified by local variations. These variations are caused by the natural, the archaeological, or more likely, the complex intertwining of the two (Wilson et al., 2009). What is more, without other parameters to compare the geochemical data with, the risk is that the soil properties which dominate the data set, are likely to be the variation interpreted. Here, we have the visual examination of the cores, familiarity with the project as a whole, the excavation and finds data, micromorphology results and GPR data. Still, the geochemical data interpretation is struggling to grapple with the juxtapositions of micro data and macro interpretation in three dimensions. Interpretations are still on the terms of generalisations.

Why is that? It is a product of the use of pXRF and the challenging nature of the preserved archaeology. Analysing the whole sample gives irreplaceable insight into soil processes, whilst simultaneously swamping the interpretation. Statistical analysis coupled with the incorporation of samples from not just the archaeology, but also the adjacent topsoil and subsoil, has helped define both, and also their inter-relationship. This makes the remaining archaeology less, but stronger in interpretative strength.

The second reason concerns scale. Remaining within the realm of Catch-22 scenarios, the use of the pXRF allowed the capture of fine scale, three-dimensional stratigraphy from a larger number of samples. It allows flexibility and minimal sample preparation, which in turn allows more samples to be taken. This volume challenges interpretative ability to make thorough use of the micro-scale. It challenges because the volume is too great to feasibly detail every micro-variation. In general, looking at the core diagrams presented in this chapter, the geochemical stratigraphy appears to match the physical divisions observed in the cores, although there are instances where it does not. For example, in core 14865, parcel 9 and figure 6.24, there is an increase in organic waste, with P and Ca, which was not recorded in the core stratigraphy. Here, both can be used to question or measure what they really represent in terms of what is mobile, and what is significant, because coring and geochemical analysis have not been widely applied in archaeology on this fine scale. Leaching into the subsoil appears to be consistent with soil properties, and elementally selective, as would be expected. In no circumstance does this hinder interpretation, as the leaching is a comparatively minor effect.

That is not to say leaching has not been studied in archaeological geochemistry. Early work into multi-elemental approaches considered down profile movement as a priority. Cook and Heizer (1965) considered sampling down-profile to establish leaching patterns, particularly for P, essential. Crowther (1997) established through multiple case studies that P retention was a product of depth, and thus soil processes and leaching, as well as past human occupation. Unsurprisingly, organic content as measured by loss on ignition (LOI) was also strongly correlated with P values. Previous work has also considered the podzolisation processes far more influential on the distribution of down-profile elemental values than the patterning of past human behaviour, at a Norwegian site on the Ra moraine (Cannell, 2013). At Heimdalsjordet, hydromorphic processes have an impact on the retention and distribution of elements. However, on the whole, the geochemical stratigraphy appears reliable, and more fundamentally, statistics appear to have allowed the identification and thus interpretation of the dominant natural processes.

The third reason interpretations hold to the general is the nature of the deposits, as discussed in section 6.8.3. Repeatedly it has been observed that the stratigraphic integrity is imperfect. The ditches consistently show signs of re-cutting, and the high degree of truncation results in uncertainty over what these secondary deposits represent in both activity and chronological terms. These deposits are the result of slow accumulation, dumps, silting and in-washing. They are both intentional and unintentional; the background to generations of settlement, and only a fraction thereof. It is all we have, and that is not unusual. Our mandate is to use this scant resource to maximum effect if it divulges a greater contextual understanding of the human past.

6.8.5 Interpreting the scales

As already frequently stated, Heimdalsjordet is a site in its death throes. Modern land use will, within a few years, erode all but the few, deeper ditches on the western edge. As it is an archaeological rarity, this is a great loss. Other Viking Age trading sites are rare in Norway, Kaupang being the only other comparable example (Skre, 2007b). Communal, or sites where communities would perhaps seasonally gather, trade and celebrate, such as Bjørkum have been identified (Cartwright, 2015). Similar communal sites, which in all probability also performed a judicial function are known, primarily on the west coast (Grimm, 2010, Olsen, 2015). Naturally, therefore, Heimdalsjordet will always be compared to Kaupang in and for every demographic or typology before comparison moves on to include other Scandinavian Viking Age trading sites. This inevitability is reserved for chapter 8 of this thesis.

Remaining within the Heimdalsjordet site but on the broader scale, the parcel ditches and site topography show interesting similarities. It is clear that the majority of the ditches in form and formation were alike and comparable. Almost all cores suggested the ditches had been recut, and to look at the GPR interpretations, many parcelled areas have clearly phased ditch alignments and formations. Over time, ditches were cleaned out. The alignment of the ditches remains with the thoroughfare, and the changes in size and alignment of the parcelled areas, from what we can see, are minor. If we consider, from the finds and the ^{14}C dates, that the cores probably represent decades, if not more, then we have a conservative picture before us. Using parcel 2 as an example, the illusive earliest phases with low level animal stocking and human occupation debris probably date to the very end of the 8th century or the start of the 9th. These deposits are truncated, and the next deposits mark a more intense occupation. Later ditch infilling in parcel 2 includes finds of rock crystal beads dated to AD 860-885 and/or 915-980 (Callmer, 1977, Rødsrud, 2014, Bill and Rødsrud, in press), and other less chronologically distinct objects such as whetstones fragments, crucibles, copper alloy bars etc. None are in situ; none can be ascribed purpose other than loss or discard based upon stratigraphic observations. And then the parcel ditches are truncated again, this time by the modern plough. It is likely, based on the ^{14}C dates and finds, that a larger proportion of the 9th century occupation is glimpsed in the ditches of parcel 2, perhaps even into the early 10th century (Bill and Rødsrud, in press). Even if, as seems likely, the site continued in one form or another until the plundering of the Gokstad Mound sometime between AD 953 and 975, or even after (Bill and Rødsrud, in press, Bill and Daly, 2012), there is nothing to say exactly when the relative chronology of parcel 2 becomes truncated. Within the topsoil are finds of most occupation phases, as the early occupation phases could easily have been truncated in other areas of the site, which are now undetected.

Is it tempting to say in the late phase, specialisation began in the form of some parcels being used for non-ferrous metal work and others not, however one activity does not dictate the cultural and economic organisation of a site. Neither does the finds distribution allow any assignment of function to parcel. Here, absence is as significant as presence, and much of the absence can probably be ascribed to the lack of chemically distinct waste, together with the low sample density on the horizontal plane.

To summarise what can be distinguished, in parcels 1, 2 and 16, the thoroughfare was the focus throughout the occupation, as the gathering point for waste and activities. This seems to hold for all phases. Parcels 9-14 have high organic inputs, which macro-fossil analysis confirm as including grain and fish. Here there is also where a disproportionate amount of weights were found, and the area is beside the tentative harbour. Perhaps this area functioned as a gateway for storage and exchange (Bill and Rødsrud, 2013, Bill and Rødsrud, in press, Macphail et al., 2014). Non-ferrous metalworking can be located in parcels 21 and 16, interestingly enough at exactly the same point in the parcels form, and both in a ditch beside the thoroughfare. Both also seem to have been used by people working with a range of non-ferrous metals, including lead, silver, and copper alloys. Working in a ditch on a site prone to waterlogging would not be the first logical thought one might expect, but this could be a product of preservation making the exception being perceived as the rule. It does also beg the question over the interpretation of the features as ditches. The intricate, interconnected designs of the ditches, linking under the thoroughfare and with such clearly waterlogged and water-formed fills make the interpretation fairly sound. This subject is also returned to in chapter 8, where non-ferrous metals working will be covered on a general, comparative level. The next section continues the theme of drainage and flooding, coupled with the wider function of ditches.

6.8.6 Draining boundaries

So now, where does that leave social manifestations of space and form? It is interesting that the ditch systems are so comparable in dimension, in horizontal and vertical form and treatment, despite them, in all likelihood, being far less required as drainage features in the eastern parcels over the sandy area. Referring back to chapter 2, section 2.4.2 and Løvschal and Holst (2014), ditches can be seen as part of the site and thus society's spatial repertoire. Perhaps ditches are how some boundaries were made, how they looked, and the function and reason became intertwined, and a new meaning created? If we take the little leap of faith, it could be said that the parcel ditches surrounded buildings, for their dimensions are comparable to buildings in other (proto) urban contexts such as York (Hall et al., 2014), Dublin (Wallace, 2016), Ribe (Feveile and Jensen, 2000, Croix, 2015). It must be stated that between these examples, house construction methods do vary, and it is not to suggest they are one and the same. The size of the buildings also vary, as do the size of the parcel ditch areas at Heimdalsjordet. But if buildings were there, perhaps the depression formed to drain the house became part of what defined the house, needed or no. As similar ditches are known from similar (but not all) early urban markets, again such as Ribe, perhaps that was a form readily copied and accepted (Feveile and Jensen, 2000, Croix, 2015). Continuing with forms of cultural acceptability and practicalities, the metalworking, and other artisanal activities were conducted in plain sight, where they would be seen and could communicate on every level. This is unsurprising, as a thoroughfare is not just for transport, but all forms of communication.

Despite the inference above that ditches were not solely for drainage, there was a need. There are many mentions of floods, precipitation and in-washing in this text associated with sediments found in the cores. To be clear, these are not deep, violent flood waters from the land or sea submerging the site under a deluge. These are lower energy events, where surface saturation may have occurred, a common feature of stagnosols, or tidal or storm sea waters may have flooded the ditches, turbating sediments, adding sands or silts, and drawing local waste materials into the ditches. More violent events may have occurred, however they are not discussed here as the evidence is lacking. The lower energy events appear to have occurred throughout the occupation represented by the cores, and in all parcels west of the labyrinth, implying the slightly higher ground there provided some immunity.

6.8.7 The methods further potential, and future adaptations

This chapter does not represent the limit of the use of the this data set, simply how this data set can be used to meet the overall aims and objectives. The purpose here was to look at the use of space within whole parcel ditch enclosures, and more work is needed to reference the excavated and core stratigraphy with the geochemical.

The three dimensional approach allows access to unexcavated areas with the aid of geophysics, in this case high resolution GPR data. This was entirely successful, in that every feature identified from the GPR interpretations was found by geo-referencing and cored. The implication has a very positive outlook for research and commercial archaeology, as many sites cannot be wholly excavated, even if they are under threat from development. The method can also be used to obtain prospection information prior to excavation to better plan fieldwork in relation to time and budget. In hindsight, coring fewer features with a higher sampling resolution would have potentially provided a more nuanced picture of the archaeological phases and use of space. At present, the data sets presented in this chapter offer a more general picture of the functioning of Heimdalsjordet, with limited chronological information beyond the intensification and increasing diversity of the settlement over time. This interpretation was in part achieved through excavation and micromorphology, without the additional geochemical data.

There is a general presence of non-ferrous metals, a low, variable enhancement of natural levels for Cu, Zn and Pb, which is under 200 ppm. With deposits being re-cut, waste mobilised in flood or wet events, trampling and such, it should be expected that a ‘presence’ would be detected in occupied areas. The same can be said for organic inputs. Peaks, or exceptions to this form the points of interest, the focus of increased intensity, or preservation. An alternative way of viewing this data would be as multiples of the standard deviation (SD), such as used by Milek and Roberts (2013) in their study of a Viking Age house. For example, the SD of Cu is 431.23 ppm, with a mean of 105.3 ppm. This places the maximum value of 5,518.56 ppm in perspective, as the mean plus 12 SD. It is easier to identify relative enhancement and depletion, and although this will not solve the issue of visualising and interpreting three dimensional data, it will be considered for future research.

6.8.8 Expectations of (proto) urbanity

One question that has not been addressed in relation to the samples is what kind of occupation is *expected* to be represented. Our expectations are based upon site related knowledge, and contextual, cultural and social background to ourselves and the site. There are expectations which have been alluded to throughout this text, including settlement density, specialisation, craft production and a distance from food production. Because of the previous excavation work and subsequent publication, Kaupang is considered an urban, permanent settlement in its second phase (Skre, 2007a, Croix, 2015). There is no reason to believe Heimdalsjordet should be excluded from such definitions. Whilst not at the same scale as Kaupang, especially in terms of mortuary monuments, the physical settlement boundary for residence, and the degree of planning and organisation stand in strong contrast to other Viking Age sites in south-eastern Norway. This subject will be returned to in chapter 8.

6.9 Conclusions of chapter

The combination of coring, geophysics and pXRF has potential, if the context and question are suitable. It is clear from this case study that secondary deposits such as these are a valid and useful source of general information on the use of space, how it changed over time from one phase to the next, and where the activity foci were.

The limitation of the data set presented here is that, whilst clear from the statistical analysis, only two archaeological factors relating to past settlement could be defined. These were organic, bone-rich waste, and non-ferrous metalworking. Raw amber was found on the site, as was a fragment of leather, and these represent just a fraction of the many potential artisanal activities that occurred on the site using predominantly organic materials (Rødsrud, 2014, Macphail et al., 2014). To be able to capture more detail from the range of potential organic materials, either more directly related contexts are required for sampling, or a greater sample density and stratigraphic control is required, if not both. There is potential to more closely combine fine-stratigraphic geochemistry and micromorphology to help confirm the source of enhancement by micromorphology, and gain the distribution and thus use of space via geochemistry.

7. Kaupangveien

7.1 Introduction

The third and final study in this research is the Viking Age site of Kaupangveien. The rescue excavation at Kaupangveien 224 was conducted under the auspices of the Museum of Cultural History (MCH), University of Oslo, in response to a planning application. The analysis of the finds material from the site and the post-excavation report are incomplete, and therefore this chapter represents preliminary work only (McGraw, in prep). The interpretations are based upon the geochemical data presented, with the preliminary micromorphology report by Richard I. Macphail (University College London) as collaborative evidence.

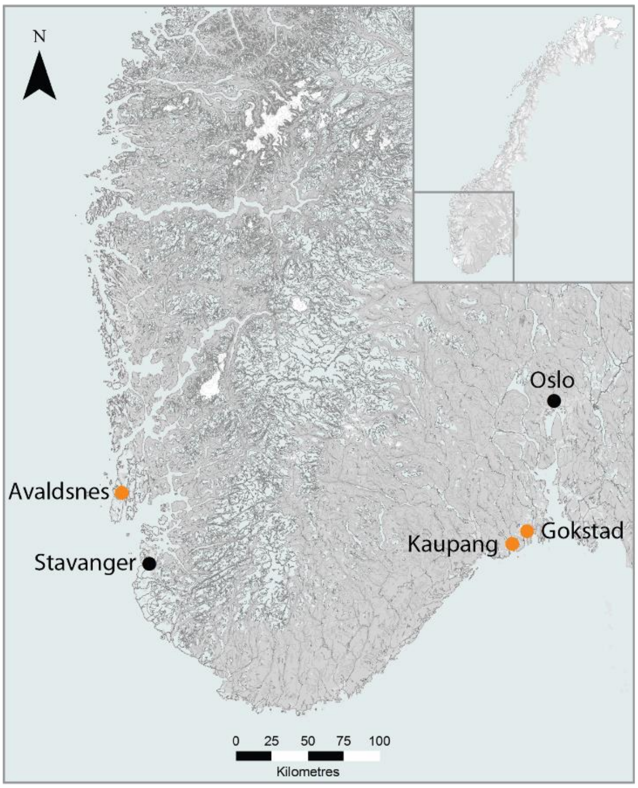


Figure 7. 1. The location of the case studies. Map source: Author/Norwegian Mapping Authority 2016.

Within a commercial setting, there are inevitably other concerns commensurate to research questions and direction, and it was important that this research functioned within these constraints and goals. Cost and speed were a priority, as well as the functional, chronological and cultural relationships of the excavated features. Kaupangveien is close to- but not within- the protected area connected to the Viking Age trading site of Kaupang (see section 7.2.2), therefore the relationship to the neighbouring Kaupang trading site was important to establish.

This final case study was not as substantial as the previous two, due to the small number of samples and the lesser excavation area, limiting data volume, and consequently interpretative weight. Moreover, within the commercial arena there are less resources for comparative contextual analysis, which otherwise can act as a counterbalance to the interpretative limitations of low samples numbers. The case study was orientated more towards applying the research aim in a commercial setting, to provide comparative data for overall interpretations for this research, and to apply the combination of pXRF and coring in different environmental conditions to meet the third objective.

This chapter begins with a brief geological and pedological background to the site, before outlining the previous excavations on the Kaupang site. The methodology is available in chapter 4, therefore only a summary is provided here. The results are presented in two separate sections, defined by the site area and the type of sampling and thus analysis that was conducted. These are then interpreted and discussed in the final sections of this chapter.

Once again, for clarity, the name Kaupang is used for the Viking Age trading site previously excavated in this area, and Kaupangveien refers to the 2015 rescue excavation from where these samples and data presented here came.

7.2 Site background

Figure 7. 2. Kaupang from above as it stands today. The harvested hay fields to the right of the image roughly overlie the previous excavation areas and the Viking Age trading centre. Kaupangveien 224 in one of the houses and gardens along the road in the right mid-ground of the photo. Photo: Magne Samdal, MCH / forskning.no/blogg/arkeologer-i-felt/nye-svar-fra-kaupang.

7.2.1 The physical environment

Climatically, Kaupang falls into the same, cool, pluvial climatic conditions as Gokstad, 15 km to the north-east. It is also coastal; therefore eustatic and isostatic changes since the last glaciation have sculpted the landscape we see today. The geology is broadly similar to Gokstad, and therefore the reader is referred to chapter 6, section 6.2.1 for background geological information. Sørensen et al. (2007), in their assessment of the environment around Kaupang stated that the lavikite geology is easily weathered into mineral forms that produce nutrient rich soils for vegetation, and this is evident in local flora. Directly forming the Kaupangveien site is the geomorphology and the marine sourced sediments. Thus the parent material for the soils and sediments are marine clays and beach deposits. Again we are in a landscape of scoured, igneous bedrock hills with marine sediments forming the lowland in-between.

The shallow bay that forms Kaupangkilen emerged into its present form probably around AD 750, forming a sheltered harbour area with access to the wider fjord to the south west (see figure 7.2). The area was prone to high tides and storms causing local coastal flooding, and still is to some extent (Sørensen et al., 2007). Kaupangveien itself sits about 10 m a.s.l., translating to 5-6 m a.s.l. in around AD 800, when the Kaupang trading site was in its earliest phase (Pilø, 2007).

As Kaupangveien is in a garden, it does not have any direct soil mapping information. However, looking at the immediate surrounds can give a reasonable indication of the conditions. The soil mapping information from NIBIO/kilden[1] in figure 7.3 indicates the site lies just north of a division in soil classification boundaries between umbrisol and stagnosol. More detailed soil mapping presented with the previous excavation publications confirms this division. Essentially, the umbrisol and the neighbouring anthrosol map the extent of the Kaupang trading site settlement, where the thicker cultural deposits have been located. The detailed mapping allowed the identification of the thicker cultural deposits (over 50 cm), however, the broader classification has very similar dimensions (Sørensen et al., 2007: figure 12.6). Umbrisol describes an organic-rich topsoil with only the lower pH hindering productivity. An anthrosol varies in composition, but as the name suggests, is influenced by human activity over an extended period of time, such as settlement, which gradually forms a topsoil of over 50 cm. In Norway, anthrosols are fairly rare, and in Vestfold in particular anthrosols compose less than 1% of cultivated areas (Solbakken et al., 2006). Stagnosols, typified by poor surface drainage, are classified in more detail in chapter 6.

Like much of the Kaupang trading site area, the immediate subsoil of Kaupangveien is fairly sorted medium to coarse sand. These are beach sediments of varying thickness which directly overlie marine clay silt. This provides an immediate well drained surface, although the depth is rarely more than 20-30 cm over the site after topsoil removal. Below this, drainage is impeded

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[1] http://kilden.skogoglandskap.no/

by the underlying marine clay silt substrate. Overlying the archaeological horizons at Kaupangveien was an organic topsoil which thickened considerably toward the south-eastern part of the site. By the south-eastern limit of excavation this clearly became two stratigraphic horizons, the lower being a buried plough soil, possibly dating to the medieval period. Together they were over 50 cm thick in parts, although this varied. Their formation is perhaps linked not only the Viking Age settlement, but also to the presence of a medieval/ early modern farmstead on the site, which at present is based on map regression and remains speculative (McGraw, in prep). Regardless of the cause, the presence of these anthropogenic soils has protected the site from later truncation.

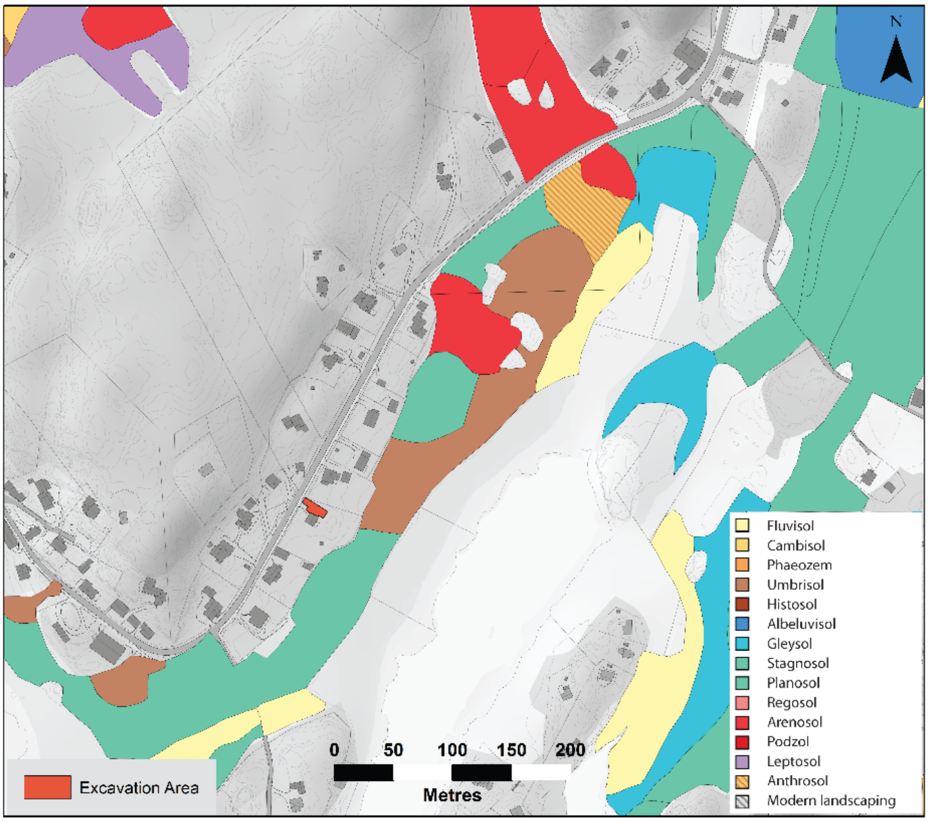

Figure 7. 3. The soil classification for the Kaupang area. The location of the Kaupangveien excavation is marked. Note the extent of the umbrisols in the bay area. Map source: Author/kilden (NIBIO)/ Norwegian Mapping Authority 2016.

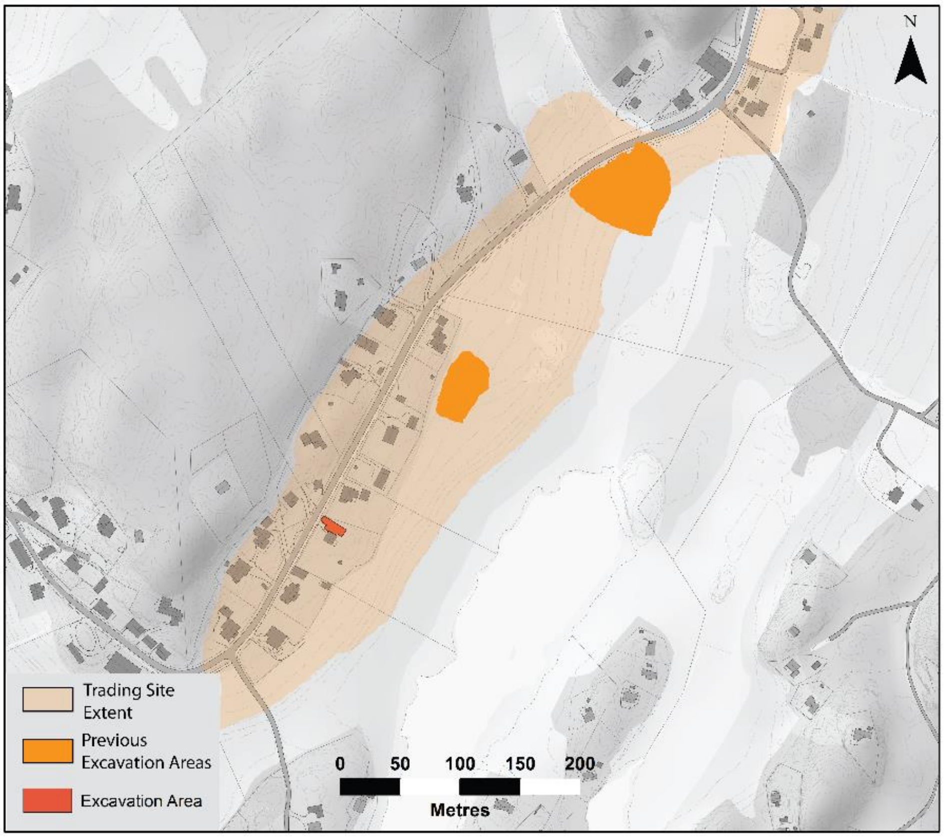

Figure 7. 4. The previously excavated areas at Kaupang (1998-2003), and the rough extent of the Kaupang trading settlement as denoted from excavation records. Please note this is approximate, and excludes trench detail for the excavation. Map source: Author/Pedersen (2016: figure 2.2)/Norwegian Mapping Authority 2016.

The site is located near the heart of where previous work has identified the parcelled area of the Kaupang trading site, as shown in figure 7.4. Please note that this is not the entire proposed extent of the Kaupang site; according to Skre (2007b) it extended slightly further to the north, with cemeteries across the inlet and on the nearby island of Lamøya.

7.2.2 The archaeological evidence

Prior to the rescue excavation, the main research carried out on this site was by the Kaupang Excavation Project (1998-2003), which aimed to expand upon the extensive previous work carried out on the site over the course of the preceding decades and centuries. The comprehensive project, involving landscape and environmental analysis, etymology, historical sources, three seasons of targeted research excavation, watching briefs and rescue excavation, and a wide range of specialist finds analysis, has been published in four volumes (Skre, 2007b, 2008, 2011, Pedersen, 2016). The excavation built particularly upon the results from excavations led by Charlotte Blindheim in the 1950's and into the 1970's, who uncovered parts of the settlement and the extensive associated mound cemetery (Skre, 2007a).

Of particular interest for this research is the excavation of six plots, where several phases of houses were recorded. The initial phase of the site was characterised by seasonal settlement from around AD 800, but by AD 810 it had become year-round. This second phase continued up to AD 840/850, after which the site is truncated by ploughing. From the extensive cultural plough soil, many objects were collected via field-walking, sieving and metal detecting, and the results from this and preserved harbour layers suggest the site was occupied up until around AD 960-80 (Pilø, 2007, Pedersen and Pilø, 2007). Of the near two hundred graves excavated in the surrounding cemeteries by Nicolaysen in 1867 and Blindheim in the 1950's, it is concluded they represent a period from c. AD 800-950 (Pedersen, 2016).

The trading site contained evidence for craft production in the form of glass bead making, ferrous and non-ferrous metalworking, amber working and textile production, with many of the resources being sourced from the Baltic, Near East and nearby continental Europe and the British Isles (Pedersen and Pilø, 2007).

7.2.3 Kaupangveien 224

The rescue excavation in 2015 revealed a series of negative features cut into the sandy subsoil, most with moderately organic, well defined backfills. Between the archaeological features there were modern disturbances, such as a concrete stair foundation. The extent of the 153 m^2 site was strictly limited by permission and mandate for the rescue excavation, as well as by existing features. These included the foundations for the residence on the site, its driveway, and toward the rear and south east of the site, a considerable bedrock rise.

The features were quickly identified as having similarities to those discovered at the Kaupang trading site, including postholes, ditches and possible pathways or roads. A slightly rounded ditch complex toward the south east of the site was interpreted as a possible house. The house, with its end entrance, curved walls, and no trace of daub in the excavation, has comparisons in Viking Age York and Dublin (Hall et al., 2014, Wallace, 2016). Beside the house were two linear features which were interpreted as ditches or pathways. In the area within and without the house, were features that cut the wall ditch and other ditches, which were interpreted as possible postholes. This suggested more than one phase of building and occupation was present. A hearth was also located within the potential building, and was sufficiently central to be considered related, however, as can be seen from figures 7.5 and 7.6, the house wall ditch extended beyond the limits of excavation.

Figure 7. 5. Photographs of the Kaupangveien site under excavation. To the left, the house wall ditch under excavation, with the hearth in the foreground. To the right the smithy under excavation. The furnace is in the foreground, with the near oval form partly visible. The waste accumulation layer is partly removed in this photograph. The circular feature stratigraphically under, visible on the left, is the well structure underneath the smithy. Scale is 1 metre. Photo: Jessica L. McGraw/MCH.

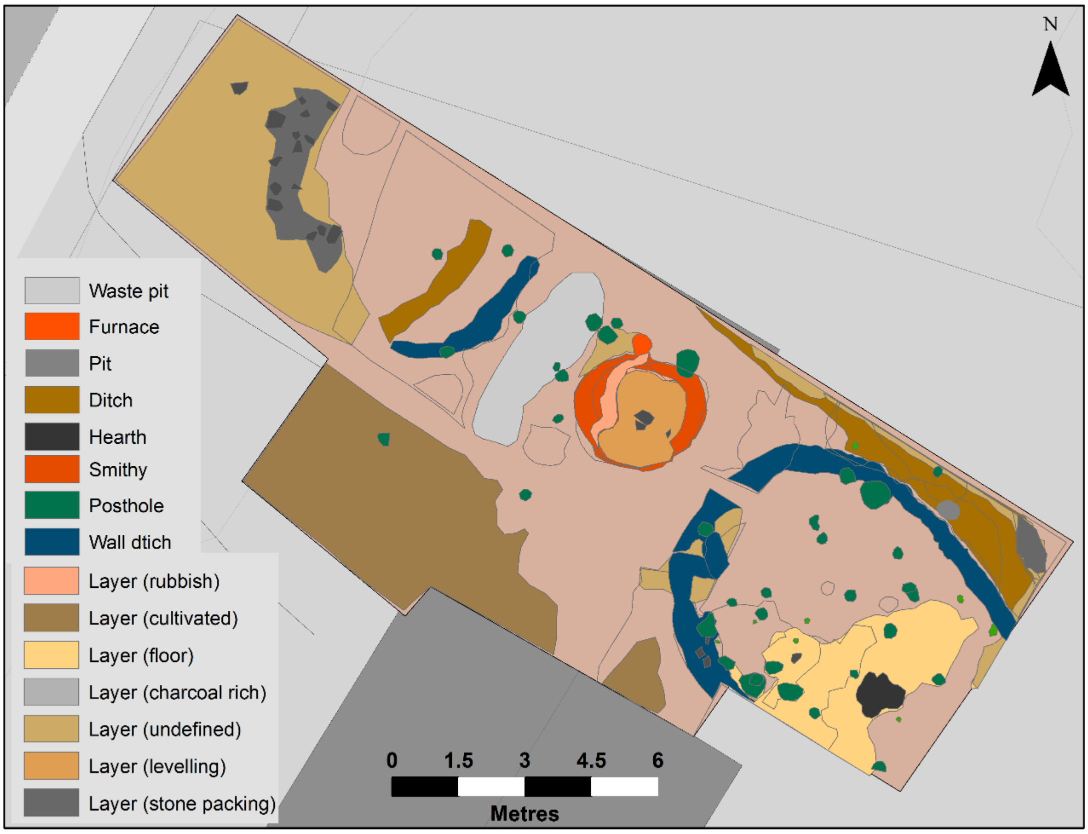

Figure 7. 6. The recorded archaeological layers on the Kaupangveien 224 site, prior to excavation of the Viking Age layers, but after the removal of later archaeology. Map source: Author/MCH/Norwegian Mapping Authority 2016.

A large near circular feature was tentatively interpreted as a well (figure 7.5). Upon excavation, it was shown that this contained a dual pit furnace above the well, and the contexts associated with the furnace contained crucible, mould and possible cupel fragments (see section 7.5), as well as small amounts of slag, metal droplets, bone fragments exposed to high temperatures, ash and charcoal (McGraw, in prep). Postholes near the furnace suggested a building once enclosed the space, which allows better control of drafts and visual interpretation of heated objects or furnace temperature. This area of the excavation is referred to as 'the smithy'.

During the excavation of the smithy, a well lying directly underneath became visible. It was backfilled with compact gleyed clay silt, and near circular in plan. Time hindered the excavation of this feature, although timbers were found in the base of the well and extracted by machine. Some of the timbers had rounded peg holes, suggesting reuse, whilst others could have been cut for the purpose of lining the well. Dendrochronology from the oak timbers produced a *terminus ante quem* of AD 823-824 for the well and smithy (ibid).

Four radiocarbon dates were obtained from samples, one from the house wall ditch, one from a posthole associated with the house, and two from the smithy. One smithy sample, from hazelnut shells located under a brass ingot, gave a date of AD 980-1025 (2σ), and one from the furnace gave a date of AD 875-970 (2σ). According to the sampled material, the house wall ditch is a little older, with dates of AD 770-880 and AD 720-870 (both 2σ) (ibid). Chronologically, these dates are in accordance to the typological and radiocarbon dates from the larger Kaupang excavation (Pedersen and Pilø, 2007, Pilø, 2007).

7.3 Sampling

Sampling was conducted over the course of three days in July 2015. Three methods were employed in response to the differing archaeological questions, the form of the features, and the stage of excavation. These were in situ use of pXRF, coring, and surface sampling. Full detail is provided in chapter 4.

7.3.1 The house

The house area was well defined by a possible wall ditch with associated postholes, hearth and a partly preserved horizontal layer, which was believed to be contemporary with the house by stratigraphic observation. For speed, and to create a finer stratigraphic interpretation and thus potentially also a chronology, the wall ditch was cored in five places, selected to be representative of the house, whilst not hindering excavation. Cored through the layer above, cores 1937 and 1940 revealed that there were also postholes present. In addition, two other ditches beside the house were cored, in order to determine their function. It was unclear whether they were boundary/parcel ditches, or thoroughfares, and it was considered that the fine stratigraphy from cores could observe features and assist interpretation, or geochemical analysis could potentially shed light on this (figure 7.7).

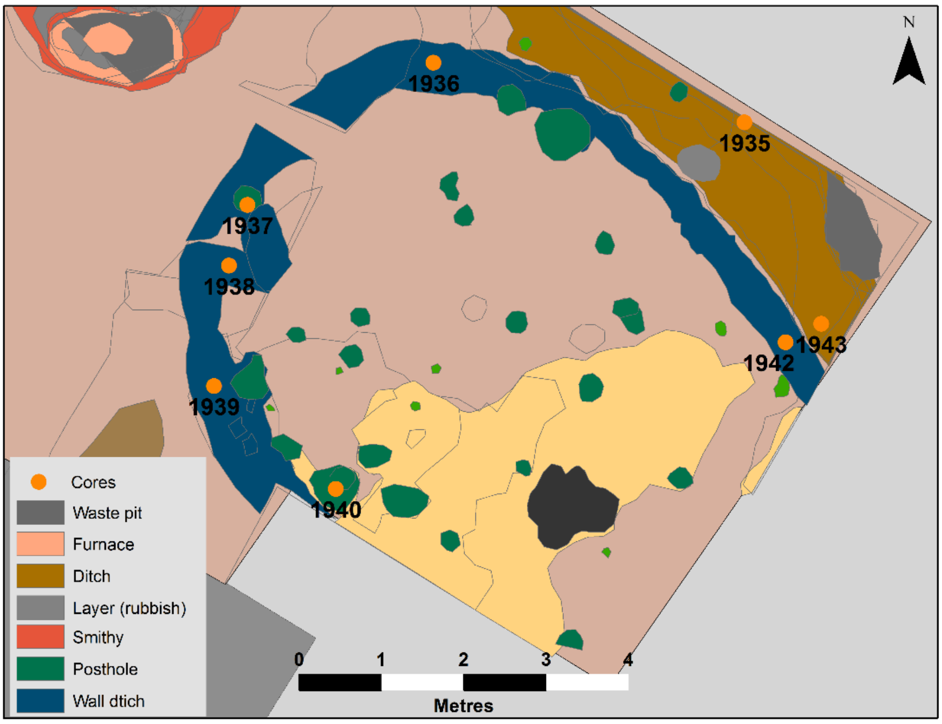

Figure 7. 7. The location of cores associated with the house, and neighbouring ditches. Map source: Author/MCH/Norwegian Mapping Authority 2016

7.3.2 The smithy

A further ditch, north-west of the smithy area was already partly excavated when coring was undertaken. Initially thought to be a thoroughfare, that interpretation was challenged by the fact the highly organic and largely homogenous backfill contained a large amount of mould fragments and crucibles. Two further cores (1891 and 1892) were taken in this feature for analysis.

Initial in situ pXRF readings on layer 2425, shown in lighter grey in figure 7.8, indicated relatively high levels of Pb together with traces of Ag and Cu. The layer appeared to be primarily composed of charcoal rich sediments and fuel waste. In situ analysis was coarse, hand-held, and with shorter analytical times than those used in laboratory conditions, as it was not intended that the data would be further used. After initial results, samples were quickly taken for further laboratory analysis. Later, during the excavation of the furnace, further samples were taken by the excavation manager, Jessica L. McGraw, for analysis. These were not intended to be a comprehensive coverage of all layers, but to add evidence for the range of metalworking that had occurred there, and compare to the waste layers cored in samples 1891 and 1892. These cores are labelled in figure 7.8.

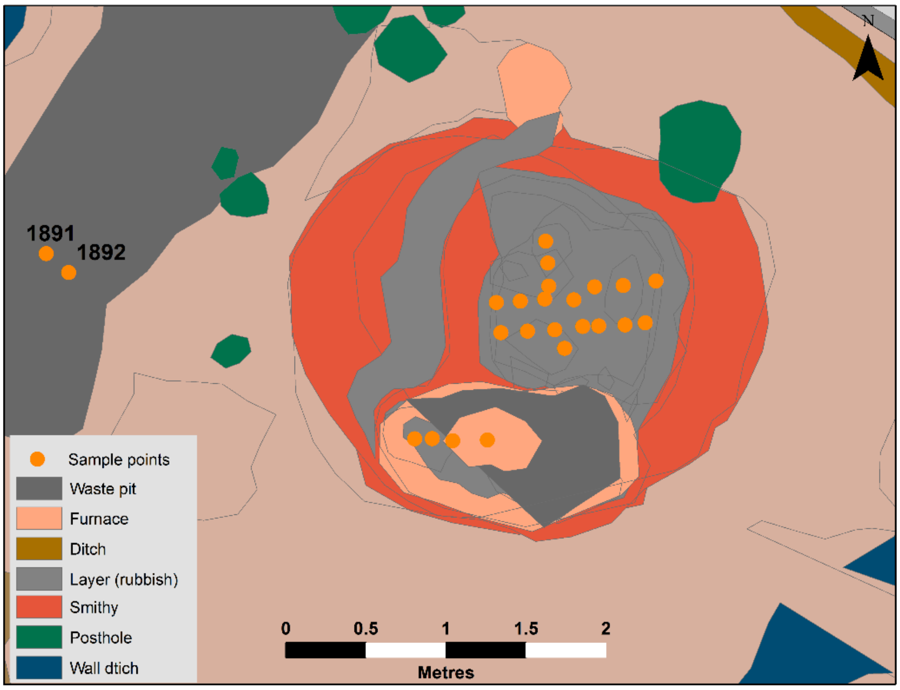

Figure 7. 8. Sample points for the smithy, in the rubbish layer 2425 and in the furnace layers 3112 and 3097. The two comparison cores from the waste pit are labelled 1891 and 1892. Map source: Author/MCH/Norwegian Mapping Authority 2016.

7.4 Results

7.4.1 Data processing

This final case study benefitted from the experience of the previous work. The data was separated into two data sets, as they represented differing site specific research aims, sampling methods and contexts. Cores from the house and the occupational features beside it, namely ditch 463 (core 1943) and the adjacent ditch (core 1935) became one data set, which is referred to as the *house* data set below. The other data set, referred to as the *smithy* data set, included all smithy samples and the two cores from the waste pit (1891 and 1892), as it was considered they represented differing manifestations of the same phenomenon.

After calibration, the house data set was normalised for PCA analysis (Zscore). As noted in chapter 6, PCA is vulnerable to outliers or extreme values, which normalisation reduces (Abdi and Williams, 2010). Varimax rotation was again used. As with the Heimdalsjordet data set, the Kaiser-Meyer-Olkin test was applied to the data set, to ensure the variation seen was not by random chance, and the data was suitable for PCA. A result of 0.653 is above the significance threshold of 0.6, and therefore PCA was performed on the 107 observations from the house context. Parameters were set to extract all components with eigenvalues over 0.8, however, the principal components used for further interpretation were selected via scree plot. It was observed that the principal components with an eigenvalue under 1.0, and a percent influence under 9% were dominated by individual elements, and therefore the data set was not being reduced into co-correlated components. Once again these were Sn and Ag forming individual principal components, as observed in the Heimdalsjordet case study. As was observed in chapter 6, this is a result of the retention mechanisms for Sn and Ag in soils, and a product of their relative abundance. The scree plot and parameters are provided in Appendix 3.

7.4.2 PCA on the house cores

Table 7.1 contains the principal components extracted for 107 samples. The interpretation of the data draws on the results from the previous two case studies. Firstly, it is worth stressing the differences in the archaeology and soils at Kaupang. The features are cut into beach sand, and in parts the archaeology has been reasonably protected by the creation of a later, possibly medieval, cultivation layer above. Without sufficient data it is difficult to equate this to 'dark earth', created by the decomposition of towns after abandonment and bolstered by cultivation. This is a common phenomenon in the UK and on the continent after the decline of Roman urbanism, where areas with formerly dense settlement become less populated and farmed to some extent. The high organic inputs from building materials and urban life contributed toward the creation of a fertile, dark soil as everything decayed and was reworked (Goldberg and Macphail, 2006, Macphail et al., 2003). The upper layers of the larger Kaupang excavation had developed into umbrisols and anthrosols with a 50 cm or more topsoil in parts, homogenised by later cultivation; therefore there are some similarities (Sørensen et al., 2007). The micromorphology from the 1998-2003 excavations (Milek and French, 2007) and for Kaupangveien (Macphail et al., 2016a) identifies beach sediments prone to leaching, Fe coatings and pans, and the eluviation of finer particles down profile. This was also apparent in the cores used for this research (see section 7.4.4).

Table 7. 1. The five principal components extracted from PCA analysis, using a varimax rotated component matrix. The interpretations in the lowest row are discussed in the main text.

	Principal Component				
	1	2	3	4	5
Influence (%)	16.5	16.4	12.1	9.4	9.2
ZSn	.201	.004	.003	-.018	-.005
ZAg	.176	-.005	.030	.063	.049
ZSr	-.086	-.028	-.088	.011	-.106
ZRb	-.060	.777	-.262	.040	-.066
ZAs	.435	-.285	-.425	-.197	-.117
ZPb	-.100	-.325	.790	.009	.033
ZZn	.128	-.210	.025	.004	.887
ZCu	.041	-.464	.239	.229	.657
ZFe	.837	-.051	.048	.008	.196
ZMn	.071	-.118	.853	.077	.073
ZCr	.832	.145	.000	.216	.073
ZV	.906	.268	.038	.026	.024
ZTi	.574	.436	-.052	-.099	-.034
ZCa	.075	.065	.612	-.091	.555
ZK	.238	.834	-.149	-.310	-.202
ZAl	.425	.754	-.152	.162	-.284
ZP	.053	.024	.089	.858	-.039
ZSi	.165	.672	.440	-.310	-.110
ZS	.120	-.234	-.027	.818	.100
Interpretation	Fe oxides	Soil matrix	Occupation debris/ metalworking	Organic waste	Occupation debris/ metalworking

Therefore it is unsurprising that that Fe oxides dominate the PCA results. As noted previously, V readily sorbs to Fe oxides, which explains the affinity here (Larsson, 2014). Fe oxides form coatings over grains within the soil matrix, which could explain the weaker correlation with Fe. On a general level, Cr is commonly associated with Fe mineral ores, and is a common isomorphic substitution in Fe bearing rocks, which could be the reason for the association (Ma and Hooda, 2010). Milek and French (2007) report that the occupation soils in Kaupang are generally between 5.0 and 6. pH. If this is also the case at Kaupangveien, which is likely, then Cr is highly stable, with very low solubility and bioavailability in these relatively oxidised conditions (Ma and Hooda, 2010). The combination here implies this first factor is mobile and immobile Fe oxides and the soils geogenic sandy structure.

The next principal component is also interpreted as the soil matrix, with Si, Al and to a lesser extent K forming the clay mineral structure, with Rb in far lower proportions. These elements correlated strongly in the Heimdalsjordet data set, and the same interpretation is applied here (section 6.5.1).

The final three factors are potentially anthropogenic, and to some extent harder to confidently assign meaning to, particularly the combination of Pb, Mn and Ca in the third principal component. Mn, like Fe is associated with redoximorphic features; those associated with cycles of reduction and oxidation. Under reducing conditions, Mn becomes reduced from Mn^{4+} or Mn^{3+}, to Mn^{2+} (Lindbo et al., 2010). In their study of geochemical enhancement through phases of a tell, Ottaway and Matthews (1988) consider the ratio of P to Mn as a means of detecting whether animal or human waste is the source of the enhancement. Domestic animal waste, such as that from sheep and cattle, has a far higher Mn to P ratio than that from humans, and in addition, animal fodder such as hay is also high in Mn. To complicate the issue, Mn is also highly variable in soils, therefore imported soils or sediments, such as clay for walling, could also produce enhancements. However, if this were the case, one would expect a correlation with elements common in clay, such as Si or Al. That there is not a strong correlation with P can be explained by the fact that sources of P will have been highly varied within the settlement context. Mn is also connected to industrial processes. A *very* tentative interpretation of this combination is that heavy metals, such as Pb, in conditions where pH is temporally raised by the presence of Ca, become bound to Mn and Fe oxides (Maskall and Thornton, 1998). From viewing the core data (see below), it is clear the correlation of enhanced Pb, Mn and Ca is highly localised. There are subtle enhancements of the three elements together in cores 1938 and 1942; however, by far the greatest enhancement is in core 1937. Here values of 4,931 ppm Mn were recorded, and bearing in mind the mean is 1,135 ppm, this is a significant enhancement. In cores 1891 and 1892 from the metalworking waste pit, Mn values are up to 10,866 ppm. It is clearly associated with metalworking waste, as has been evidenced by Maskall and Thornton (1998) for historical lead smelting sites. Core 1937 sampled a posthole, and at the base of the core a possible mould fragment as found. This, and the geochemical evidence, suggest the backfill of this posthole is contaminated with metalworking waste. That Mn is also enhanced in other cores, albeit to a far lower level, has implications for chronology, which is returned to in the discussion below.

The combination of P and S has been noted in the two previous case studies as indicative of general enhancement in organic inputs by human occupation, although S retention is also attributed to metals aiding retention of an otherwise soluble ion. Within the organic fraction of the soil, however, S is retained and stable (White, 2006), and the high organic content, which is also enhanced with P, have created the correlation here.

The final principal component is Cu and Zn, with a lesser influence of Ca. In the majority of cores, the upper strata in particular are enhanced with both Cu and Zn, as is the smithy data set. The presence of Ca in association with non-ferrous metals could be a product of using bone material in metal refining, or be connected to ash. Due to the localised enhancements and the stratigraphic locations of these, this principal component is also considered to be related to non-ferrous metalworking. This is considered in the further discussion, and the retention of Ca in connection to principal components three and five is considered here. In the mildly acidic conditions, Ca will be readily leached (Oonk et al., 2009). Both the lack of unburnt bone on the site, the lack of ash, and the weathered state of the bones in thin sections for both this site and the larger Kaupang site suggest this to be the case (Milek and French, 2007, Macphail et al., 2016a). In these conditions, P and Ca are leached and can form Ca-P-Fe features, which is not evident here. Alternatively, post-depositional enhancement of bone with Cu and Zn has been observed in similar studies (Davidson et al., 2007), which could explain the weaker correlation here. Burnt bone was found in the wall ditch and furnace area, however, this cannot, from this combination, be assumed to be the source. The enhancement of Pb is easier to ascribe, as it was present in comparably large quantities in the larger town, and in the furnace area. Lead was used for models and weights in Kaupang, Heimdalsjordet, and to a lesser extent other comparable trading sites (Pedersen, 2008, Bill and Rødsrud, 2013, Pedersen, 2016), and was clearly worked both in the furnace at Kaupangveien and on the larger trading site (see below for the smithy data set).

7.4.3 Correlation matrix from the smithy data set

For the 22 samples from the smithy, the data volume was insufficient for statistical testing using PCA. Many of the variables were also skewed, again limiting statistical applications. A two-tailed Pearson’s correlation and bootstrap test was performed, however the application of the results is limited by the low number of observations and the data distribution. The significant results from Pearson’s correlation (≥0.01, two tailed), *and* with positive correlations from bootstrap testing, are in table 7.2. Unsurprisingly, from the fact the finds-based and in situ evidence strongly suggested non-ferrous metalworking, it is these elements that correlate, together with elements that have affinity with these, such as S, and high organic inputs, i.e. P and Ca. Vanadium was excluded from this table, despite having a significant correlation to Fe, as this affinity is believed to be natural. Also excluded from the table are Si, K and Al, as although they have a significant correlation to Rb, this has been considered in the previous section.

The clearest correlation is between Pb and S, which is a product of the close affinity between the elements, and the frequent occurrence of Pb as Pb_2S in ores. P is only correlated to Ca, which is considered to be an indication of bone as well as ash as sourced from the heating of the furnace. The presence of Ag is low in both the furnace samples and the cores from the waste pit (1891 and 1892), with all values being under 50 ppm. The other metals associated with non-ferrous metalworking, Sn, Zn, Cu and Pb are present in abundances varying from 120.76 - 9,448.64 ppm for Cu, 0 - 850.98 ppm for Sn, 85.6 - 797.12 ppm for Zn, and 24.23 – 7,680.06 ppm for Pb. Of note is that one sample, 2797, has universally lower values for all of these elements. This sample was located near the western limit of the context, and near the furnace remnants. It is difficult to interpret from one sample alone, and as the sample beside had comparatively mid-range values for all elements, this could indicate there was an analytical error.

Of the 22 samples analysed in the smithy area, four were in the furnace itself. These four samples (3112, 3161, 3159 and 3160) contain lower levels of non-ferrous metalworking, with moderately less P, Ca and Mn as well. This is consistent with the furnace being cleaned out and reused, whilst the other samples represent the gathering of waste in the work space beside the furnace. Here the measured values show no consistent pattern besides containing high levels of non-ferrous metalworking waste and ash accumulation.

Ca, as stated previously can be sourced from ash as well as bone (Canti, 2003, Milek and French, 2007, Wilson et al., 2008). It is worth noting that there are other sources, such as construction materials and soil improvement additions (Entwistle et al., 1998, Wilson et al., 2008), but it is considered these are less likely here.

Widening the interpretation of the smithy to include the waste pit (feature 225), cores 1891 and 1892 (see figures 7.17 and 7.18) have the highest measured values for Mn (10,866.22 ppm), P (28,016.27 ppm) and Ca (46,494.9 ppm). In addition, there is a peak of Fe in core 1891 (82,467.27 ppm). This has been attributed to the presence of Fe slags in the waste pit, which is likely to be the result of secondary iron working. In core 1892 in particular, there is evidence for leaching of P and S into the underlying sandy substrate. The measured values in the cores for Cu, Zn, Pb, Fe, P, S, Ca, and Mn are all attributed to the dumping of smithy waste in the pit. Judging from the stratigraphy and the chemistry, this appears to be episodic, however this cannot be taken as evidence of periodic use of the furnace, only that waste was dumped in the pit episodically. In light of the leaching from, and thus between archaeological contexts, relating the measured values to certain strata is possible, but caution must be considered before assigning undue meaning.

Table 7. 2 (next page) Pearsons Correlation and Bootstrap testing for the smithy samples. See text for interpretations.

Element		Sn	Pb	Cu	Zn	P	S	Ca	Ag	Fe	Mn
Sn	Pearson correlation (2 tailed)			614 (.002)	.569 (.006)						
	Bootstrap Upper			.338	.056						
	Lower			.810	.855						
Pb	Pearson correlation (2 tailed)			.842 (.000)	.832 (.000)		.950 (.000)			.648 (.001)	
	Bootstrap Upper			.604	.537		.909			.381	
	Lower			.930	.945		.982			.825	
Cu	Pearson correlation (2 tailed)	614 (.002)	.842 (.000)		.824 (.000)		.794 (000)	.561 (.007)	550 (.008)	.574 (.005)	.619 (.002)
	Bootstrap Upper	.338	.604		.604		.481	.263	.254	.202	.330
	Lower	.810	.930		.931		.926	.810	.830	.820	.816
Zn	Pearson correlation (2 tailed)	-569 (.006)	.832 (.000)	.824 (.000)			.799 (.000)	681 (.000)		.668 (.001)	.733 (.000)
	Bootstrap Upper	.103	.537	.604			.467	.382		.267	.533
	Lower	.834	.945	.931			.937	.915		.880	.911
P	Pearson correlation (2 tailed)							.708 (.000)			
	Bootstrap Upper							.349			
	Lower							.913			
S	Pearson correlation (2 tailed)		.950 (.000)	.794 (000)	.799 (.000)					.728 (.000)	
	Bootstrap Upper		.909	.481	.467					.443	
	Lower		.982	.926	.937					.884	
Ca	Pearson correlation (2 tailed)			.561 (.007)	681 (.000)	.708 (.000)			619 (.002)		
	Bootstrap Upper			.263	.382	.349			.307		
	Lower			.810	.915	.913			.840		
Ag	Pearson correlation (2 tailed)			.550 (.008)				619 (.002)			
	Bootstrap Upper			.254				.307			
	Lower			.830				.840			
Fe	Pearson correlation (2 tailed)		.648 (.001)	.574 (.005)	668 (.001)		.728 (.000)				
	Bootstrap Upper		.381	.202	.267		.443				
	Lower		.825	.820	.880		.884				
Mn	Pearson correlation (2 tailed)			.619 (.002)	.733 (.000)						
	Bootstrap Upper			.330	.533						
	Lower			.816	.911						

7.4.4 Core stratigraphy from house area

In light of the low number of cores and the stratigraphic distinction between the cores, all cores are presented in this section together with a brief interpretation of the archaeological and geochemical results in reference to the PCA analysis. In figures 7.9-7.18, the yellow layer at the core base is the sandy substrate. Once again, the contexts are numbered per core, with the first four digits being the core number, followed by the context number, labelled descending from the top. By this formula, 1937/3 denotes the third context in core 1937.

Core 1935

Located in a feature interpreted as a shallow ditch, the core has just two archaeological contexts with a combined thickness of 11 cm. The upmost context was a gleyed clay-silt with humic infilling of cracks, root channels and burrows. Rare inclusions included burnt clay and charcoal. The context is probably inverted stratigraphy excavated from a lower soil horizon. The layer below is a humic loam, with root channels, with few anthropogenic enhancements, although P peaks here.

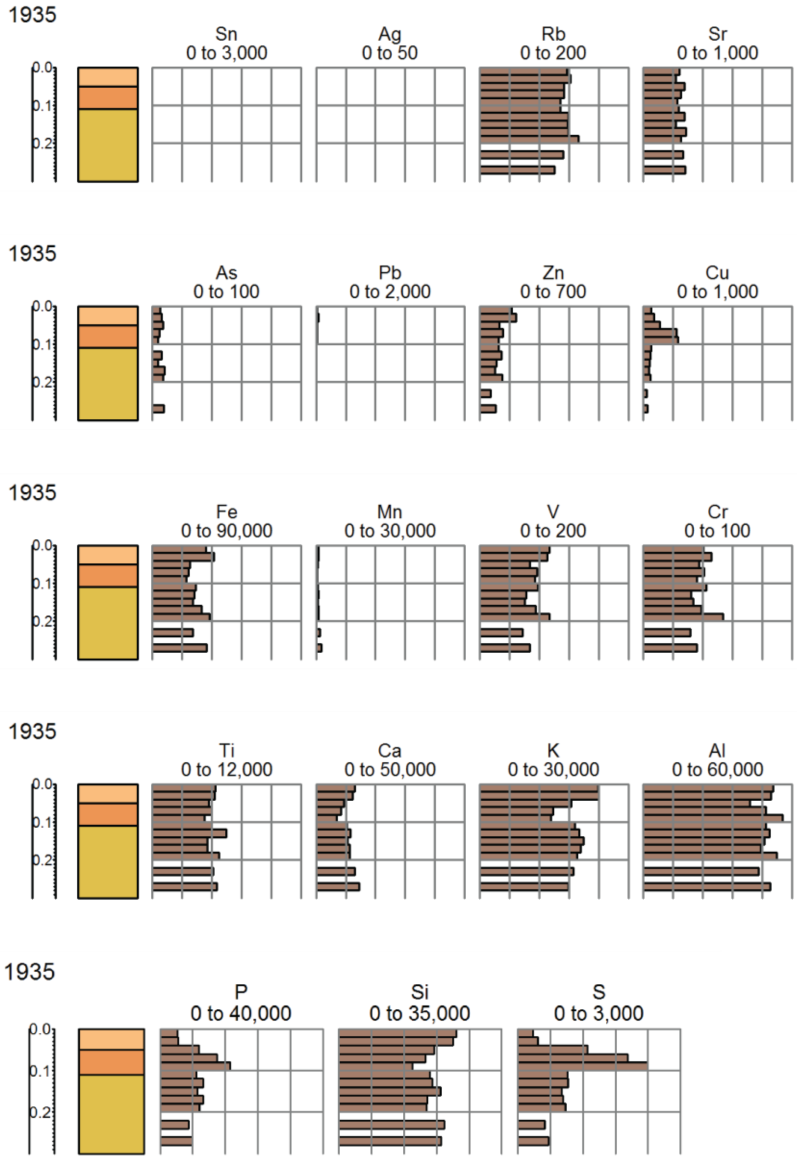

Figure 7. 9. Core 1935, with all elements discussed in the text by stratigraphic layer.

The subsoil is the site's typical moderately sorted and poorly consolidated beach sands. The upper subsoil interface has a gradually decreasing humic content, the result of leaching, which is seen in almost all core samples. The substrate also has Fe coatings, especially in relic root channels.

Core 1936

Core 1936 was located in the wall ditch to the house feature. The shallow stratigraphy had no clear evidence of phases, and the overall enhancement of anthropogenic inputs appears to be low. Toward the surface, levels of Cu and Zn increase slightly, as does S. The reverse appears true of P, although this can be attributed to some degree of leaching, as seen in all cores.

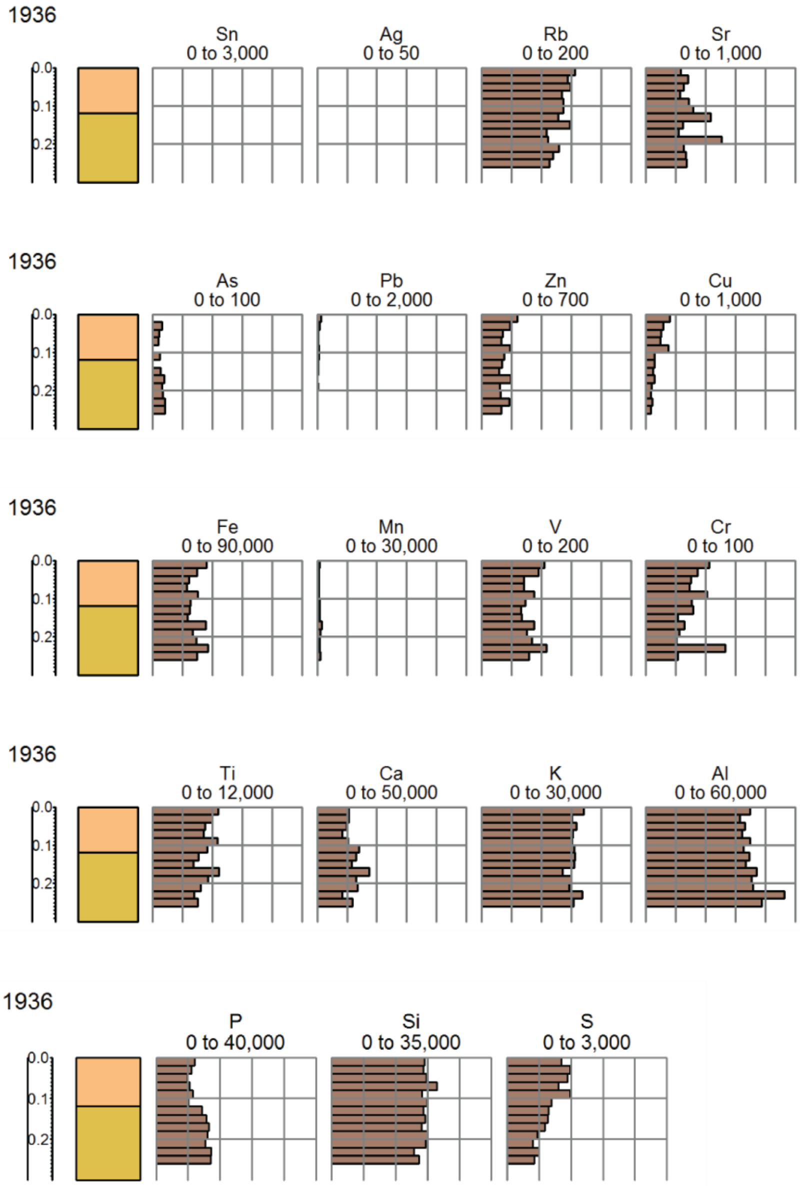

Figure 7. 10. Core 1936, with all elements discussed in the text by stratigraphic layer.

Core 1937

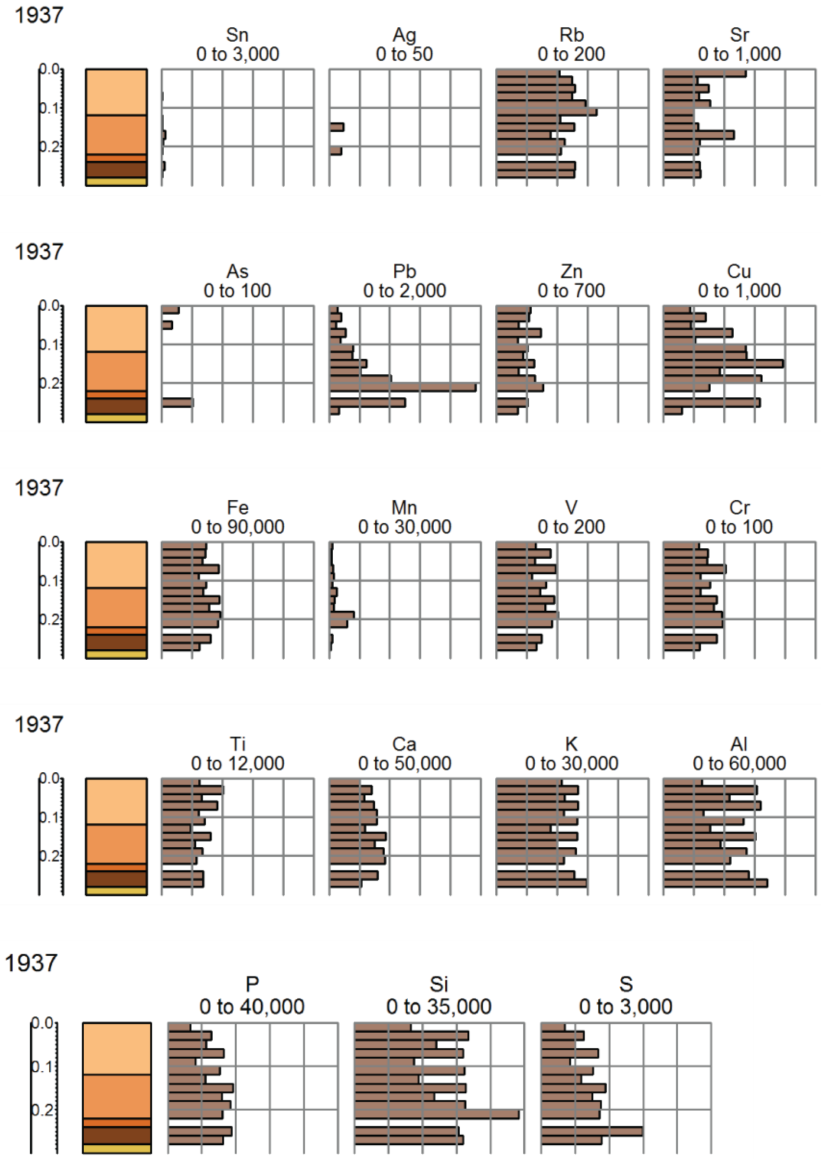

Figure 7. 11. Core 1937, with all elements discussed in the text by stratigraphic layer.

Located in a posthole which cut the house wall ditch, the first thing to note is that the depth is greater than the wall ditch. Near the base of the core, forming context 1937/3 at 22-24.5 cm, a mould fragment was discovered. The corresponding peak in Pb, Zn and Cu is clear, as well as the peak in Si from the mould fabric. The context immediately below, and at the base of the feature, was rich in fine charcoal and burnt bone. It likely this is debris/waste from metalworking that has been placed in the posthole, either during the removal of the post, or to level the base during construction. The upper contexts of the core also contained burnt and unburnt gravels, burnt bone and charcoal within an organic, loamy matrix. At 8-10 cm there was a clear layer of Fe coatings on grains. This upmost layer (1937/1) was compact, and was a mix of occupation sediments. Context 1937/2 was also compact and had a very level, sharp lower boundary over the mould fragment.

From a lone core, the construction sequence of the posthole cannot be entirely resolved. However, it appeared that the mould and metalworking debris had been placed in the base to level and steady a post, whilst the upper fills represented accumulation/infilling after the removal of the post.

Core 1938

Like core 1936, core 1938 was within the house wall ditch, and the depth of the archaeological stratigraphy is very similar. There are higher levels of Zn and Cu in the archaeological contexts, as well as a slight increase in Fe compared to the sandy substrate. Sulphur is also enhanced in the archaeological context, although P once again appears to be affected by leaching, and the highest values are found in the sandy substrate.

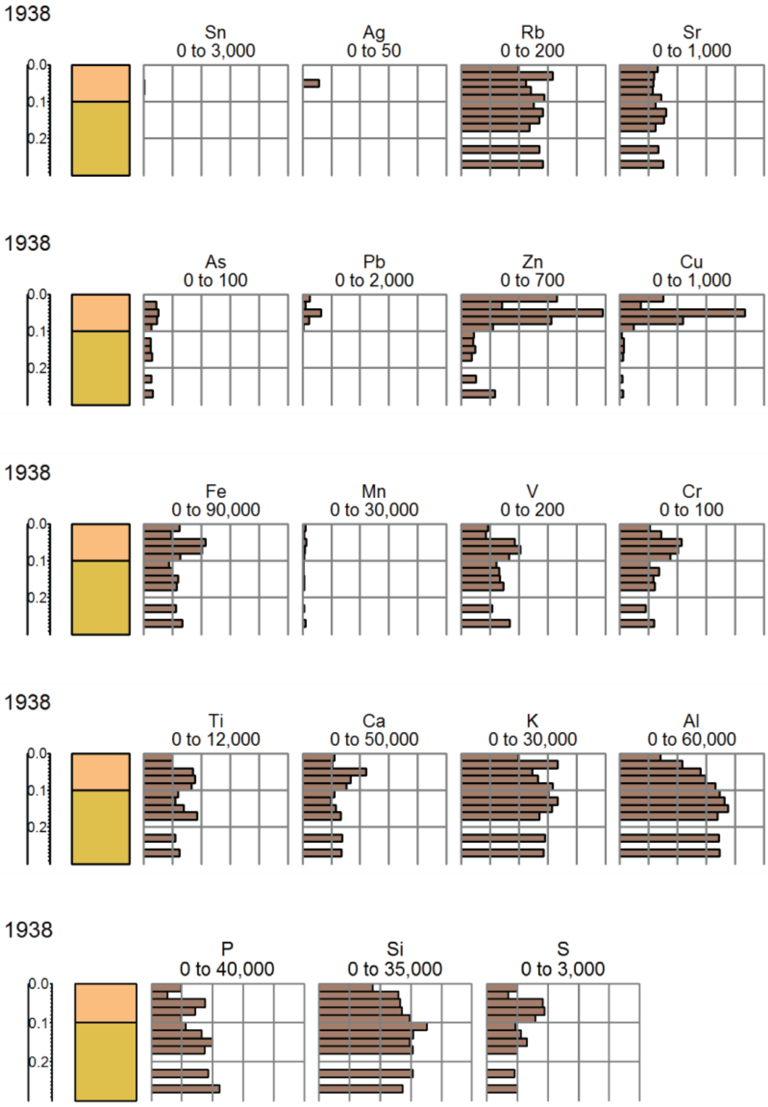

Figure 7. 12. Core 1938, with all elements discussed in the text by stratigraphic layer.

Core 1939

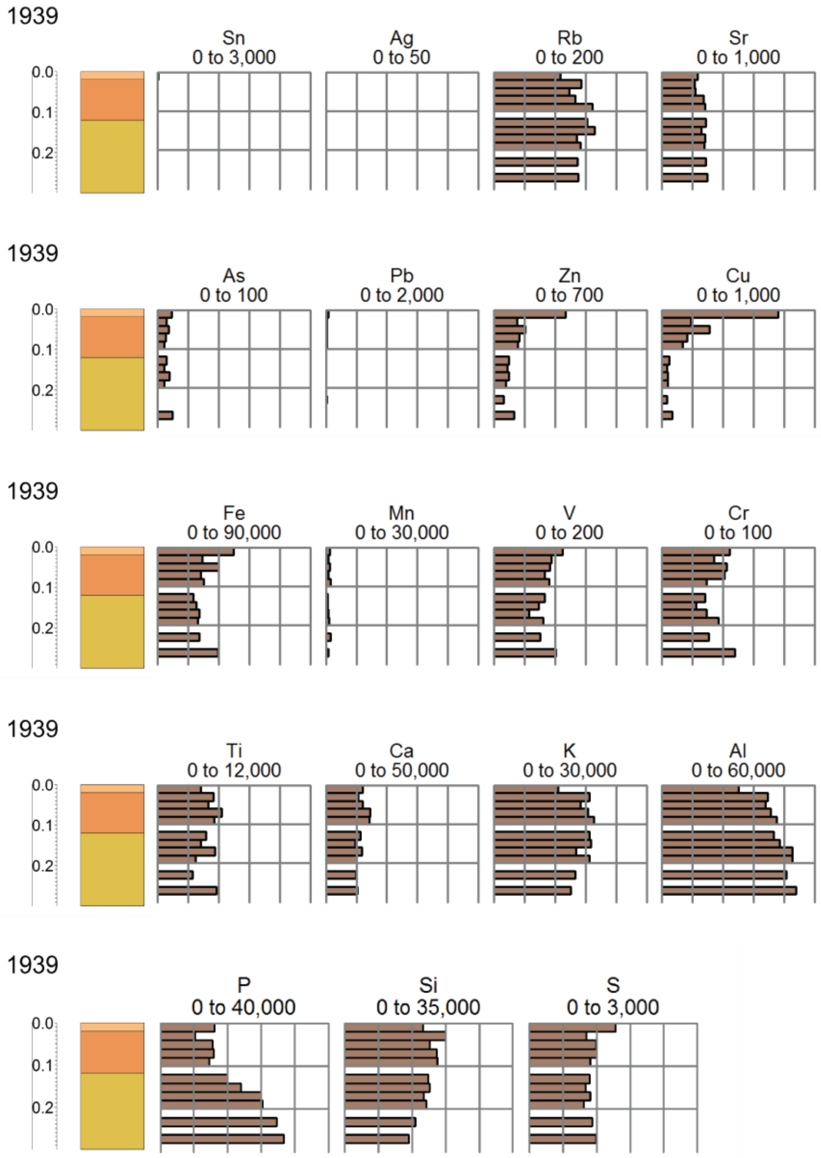

Figure 7. 13. Core 1939, with all elements discussed in the text by stratigraphic layer.

Once again the stratigraphy is similar to cores 1936 and 1938 in the wall ditch. The upmost 10 cm and two contexts have high Cu, Zn, Fe and S values, and once again the P values suggest leaching. Chronologically, it is clear the upmost context of 2 cm is affected by metalworking waste, however, this was interpreted as a more recent infilling on the feature, possibly infilling after subsidence from an above context. The second context (1939/2) was of coarser gravels of mixed geology, with rare burnt bone and charcoal. This was interpreted as backfill. The lower context had few anthropogenic inclusions, and it was fairly well sorted. There was some question during interpreting this core as to whether the lower c.15 cm was substrate with humic and Fe coatings or anthropogenic backfill. Due to the strong evidence of leaching from other cores, the final interpretation is that it is subsoil.

Core 1940

From a posthole, this core has an immediately striking peak in Sn and Ag in the second context, representing a fragment or object in amongst the heterogeneous loam. This was poorly consolidated secondary backfill after the post removal, and has a tandem enhancement of P and S, mirrored by the decline in Si, Ti and K where the richer organic material is. Fe also peaks here.

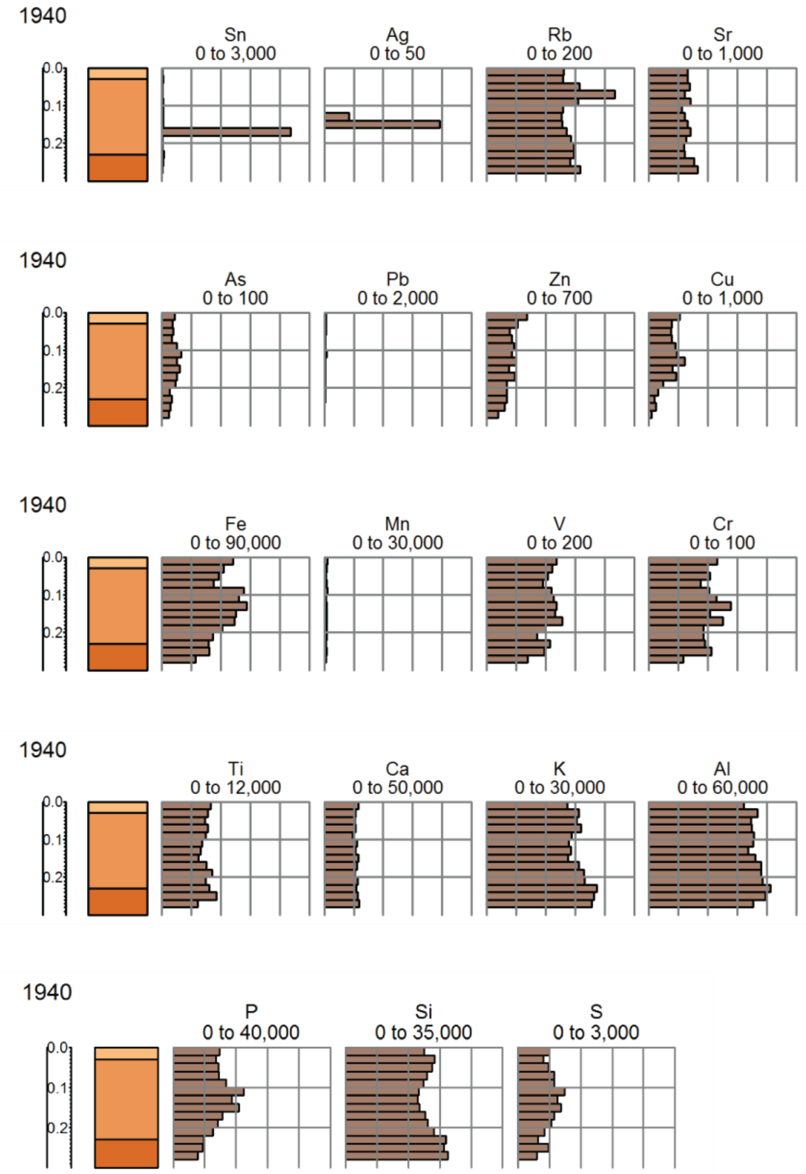

Figure 7. 14. Core 1940, with all elements discussed in the text by stratigraphic layer.

At 21-23 cm, at the lower interface of context 1940/2, there were clasts of blue clay silt. These were interpreted as a possible base for the post, which was disturbed by the post removal. This is similar to core 1937 where material has been used at the base of the posthole for consolidation purposes. The lowest context appears to be disturbed sandy substrate with leached humic and Fe coatings.

Core 1942

The final core from the wall ditch, core 1942 showed some indication of stratification in the archaeological layers. The upper context, from 0-7 cm, was a humic silty loam, with traces of wooden material at 3 cm. There were also frequent inclusions of burnt bone and charcoal, which together with the elevated Cu and Zn, suggest mixed occupation waste.

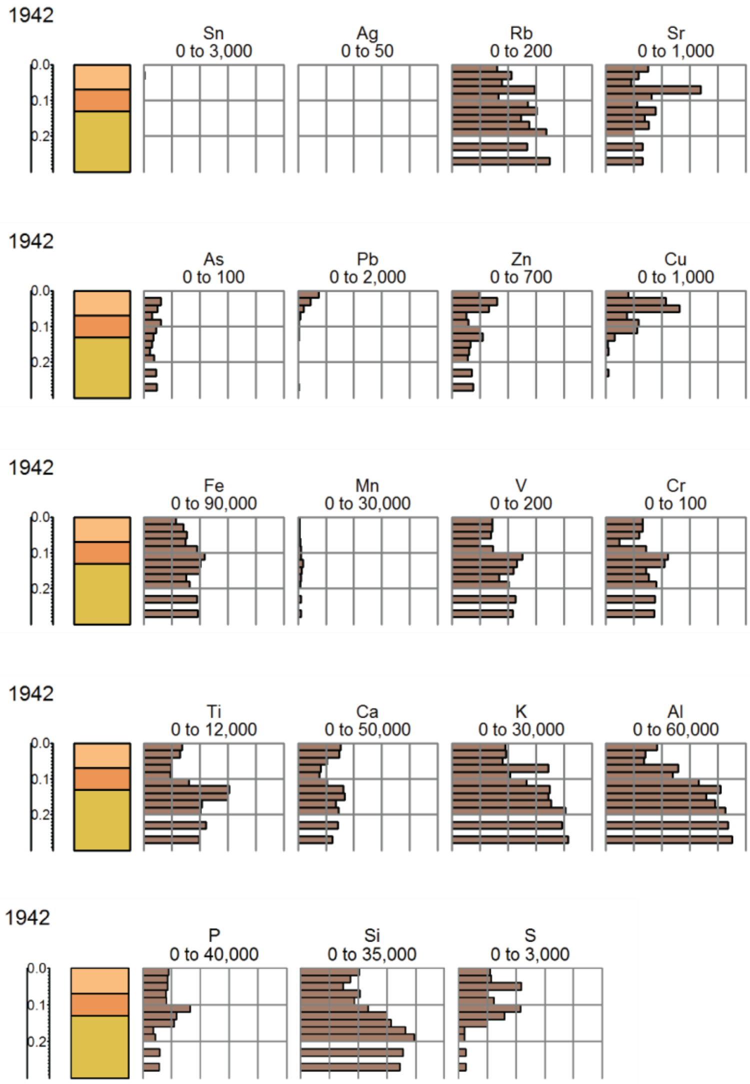

Figure 7. 15. Core 1942, with all elements discussed in the text by stratigraphic layer.

The sharp boundary and change in texture between the contexts could suggest the upper 7 cm are a later backfill than the lower 4 cm, which may represent slower accumulation during use. The lower context, from 7-13 cm, was slightly laminated with alternate gravels and humic matter, suggesting slow, periodic accumulation. A lens of fine, sorted sand suggests in-washing from a rain event or similar. A few fine fragments of burnt clay were visible. The chemical data shows an increase in Cu, Zn and S associated with the upmost context, whilst the lower context has an enhancement of P, S and Fe, all which are prone to down-washing and leaching.

Core 1943

The final core is from within a shallow feature, which was tentatively interpreted as either a ditch or a pathway. The compaction of the archaeological contexts here was greater than other contexts, and the gravel content of the sandy loam was lower than elsewhere. Beyond this whether it was a ditch or pathway is left to micromorphology to determine, although rudimentary indications based upon observed compaction and particle sorting suggest a pathway. The upmost few centimetres are affected by raised Cu and Zn, together with low levels of Pb. At the base of the anthropogenic contexts there is a peak in P, and the interface was disturbed. It is likely that leaching of P and Fe has perhaps masked some of the detail.

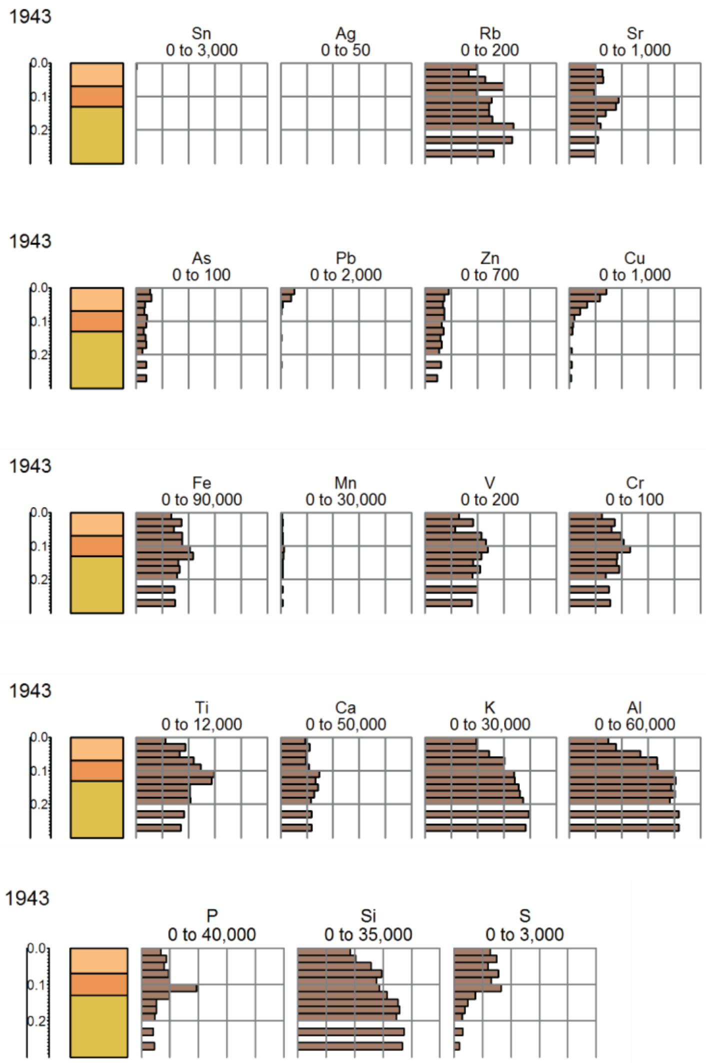

Figure 7. 16. Core 1943, with all elements discussed in the text by stratigraphic layer.

7.4.5 Cores 1891 and 1892

These two cores were located in pit 225, which was interpreted as a waste pit for the smithy area. Although a clearer textual stratigraphy was visible in core 1891, all archaeological contexts in both cores contain Cu, Zn, Ag, and Pb in high quantities, as well the associated Ca and P from ashes, bones and other fuel sources. Interestingly, both have Ag present only in the centre section of the core, between 4 and 20 cm. That said, as Ag is never over 50 ppm, the low level is probably more enlightening than the absence at the top and base. Pedersen (2010) has suggested that precious metals such as silver were handled with great care to avoid loss;

therefore the quantity in the waste pit does not necessarily reflect the overall presence, but rather the handling and use of the different metals.

Figure 7. 17. Core 1891 from pit 225, with all elements discussed in the text by stratigraphic layer.

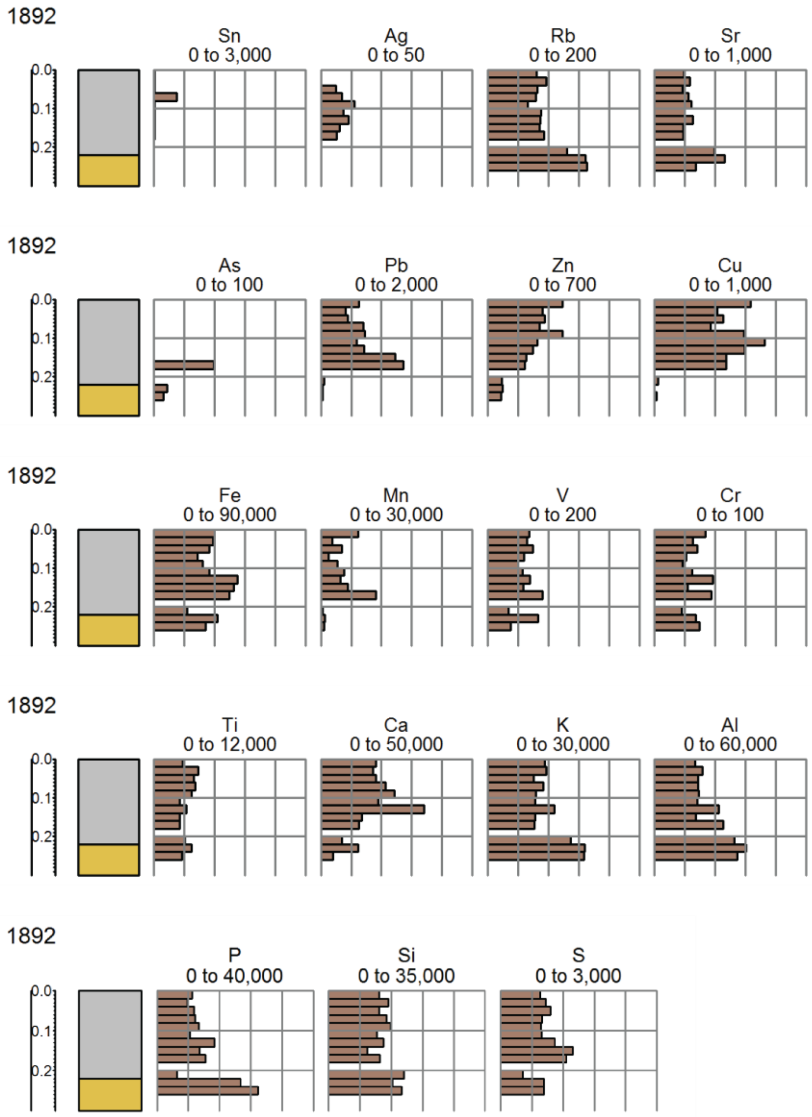

Figure 7. 18. Core 1892 from pit 225, with all elements discussed in the text by stratigraphic layer.

7.5 Discussion

7.5.1 Waste and production; the smithy and the waste pit

The initial interrogation of the finds material from the waste pit and smithy by the field leader, in collaboration with Arne Jouttijärvi, disclosed the possible presence of cupels (cupellation crucibles) (McGraw, in prep). These are used to refine silver or gold via cupellation. This is an oxidation process for selective refinement, by adding copper-alloy silver or gold to lead and then heating in highly oxidising conditions. The lead acts as an oxidising agent as it turns to lead oxide. A mixture of ash and bone, or bonemeal, was used as a lining for the cupellation hearth or on or in the fabric of the cupellation crucible, as this would absorb the molten copper and lead, leaving the silver or gold purer (Söderberg, 2004, Söderberg and Gustafsson, 2006, Pedersen, 2016). The form of cupels varies, as does the process. This process was undoubtedly occurring in Viking Age contexts, as in addition to those found at Kaupangveien, 21 certain fragments were also found in the larger Kaupang excavation. Similar finds have also been identified at Birka, Fröjel and Hedeby (Söderberg, 2004, Söderberg and Gustafsson, 2006, Pedersen, 2016).

During the period of settlement of Kaupang, silver in the form of hacksilver, object and coinage became a currency, which slowly evolved into a monetary economy toward the mid to late Viking Age. This is a considerable topic beyond the scope of this thesis, and the reader is referred to Skre (2008) and references therein for a more nuanced picture. From the silver in various forms from Kaupang and other contemporary trading sites, such as the nearby Heimdalsjordet, together with cupels suggesting refining silver at Kaupang/Kaupangveien, silver was present and was being worked and refined. The measured values in the geochemical data sets are generally low; below 50 ppm. Chapter 6, section 6.5.1, notes that Ag is strongly retained within soils, therefore the low values cannot be ascribed to leaching. As stated previously, Pedersen's research from Kaupang suggests that precious metals were treated with care and caution to reduce loss, and this is perhaps reflected in the data presented here (Pedersen, 2010, 2016). Regardless, it must be recalled that the samples here do not reflect every layer and context. It also clearly demonstrates that there is not necessarily a direct correlation between proportions of measured elements or discovered objects, and what was occurring. The measured values from the soil are best used to demonstrate possible range and spatial organisation of activities.

7.5.2 The chronological and material relationship

The main focus of this discussion is relative chronology through geochemistry and stratigraphy as the low number of samples limits the ability to create patterns of spatial use. Of key importance to the site, there are points of chronology that must be addressed. Placing Kaupangveien within the context of the wider Kaupang settlement will allowed a greater understanding of its social and economic role, especially in relation to the non-ferrous metalworking identified in plot A1 in Kaupang proper.

Beginning with the most basic and certain, the well pre-dates the smithy, and provides a *terminus post quem* of AD 823-824 from when the dendrochronologically dated tree was felled. Timber lined wells were found in the larger Kaupang excavation, and they are found in various shapes and forms in other, comparable early urban sites such as York (Pilø, 2007, Hall et al., 2014). The only surprising thing about its presence is the smithy sitting squarely above it. Why this was done is impossible to fathom with confidence; it could have been culturally or practically motivated. The well, once backfilled, may have been a convenient depression of firm, clay silt ground in the otherwise poorly consolidated sands upon which to build a furnace without preparing a surface, although this is speculation.

One radiocarbon date for the smithy comes from a hazelnut shell preserved under a brass ingot, discovered in the upper layers of the smithy waste contexts.   The date range was AD 980-1025 (2σ). The radiocarbon date from the furnace gave a date of AD 875-970 (2σ). The lifetime of the well is unknown, but the smithy is likely to be 10th century. The lack of overlap in the date ranges at 2SD, if the dates are accepted to be within the statistical range, can only mean either the charcoal sampled is older from sampling error, intrusion/re-depositing, or that the smithy had a lifespan of over ten years. The sample material for the furnace could have been of an age before it was burnt, whereas the hazelnut shell is more likely to be chronologically accurate. The issues with ^{14}C dates are many of course, beginning with contextual security and ending with calibration (Aitken, 1990, Walker, 2005). It is possible, however, that the smithy was in use for a period of decades. The longevity of the Birka bronze workshop, which is dated to earlier than the Kaupang examples, testifies that use of the same area for non-ferrous metalworking could continue for many years and even decades (Ambrosiani, 2008).

The house also has stratigraphic relationships indicative of chronology. The wall ditch respects the ditch beside it and vice versa. The wall ditch, as represented by cores 1936, 1938, 1939 and 1942 appears to be a shallow feature cut into the beach sands; there is no evidence for whether this was unsettled land or not prior to this. The lower proportional of anthropogenic physical and geochemical inclusions in the first backfill of this feature *could* indicate this is the first building in this location. From the radiocarbon dates from the hearth and posthole, this could be anywhere from AD 720, or as late as AD 870 or 880. The latter half of the late range is more likely, given that the main settlement began around AD 800 (Pedersen and Pilø, 2007), and became permanent a decade or so later. To add emphasis, the suggestion from the radiocarbon dates is that the house is not contemporary with the smithy. Now as this is based upon four dates, in contexts that all show signs of disturbance/movement (i.e. secondary), undue weight should not be given. Finds from the house context, including beads, are unfortunately un-diagnostic other than they are comparable to Viking Age examples, and therefore contribute little to fine tuning chronology.

This moves us on to consider the evidence for phasing from the house area cores. Some of the postholes do not respect the wall ditch, and they are too numerous to belong to a single building phase. Cutting directly into the wall ditch, and with metalworking waste used to consolidate the base, core 1937 in feature 2071 is probably later. Figure 7.19 reproduces illustrations of Dublin houses type 1 and 2, which also feature curved, un-daubed walls, and the type 1 house has an end-on entrance. The supporting posts for the roof in the Dublin houses were not always in neat and predictable patterns (Wallace, 1992, 2016), however, even with this allowance, there are too many postholes in the house area to represent a single building phase.

Figure 7. 19. For a point of comparison, two buildings excavated at Fishamble Street, Dublin, are included. The image on the left is house is of type 1 and has double-lined wattle walls and an end-on entrance. From Wallace (1992: figure 74, page 100). The image to the right is a house of the smaller type 2 and has a single-lined wattle wall. On the right hand side, a wattle-wall of another house-plot is adjoined. From Wallace (1992: figure 84, page 110).

For the sake of simplicity in the face of uncertainty, let us consider that the house is likely to be older than the smithy, but has more than one phase. The house wall ditch is represented by cores 1936, 1938, 1939 and 1942. Of these, 1936, appears the least enhanced by occupation and the levels for non-ferrous metals are proportionately low. This core is located on the northern edge of the wall ditch, toward the linear ditch and possible pathway or ditch. Core 1938 has a corresponding peak at 6 cm in depth of Cu, Zn, Pb, Ca and P. It must be noted that core 1938 is located at the point where the form of the ditch deviates from the curve, and suggests a later or earlier alteration to the ditch form (figures 7.7 and 7.20). Moving on, core 1939 has a slight increase in Cu and Zn in the second context, but a sharp increase in the final 2 cm, which is interpreted as later backfill. This is similar to 1942, in that the later context has the greater amount of Cu, Pb and Zn, and the later context was interpreted as possibly a later backfill based upon textural and contextual observations.

The remaining house cores, 1937 and 1940 are through postholes. At the base of 1937 there is a mould and other metalworking debris, implying the post was built whilst metalworking was established. Core 1940 is less distinct; although the mid-way down context 1940/2 there is the peak in Sn and Ag. In all of the other peaks in metals associated with non-ferrous metalworking, there is an accompanying peak in either P, Ca or both, which does not occur here. The assumption is, therefore, that this is an object, and not a dump or accumulation of metalworking waste.

The house seems to have been established prior to there being an accumulation of metalworking waste in the immediate environment. Material from outside a building regularly becomes trampled into interior floor surfaces and is found in micromorphology samples (e.g. Milek and French, 2007, Macphail et al., 2011), and material is moved within the settlement contexts from inside to outside and vice versa. Ash from another source than the house hearth can be used for floor covering (Milek, 2006, Milek and Roberts, 2013, Wallace, 2016), just as the house floor can be removed for use elsewhere (Milek and French, 2007). The close proximity of the smithy and the house make the likelihood of material from one area intruding on another highly plausible. The wall ditch, and by extension the house, was used for a period of time prior to metalworking waste becoming prominent. This phase could include posthole 2081, represented by core 1940. During later occupation, possibly contemporary with the use of the smithy, rebuilding occurred, which altered the form of the wall ditch, and perhaps also added posthole 2071 (core 1937). It is impossible to say whether the house endured in similar form whilst the smithy was in use, nor is the area beyond the limits of excavation known.

7.5.3 The spatial use of the house

Consequently, from the above, the oldest form of the house is represented by cores 1936, 1939, and 1942, and possibly posthole 2081/core 1940. Spatial patterning from so little is dubious at best, therefore observations are minimal. Certainly in core 1939, the P levels are far higher than elsewhere in the house and although strongly leached, the values are up to 29,410.24 ppm, compared to a mean of 11,273.64 ppm for all cores. This is also without the associated peak in Ca and S, which could be ascribed to the potentially highly oxidising and leaching conditions of a wall ditch. The backfill of posthole 1940 has higher levels of P, which correspond to S, which implies organic waste, although the backfill is not necessarily contemporary with the early wall ditch. As mentioned previously, overall, core 1936 has the lowest geochemical enhancements from anthropogenic inputs. The implication is that the south side of the entrance has higher P rich waste than the north. This in itself offers no great insight, but as the house in incomplete and the cores few, no further interpretation can be made.

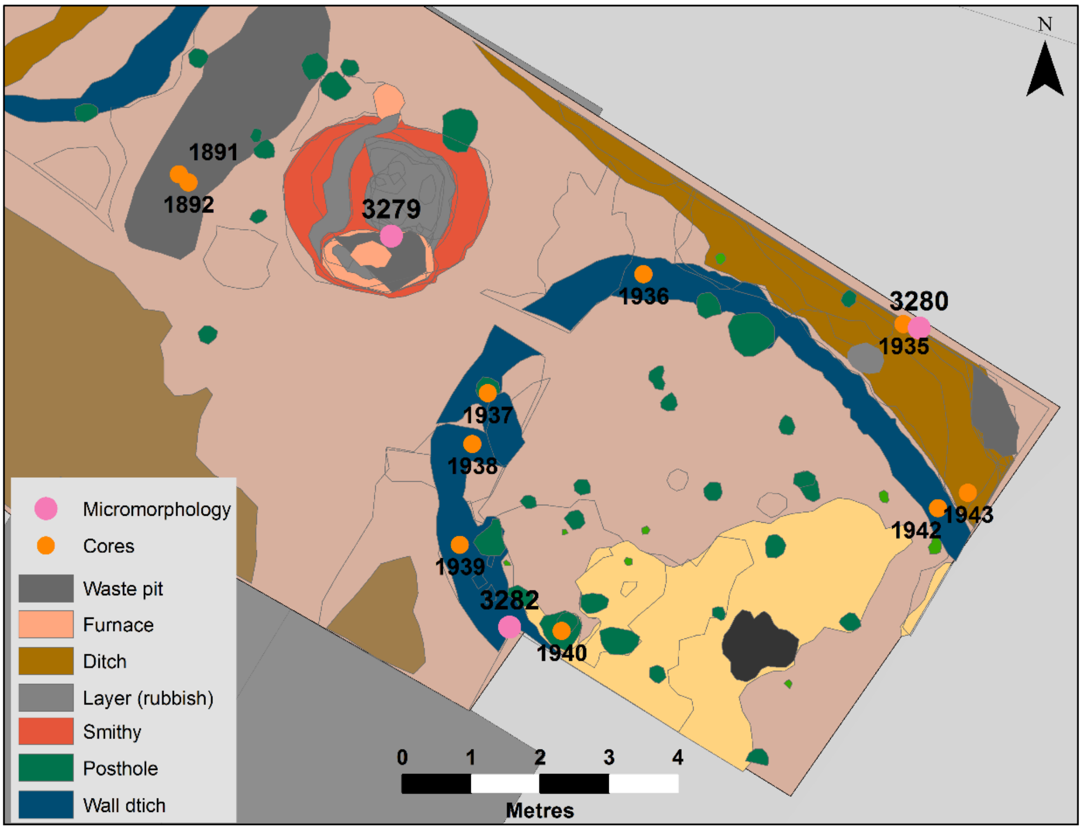

Figure 7. 20. The location of core and micromorphology samples on the Kaupangveien site. Map source: Author/MCH/Norwegian Mapping Authority 2016.

7.5.4 Bringing in the other data sources

The primary source of collaborative data is micromorphology, which confirms some interpretations. Figure 7.20 contains the core and micromorphology sample locations. Three monoliths were analysed by Richard Macphail, making a total of five thin sections (Macphail et al., 2016a). Sample 3282 was taken at the limit of excavation south of core 1939, in the wall ditch. The earliest fill of the wall ditch was a heterogeneous charcoal-rich fine fabric with beach sands from the beach layer it was dug into. The upper fill contains more burnt and unburnt organic matter, rock and bone fragments as well as charcoal. It was tentatively suggested that the layering present in the sample, particularly in the early layer, represented seasonal weathering. The sample from the ditch (3280) included hearth waste and imported marine clay loam that showed indications of in-situ frost damage. Both samples indicate Fe and/or Fe-P staining on roots. From the furnace the sampled layer showed fuel ash slags, imported clay, and slags from ferrous and non-ferrous metalworking (Macphail et al., 2016a). This broadly supports the overall interpretations, however, it does not greatly advance the chronology beyond the suggestion that the early phase was seasonal. The small scale of the site, and the limited resources, mean that interpretations are based on few samples and materials, which is clearly a limiting factor.

7.5.5 A valid application?

Commercial archaeology should not be overlooked when developing methods and approaches in archaeology, as it forms the bulk of the opportunities for archaeological excavation. Methods must function with slightly different remits in the rescue sector; therefore it is worth evaluating the success of the geochemical sampling here within those bounds. The first application of geochemical analysis on the site was in situ, using pXRF. It was done in order to assess whether the newly discovered smithy was for ferrous or non-ferrous metals, and whether the waste contexts should be sampled further. The high amount of non-ferrous metals led to further sampling, and soon finds of crucibles confirmed the interpretation. Whether the geochemical analysis of the smithy area has confirmed anything that a detailed analysis of the crucible and slag material cannot is currently not known, as that analysis has yet to be been completed. However, it can be suggested that the rapid results allowed the application of a more honed sampling strategy during the excavation. The cores 1891 and 1892 give little clue as to chronology, however confirm some homogeneity in the waste, in that non-ferrous metalworking composed the material throughout.

As for the house area, coring was a quick sampling method with chronological potential. It is slightly destructive, as discussed in chapter 2, but all sampling and excavation has a degree of accepted risk and damage. The results will be integrated with other sources, once the full post-excavation analysis is completed. Based upon the preliminary results presented here, the geochemistry may well aid the distinction of phases on the site, and also the co-relationship between the smithy and the house. That they co-existed implies a separation of specialist activities within the presumed plot. This spatial and chronological relationship could improve our understanding of the use of the managed and demarcated space within early urban contexts of the Viking Age.

7.6 Conclusions of chapter

The number of samples is related to resources and opportunity, and it seems that the ability to interpret spatial use is also directly correlated to the number of samples and their location. The cores and the geochemical data inferred chronological information, and broadly confirmed the interpretations from micromorphology and excavation, although the sample number is too low to infer spatial patterning on the horizontal plane. That chronology is evident here is purely a product of the metalworking evidence. If the central activity evidenced on this site had been otherwise, reliant on a range of organic inputs, then the soil processes, in particular the leaching, would have obscured temporal patterning.

The application to commercial archaeology, however, is valid. Coring, as a sample method, is rapid, as is in situ analysis using pXRF. These can be integrated within the commercial setting, and the sample locations and analysis honed toward the site based research questions.

8. Discussion

8.1 Introduction

Several themes will be lifted from the previous chapters for further debate and scrutiny here. What is chosen for discussion are those topics, issues or revelations that unite two or more case studies in a point removed from the numbers themselves, be it technical or theoretical. As these subjects are discussed, where relevant, the main guiding lines from the introductory chapters will be included. To set some logic to the proceedings, technical issues are considered before theoretical and archaeological. The final words are devoted to addressing the overall aim and objectives of this research.

8.2 The soil as a source

It is easy to lose sight of certain assumptions in archaeological geochemistry when the labels are made archaeological, and the interpretations related to archaeological features, human-made objects and how they all tie together in one big settlement picture. Geochemistry is essentially measuring the soil processes; its ability over time to breakdown and retain/redistribute organic and mineral inputs and disturbances. The time-frames archaeologists work on are generally superficial for soil formation, but still, the soil in all its organic and inorganic physical and chemical processes, will have decomposed, altered and utilised those inputs to some degree. Plants will have recycled them, readily using the abundant micro and macronutrients supplied by the high organic inputs imported from different climates and thus combating any local deficiencies. This occurs generation, after generation, after generation. Minerals are weathered, corroded, leached, adsorbed, reduced, taken into solution, oxidised and redeposited or lost to groundwater. We are relying on the inputs being so overwhelming, that the soil will not have been able to drastically redistribute or remove both the quantity and spatial patterning of those inputs in the superficial soil time that has passed since the human activity ceased. It is quite an assumption, and is one of the reasons that soil geochemistry is better suited to more recent human activity. The other reason is that technological developments introduce more diverse resources and increased specialisation into the human sphere, and sedentary settlement, which gives a greater potential for differentiation between activities.

Of the thirty two broad soil classifications and the innumerable sub-classifications each contains, fifteen are found in Norway. The case studies used in this research cover just three, albeit those, on a basis of cultivated land, are the more common (Solbakken et al., 2006). Even within these three sites, and even within the pedological horizons at Heimdalsjordet, it appears the interpretation of the archaeological features has to be on the terms of the pedological processes. This is an echo of Bethell and Smith's (1989) paper on the Sutton Hoo burial, where they concluded that the body in the grave did indeed have a chemical signature that was significantly different from the surrounding soil matrix, but that the signature was environmentally dependant (Bethell and Smith, 1989). In short, what signifies a body, or an activity on any one site, cannot be exported wholesale to another set of environmental conditions. Each site is unique, and the soil and archaeology make it so. In this vein of thought, analysing the whole sample, as pXRF does, has its advantages in that the dominant soil properties can be measured. These may well have the effect of 'drowning' out the anthropogenic, but in these case studies that has not prevented some archaeological interpretation. It could be argued it has made it more secure.

8.3 Chronology and space via coring and geochemistry

A theme that expands with each case study is whether cores and high resolution geochemistry on those cores using pXRF can equate to chronological changes in the archaeological material. A more conventional approach was tested at Avaldsnes, sampling a horizontal plane and a selected feature – however, there are flaws with this approach (section 2.6.4, section 5.5). As a multi-period site, when sampling one stratigraphic layer late in the excavation, the method becomes reliant on soil processes having paradoxically both leached and retained elemental enhancements from now removed phases and gathering them in one horizon. This can have some measured success, but it is not working with respect to the mechanisms within the soil the method relies upon. Alternatively, as was demonstrated by the limited cores at Avaldsnes, chronology could be represented in cores. This methodology was expanded for Heimdalsjordet, to test chronology and space from coring secondary deposits. The resultant geochemical data set not only indicates chronological change in the archaeological deposits, but by using a total method such as pXRF, the impact of the soil processes can be integrated into interpretations. This is also evident at Kaupangveien, with the strong leaching of P and Fe in the sandy subsoil.

There is a clear limitation as well. The most immediate is that contexts cannot be said to be directly related from one core to the next, even within the same feature. This curtails the possibilities for statistical analysis in three dimensions, and the interpretations of the use of space. On a technical note, it has been shown that direct measurement on undried cores tends to result in lower elemental values. These issues limit the data to general interpretations, which are dependent on change and contrast to assert chronological and spatial meaning to the data. This, in secondary deposits, due to the nature of their composition, and the nature of archaeological stratigraphy in general, means activity specific interpretations can be limited to the deposition itself. This is returned to in the next section.

Statistics and geochemistry go hand in hand. The volume of the data set requires reduction for meaning to be extracted and disseminated. The use of statistics in these case studies is similar, with PCA being the prime statistical test to reduce and thus interpret the data set. This method identifies soil processes and archaeological inputs, or at least what are here interpreted as such. By geochemically identifying both, using the same instrument, we can tailor expectations and interpretations on the background of similar premises. Oonk et al. (2009b) proposed using regional background geochemical data to form 'natural' background. However, this assumes a degree of homogeneity that is not necessarily real. Whilst regional and even international statistics are used in this thesis to some degree, it not assumed the figures can be directly related to the individual sites. In a similar vein, soil mapping data is used here to form a general impression, although on site observations are, needless to say, far more reliable and therefore carry far greater interpretive weight. Therefore contextual observation is the only means to ascribe the limit to the validity of interpretation, whether it be demonstrated via statistics or archaeological interpretation. This is a strong advantage of the coring method. Having cores available provides far more additional information on the representativeness of the sample, stratigraphical and pedological changes, and variation in archaeological deposits than can possibly be represented with small, squished and shaken sample bags full of soil. In taking a stratified piece of the site to the laboratory, and adjusting sampling according to research aims and site conditions, far more information is gathered. It is the cores that allow chronological interpretations, whereas spatial interpretations are more easily achieved on the horizontal plane, as at Avaldsnes. Despite this, from an archaeological and pedological perspective, this has the same inherent problems as listed above.

8.4 Additional variables

As considered previously in the discussion, and in relation to each case study through the interpretation process, soil processes govern elemental retention. In previous work, factors such as pH, particle size, conductivity, and organic content have been measured in conjunction with geochemical analysis (e.g. Crowther, 1997, Entwistle, 2000, Oonk et al., 2009a, Linderholm, 2010, Cannell, 2011, Milek and Roberts, 2013). To some extent, these factors can be coarsely determined in the field by observation during sampling, in reference to the soil type and thus properties. Where there is analysis on a horizontal plane, and/or confined to a single context, the need for additional parameters is perhaps reduced, as the samples must be considered comparable in soil/sediment properties for the method to be attempted. When the sample set consist of material from varied contexts with heterogeneous or highly diverse matrix types, then factors such as organic content, pH and particle size will affect relative retention capacity. Essentially, the cation exchange capacity of the soil, which is a measurement of the soil's negative charge and thus retention capacity for cations, is dependent upon pH and the soil's organic and inorganic colloid composition (Birkeland, 1999). This can be measured, or alternatively organic content as measured by LOI, pH and particle size can be used as coarse proxies. They measure slightly different things, however, the point is that these factors can and do govern elemental retention, and when comparing significantly different soil matrices, the effects of soil composition can affect retention. Thus geochemical variation can be a product of this rather than input.

It is not to suggest that measuring all parameters is necessary in every case, as stated, observation can provide key indications, although it will be considered for future work, on a case by case basis.

8.5 Contextual security and secondary contexts

This brings us to the gap between sciences and excavation and humanities in archaeology. Ideally they should all converge on the archaeological site itself, and increasingly, they do. Still, sampling for archaeological geochemistry in the commercial sector is not always done by the scientist or geoarchaeologist. Contextual scrutiny is not solely from a pedological perspective, but also an archaeological one, in order to assess what is actually being measured. This requires communication and collaboration.

To steer to the archaeological, secondary contexts as a source have potential. Just as Andrén (1985) suggested that the 'latent', or the unintentional, meaning can still be extracted. Grabowski (2014), in a study of Iron Age settlements in southern Scandinavia, uses posthole backfills for magnetic susceptibility, fractionated phosphate and macro-fossil analysis. These are secondary deposits on truncated sites. The aim was to define the functional areas within the longhouse and/or settlement, and had measured success. This is essential use of the sources we have, but it should not be used indiscriminately or without source criticism. Gustafson (2005), in an attempt to date a longhouse from the same period, sampled the backfill of every posthole and therefore secondary deposits. They found that the resultant dates spread over several thousand years, and serves as an example for the fact that the use and usefulness of secondary deposits depends on the aim, purpose and in situ assessment.

The potential is site dependant. As suggested above, secondary deposits limit interpretations to the general or the easily recognisable. This is in contrast to Avaldsnes, where geochemical interpretation could be a little more specific because a greater volume of collaborative evidence was available, and because sampling had a greater spatial dimension. Sampling on the horizontal plane certainly has spatial benefits, however as evidenced from the other case studies, this is not always a suitable approach. The degree of leaching of certain elements at Kaupangveien means that horizontally sampling the sandy subsoil within the house context for spatial assessment would result in a highly skewed picture, and at Heimdalsjordet, the degree of truncation would bring into question what was actually being measured.

One activity that has been repeatedly identified is non-ferrous metalworking. The term is in itself problematic (Pedersen, 2016), especially as the finds evidence from Kaupangveien suggest that secondary iron working was occurring at the same smithy (McGraw, in prep), however, it is used here as an umbrella term to identify the main source of the geochemical enhancement. The reoccurrence of this craft in all case studies is a consequence of two factors: firstly the type of settlements the case studies represent. Proto-urban sites such as Kaupang and Heimdalsjordet are the most likely place for such activities to be located (Söderberg, 2004). Due to the imported nature of the raw materials, and the select group the manufactured objects served, non-ferrous metalworking is largely confined to the trading or urban site (Sindbæk, 2007). The only other type of site where non-ferrous metalworking has been located in Viking Age Scandinavia is the estate centre, or the Manor, if you will. Sites such as the substantial high status site of Tissø in Denmark and Jarrestad in Sweden, both contained evidence for non-ferrous metalworking (Jørgensen, 2002, 2008, Grandin and Hjarthner, 2003). These central places that emerged from the Migration Period onward, initially performed many of the functions that later were transferred to the trading centre (Gansum, 2009).

Secondly, a more minor factor in terms of influence compared to the type of sites represented here, is that instrument and method do influence what is detected and interpreted. A weakness of pXRF named in chapter 3 is the low resolution for lighter elements (section 3.4.2). For the elements typical of non-ferrous metalworking (Cu, Zn, Sn, Pb), the instrument has a resolution of around 10 ppm. High levels of Pb produce a strong instrument response, with the energy of the K and L lines having the potential to dominate the detection by the instrument. Moreover, Forster et al. (2011) found that heavier elements (≥26 Fe) were also less vulnerable to matrix effects and air attenuation than lighter elements. Connected to this is our ability to interpret. Many activities that could potentially be present on a Viking Age trading site, such as glass bead making or bone/antler working, do not have such a distinct ‘signature’ as non-ferrous metalworking. When considering a horizontal plane, such as a floor, the patterning may indicate high inputs of dyes, imported sands or ‘foreign’ material if it produces a distinct cluster. When primarily working with secondary deposits, a distinct cluster is less likely to occur. Coupled with the lack of an accepted ‘signature’ for an activity, this makes detection and determination challenging. Previously, multi-elemental approaches have successfully identified craft production activities, such as Parnell et al. (2002) connecting heavy metals such as Hg, Pb and Zn to pigment making, and Fleischer and Sulas (2015) identifying fishing, coral extraction and bead making through combinations of elemental enhancement. These interpretations are possible by culturally specific knowledge, or context. Even then, many activities that produce primarily organic remains will be drowned out in the mass of high organic inputs in the secondary contexts. This issue will perhaps require further experimental and archaeological work to resolve. As non-ferrous metalworking is the common to all sites, it is considered in the next section.

8.6 Non-ferrous metalworking

In the case studies presented, two furnaces used for non-ferrous metalworking are presented. At Heimdalsjordet, little more remains than a circular clay disk in the earth, whereas the Kaupangveien example is a little better preserved. Even so, they are both constructed of clay materials, and waste is the prime evidence for function. This is due to the methods used in the late Iron Age and Early Medieval period, requiring little in the way of a permanent or built structure. A crucible could be heated over a small clay-built oven or furnace with small, portable bellows, and the object cast in a clay mould. Crucibles can be reused, and clay moulds can be thrown away in another location, reused as temper or, as they are fragile, simply disintegrate over time (Pedersen, 2016). As a result, the process as a whole, especially for occasional repair or production, could leave minimal physical evidence (see figures 8.1 a & b) (Söderberg, 2004).

Figure 8. 1a & b. Experimental/re-enactment metalworking at the Oslo MIddelalder Festival (Oslo Medieval Festival), using a furnace made of tempered clay and wood. The bellows are portable. In the upper image, the crucible holding melted bronze is being lifted from the furnace. Note that the use of this furnace over the course of two or three days leaves little trace and debris. Photo: Author, taken with permission.

The pouring of the molten metal and the later filing of the product may result in some fine waste, but as Pedersen (2010) notes for more precious metals, there is an obvious degree of care in regard to minimising loss of the metal during production. Casting workshops have now been found at Ribe and Birka, but again the most prominent evidence is from the waste itself in the form of moulds, crucibles etc. (Feveile and Jensen, 2000). In the absence of floors or furnaces, for alternative sources of information, hearths have been turned to, although this is far from common. Cook et al. (2009), investigated hearths in the Roman town of Silchester to determine their use. This successfully identified metalworking in hearths, some of which would otherwise have been interpreted as potentially domestic. Therefore non-ferrous metalworking on smaller scales, such as lead working or repair, could easily go undetected in excavation (Söderberg, 2004, Pedersen, 2016). This skews the picture somewhat toward the exclusivity of the practice in urban and elite contexts. This is where the practice was perhaps the most skilled and intensive, however, it is not necessarily the only form. Potentially, therefore, pXRF or more routine geochemical analysis can expand this picture.

8.7 Proto-urban space and definition

Unlike continental Europe, Scandinavia had little permanent urban development prior to the beginning of Viking Age. Toward the end of the Merovingian period, urban sites such as Ribe and Birka began to develop, however it was in the Viking Age that urbanism developed and expanded (Ambrosiani, 2008, Skre, 2008, Croix, 2015). One question that the geochemistry has not been able to fully answer is whether the parcel ditches at Heimdalsjordet relate to buildings and permanent settlement, and therefore if this site is comparable to the nearby Kaupang in terms of trade *and* urban cultural development. Whilst the Heimdalsjordet site is smaller in terms of settlement area and the associated cemetery, whether it can be considered proto-urban or urban is not necessarily size dependant. It is based upon economic functions aside from subsistence, craft production specialisation, political control, international trade and exchange, planning, and permanency of residence (Skre, 2007b, 2008, Croix, 2015). For the question to be addressed, the settlements have to be put in context.

The context to consider is not solely, as others have focused upon, other early urban sites in Northern Europe (Sindbæk, 2007, Skre, 2008), but the settlement tradition in the hinterland. In eastern Norway, known late Iron Age settlements are usually composed of one or more longhouses, with one building being the most common, and secondary buildings have functions other than as a main residence. The longhouse is a feature of past settlement in Scandinavia that has endured since the late Neolithic, and into the Bronze Age. Although changing slightly in form, building materials, techniques and landscape location, the settlement form dominated by the longhouse endured into the Viking Age. Therefore, for near three thousand years, settlement and space were constrained and created by the longhouse. Within the longhouse construction, in all periods there is also variation in the placement and number of entrances, hearth placement, internal divisions, the inclusion of a byre, landscape location, orientation, and size, reflecting local traditions, society’s changing hierarchical constitution, local climatic conditions and materials. For a discussion on the definition of the longhouse in Iron Age Norway, the reader is referred to Hem Eriksen, (2015) and Herschend (2009). In her thesis, Hem Eriksen observed that throughout the Iron Age, over eighty percent of longhouses in her study were three-aisled buildings, often with convex walls, with a central hearth room/area. As the Iron Age progresses, the general trend is for houses to become shorter as the byre is removed to an ancillary building(s), and the internal divisions within the residence increase as society becomes more stratified (Herschend, 2009, Hem Eriksen, 2015). A high proportion are also orientated north south, with doors placed on the long side and not the gable end. As Hem Eriksen emphasises, over such a diverse climatic landscape as Scandinavia, over the duration of the Iron Age, if not longer, what is surprising are the similarities. Even the emergence of the Hall in the Roman Iron Age elaborates upon existing architectural norms, rather than diverging from them.

Referring back to section 2.5, the ‘spatial repertoire’ of the longhouse, thus what an abode should be, was highly conservative in Iron Age southern Scandinavia. This does not mean longhouses from all sub-periods and regions conveyed the same meaning, but the longhouse was *the* culturally acceptable form of house and home for many generations.

To return focus to the Viking Age, in eastern Norway, eleven longhouses have been excavated and dated to the Viking Age. To illustrate the variation within longhouse building traditions, these will be briefly considered. The preservation varies, but all are post built, timber houses between 11 and 50 m in length, and up to 9.3 m wide. Most have three aisles, although a one aisled house from the Viking Period was excavated at Garder, Østre, Akershus. Some, such as those at Åker gård, Hedmark and the 50 m long house excavated at Bjørnstad Søndre, Østfold, have rooms with a greater span between trestles, creating a large space often interpreted as a ‘hall’ room, and thus a high status room with controlled access to people in the upper strata of society. Again, slightly convex walls are the most common, however not universal (Hem Eriksen, 2015).

The picture becomes a little more varied when the rest of Norway is considered, but the roomed, aisled, longhouse dominates. Therefore the trading sites at Heimdaljordet and Kaupang(veien), with small, similar parcels of land for dwellings, located close together along a thoroughfare, represent a markedly different type of dwelling, comparable to other urban centres in north western Europe. The house at Kaupangveien is small, with a reasonably central hearth, yes, and as was becoming more common in the late Iron Age, the walls bear weight. The entrance is on the short side of the house, and the walls are possibly curved reminiscent of houses from 10th century Dublin (Wallace, 2016). The larger Kaupang excavation also found house remains of similar dimensions divided by ditch and thoroughfare (Pilø, 2007). These two sites, occupied at the same time but with differing trade connections, fulfilled similar cultural and economic functions in a similar climate and society, but on different scales. They have common traits with other (near) contemporary proto-urban settlements such as York, Dublin, Birka and Ribe (Feveile and Jensen, 2000, Ambrosiani, 2008, Hall et al., 2014, Wallace, 2016), although Bill and Rødsrud (in press) note that the parcel ditches are not quite as regular as other comparable sites. For early Ribe (AD 670-820), Croix points to the broad similarities in early urban architecture to Hamwic, Lundenwic, Birka, and Kaupang (Croix, 2015).

Considering the hinterland again, where for three thousand years it must have been a given that dwellings had those certain irreducible features of the longhouse and the isolated farmstead, to change this to a proto-urban form cannot be understated in terms of social, economic and cultural change. It is not to imply that people were not aware of coastal trading sites or urban sites further south and east, however, as the house, and the farm was a deeply embedded mental and economic unit, the change must have involved internal and external pressures, opportunities, adaption and fundamental economic changes. These are materialised in the form of the settlement, at Heimdalsjordet and at Kaupang. Life in the urban is profoundly different. Kinship is no longer the primary source of alignment between neighbours, subsistence is dependent on others, and identity becomes more internalised, and pronounced (Barth, 1969, Gansum, 2009).

Considering this, in a time of change for an architecturally conservative culture, to assume that the settlements at Heimdalsjordet and Kaupang had radically different modes of functioning in terms of building and residency would be bizarre. Whilst lack of evidence from the truncated Heimdalsjordet parcels makes way for possibilities of every kind, to make a bold cultural exception from this defies the macro-scale evidence. There is little reason to assume the settlement and houses established at Kaupang and Heimdalsjordet were *not* similar, despite the differences in scale. If we accept that built urban type houses are likely, such built structures within an urban-like layout does not necessarily mean *urbanism*, as according to current definitions, it is economic and political functions that define (Skre, 2007a, Skre, 2008, Gansum, 2009).

Alternatively, (proto) urbanism can be seen as an elite imposition, and an attempt to control resources and thus preserve status. As the definitions of urbanism are often intrinsically linked to elite theory and control, including planning and management of the settlement, by some this is seen to be the case (Skre, 2008). A third alternative was proposed by Sindbæk (2007), which centres around the international network as testified by certain key finds on each potential urban site, and it is the network that defines status as urban. The means of comparison are the concentration of key imports, such as Badorf ware, in excavated contexts. The issue with this assessment is preservation. In sites where thick cultural layers are preserved, which are broadly comparable in date, this is perhaps a valid assessment. Such preservation is not evident in the cases in this thesis. The other criteria Sindbæk proposes are categories of craft production that utilised raw materials that are very specifically sourced, such as copper alloy working. This contrasts to, for example, comb making, that whilst it requires skill, the materials can be readily acquired. Therefore we find that Heimdalsjordet falls within and without current definitions based upon the perspective of the definition.

For Kaupang, there is evidence that the first phase of the site was seasonal, which lasted for a decade or so before occupation became year-round (Pilø, 2007, Pedersen and Pilø, 2007). As evidenced in chapter 6, from the geochemistry and micromorphology, the first phase of settlement at Heimdalsjordet has a lesser impact on the soils and sediments accumulated in the parcel ditches. As also evidenced, ditches were re-dug or cleaned out. The later phase in evidence appears to have contributed more to the accumulating soils and sediments, representing a more diverse range of activities and more intense inputs. What is missing from between these phases is impossible to know. As it stands, there is a *possibility* that Heimdalsjordet too went from seasonal to permanent over the course of the early 800's, simultaneously expanding the types of production represented, and consequently increasing the amount of waste produced.

Perhaps the layout of the site, with its central thoroughfare, ditches segmenting the plots that stretched back toward the coast or hinterland cemetery do not necessarily need to have the correct imported ware to be classed as urban, or the 'right' specialist functions controlled by an elite. Perhaps the settlement morphology, and by this the spatial repertoire of urbanism, should be the focus. This is what urbanism, in all its social connotations *looked* like to those that built, commanded or resided in it. That was what was being emulated, and this form was found in early Birka, Ribe, Kaupang and later repeated in places like Dublin and York. Heimdalsjordet cannot compare in terms of volume and range of imported goods to all those listed, yet the intent in the creation of the spatial formation was the message it was designed to emulate. It was the language it was trying to speak to the viewer, just as Avaldsnes, with its hall building and divided production areas was speaking the same language as other contemporary manorial sites. In Heimdalsjordet, the statement is perhaps aspirational, but it should not be seen as the pretender to the throne. Coastal trading sites existed up and down the coast, in various guises and sizes, performing one or more of the central functions that characterise and define the 'urban' (Brendalsmo et al., 2009). By wrapping ourselves up in the purity of definition we become more intent on our own criteria, than those of the past (Gansum, 2009). It was their understanding, not ours, that created a spatial format to be followed, or imitated. It was their understanding of a trading site and central place demonstrated via structured space.

Once in the settlement, the spatial language of urbanism continues, in that for Heimdalsjordet at least, life happened beside the thoroughfare. The artery of any central place is what everything is orientated toward, including where specialist production occurred and waste accumulated. Tuan (1977) suggested that buildings, settlements and even urban centres have both ‘front’ and ‘back’ spaces that are socially constructed and recognised. Hem Eriksen (2015) adds to this by suggesting internal spaces within houses also had clear notions of front and back, defined by doors and thresholds. We see this in the Heimdalsjordet evidence that the front of the house and settlement was the street, and the back was away from it, where less happened, or less was disposed of.

8.8 From the beginning

This thesis began with an essay on the opposing poles of science and humanities. These were deemed dysfunctional, and a product of learning and repetition rather than a fruitful structure for research. Just prior to the completion of this thesis, Sinclair (2016) published an article with visual representations of terms, authors and sources in archaeological research from 2004 to 2013. The data is drawn from citation indexes. Looking at the visual web of terms, the clusters are clear. There is a near hollow in the centre, surrounded by groups that represent dating methods, landscape and geophysical survey, core archaeological terms, genetics, diet and mobility, environmental change, and scientific practice in archaeology. They exist as clusters, conjoined in parts, however the poles still exist. Scientific practice and archaeology have virtually no shared terms, nor does it with the core practice of archaeology. Much as progress was cited in chapter 2, it is still a real phenomenon which is compounded by the common form of publication channels. We emulate the peer group, and reinforce the boundaries. Whether this thesis had made any headway into that void or simply produced ‘silo science’ is a matter of opinion and in presenting this data the challenges of crossing that divide have become ever more apparent. It is not only demanding from the perspective of the author, but also the reader. Comprehending terminology and complex social or scientific phenomena demands more of both parties, and is perhaps another reason for calling on greater collaboration and clearer language to be the aim. We must encroach on the void to enrich our understanding of the past, the means we use to do this maybe already becoming apparent in the form of open-access publication and greater use of media outlets to disseminate beyond our own little research bubbles to a wider public and academic audience.

9. Thesis Conclusions

Through the three case studies, different approaches have been applied to differing archaeological and environmental conditions, on sites dating from the Viking Age in southern Norway. The uniting factors are the use of pXRF for archaeological geochemistry, using either in situ, direct core measurements, with sample pre-treatment for laboratory analysis, or a combination of all approaches. Sampling on the horizontal plane and the vertical via coring has been attempted to assess spatial and temporal aspects of archaeological deposits as measured by geochemistry. What has become clear, at least to the author, is that this flexibility is only possible through the use of pXRF as the analytical tool. Portable XRF removes the degree of separation between analysis and archaeology, by allowing the instrument to come to the archaeology, and analysis to be applied as the archaeology requires. Creating responsive approaches allows geochemistry to be honed to the archaeology, rather than vice versa. Although boundaries are still set by the archaeologist, this at least moves us away from the rigid, one-horizon grid and the instrument operated in some distant laboratory. Much as this grid approach worked well at Avaldsnes, it would have been uninformative at Heimdalsjordet or Kaupangveien.

Engaging in the third dimension of site formation and acknowledging that contexts and geochemical traces are formed through a plethora of anthropogenic and natural processes complicates interpretation. The ‘whole’ method of analysis that XRF represents can have the effect of the natural ‘drowning’ out the anthropogenic inputs. However, this drawback is more than offset by the detail provided for the local soil processes, which are of course decisive in the retention and form of macro- and micro-trace elements. The application of coring, and the consequential ability to measure challenging secondary contexts in vertical formation, expands the range of archaeological geochemistry. Questions of contextual security may seem to become more acute with this method, however, all sampled archaeological contexts should be interrogated for contextual information and formation, regardless of the sampling method. A flexible sampling approach, truly integrated within excavation in the commercial and research sectors, will be able to treat each site and research aim as unique, and tailor the approach accordingly.

Within the field of archaeological geochemistry, pXRF has this potential. It can enable rapid, affordable analysis, honed to site specific approaches. It is non-destructive and accessible, and the data produced is only ever as relevant as the research question. There is little doubt that the use of pXRF will continue to grow, and it should. The greater issue is with archaeological geochemistry itself rather than the instrument used. For what could be labelled craft production, or at least non-subsistence activities such as non-ferrous metalworking or glass making, the distinct enhancement of certain elements within occupational deposits or even the ploughed topsoil, geochemistry can be a great benefit to archaeological investigations. From the spatial patterning in three dimensions, we can begin to understand the use of space on a far more nuanced level, and this research has demonstrated that phasing and chronology in geochemistry is not beyond reach. The issue is when we step away from the distinct, and really consider what we are measuring. Within the more vague areas of general habitation, field management and household practices, where organic processes dominate, geochemistry struggles to define the specific. Enhancement of P and Ca are not necessarily just bone, and soil processes can easily augment or diminish any clear spatial patterning via leaching or eluviation. Some would perhaps argue that as pXRF cannot measure lighter elements such as P, S and Mg to a high resolution or precision, that other instrumentation methods are required. ICP-MS and various extraction methods theoretically extract the soil phases we are interested in, and the instrument has far better resolution and precision. However, measuring something more precisely does not answer the question of whether what we are measuring is representative beyond the general. It often takes micromorphology to identify the primary and secondary minerals formations that result from the combination of past human occupation and centuries of soil processes. Away from the industrial or the craft production that imports large quantities of non-local minerals and metals to a small area, geochemistry cannot stand alone and produce meaningful and reliable, specific interpretations, no matter the instrumentation.

This should not be cause for pessimism. There is potential. Using geochemistry intuitively, which pXRF allows, a combination of methods can provide complimentary micro- and macro-scale analysis to meet the archaeology. The disadvantage of micromorphology is often the cost, and that it represents one point only. The disadvantage of geochemistry is that has a questionable ability to understand past use of space, without fully knowing what soil and anthropogenic processes have caused them. If geochemistry can begin to add chronology, even on broad terms, then a combination of in situ analysis, coring and sampling can be combined to better plan where to concentrate efforts, and where it requires the ‘back up’ of a more detailed, laboratory based approach and micromorphology. This research has also demonstrated that even truncated sites have untapped potential. If we embrace this, then perhaps, both the how and why of spatial and temporal patterning may bring us closer to understanding past lives.

Moving away from the technical, the contribution this research has provided to these case studies and Viking Age archaeology in Norway should be considered. Within each of the case studies, the geochemical analysis provided data on the past use of the sites that could not be otherwise obtained. Whilst on sites such as Kaupangveien, the details of the metalworking will be discovered in far greater technical and cultural information via analysis of the finds, the budget is not limitless, and therefore not every fragment can be assessed in detail. Geochemistry provided a broad background for the waste accumulation and the range of metals worked, onto which the more detailed evidence can be added. The more nuanced chronology of the house construction and its phases can now be tightly related to the use of the smithy area, from the geochemical traces found in the postholes. Therefore even with this limited data set on a small site, intuitive geochemical sampling and analysis contributes to our understanding of the site.

In the case of Avaldsnes, the careful integration of the various data sources has led to a greater spatial understanding of an important area of the site. The combination of macro-fossil, micromorphological and geochemical analysis enhanced our understanding of settlement activities and distribution over time. In addition, although the evidence for non-ferrous metalworking here is slight, without the geochemical analysis there would be none. From this, the longevity or impact and spatial endurance of activities such as food processing, can be compared to the intermittent, fleeting traces of other activities such as metalworking, creating a far more detailed picture of the site was a whole.

Heimdalsjordet represents what can be achieved through an integrated, reflective approach on even the most truncated archaeological sites, where all that remains are secondary backfills and ploughed up finds. The data presented here allows our interpretations to begin to understand the changing use of the site over the Viking Age, and how it was formed and lived in. We can also begin to imagine a picture of a life lived via the thoroughfare, in view, in public, with perhaps the rear of houses and plots forming a more private or domestic role. It takes us a step closer to understanding the habits of those that made the settlement.

It is now clear that metalworking was more widely practiced that previously thought. Without the geochemical data, the two potential ovens would not have been so clearly identified, if at all. Non-ferrous metalworking is very rarely detected in late Iron Age contexts in Norway. The only other example known was excavated in 2013-14 at Sømmevågen, in south-western Norway, and is dated to the late Merovingian Period/Early Viking Age. As at the larger Kaupang site, the identification here is purely through waste materials; the actual oven remains were not found (Meling, 2015). Therefore the examples presented here are currently the only known examples where the oven form and/or location is recorded. At Heimdalsjordet, there is even a hint of how the smith worked, and what with. This greatly expands our knowledge of the technical and cultural role metalworking had in the changing society of the Viking Age.

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