

Department of historical, philosophical and religious studies
Umeå University, SE-901 87 Umeå, Sweden

The soil as a source material in archaeology.

Theoretical considerations and pragmatic applications.

Johan Linderholm

Akademisk avhandling

som med vederbörligt tillstånd av Rektorsämbetet vid Umeå universitet för avläggande av filosofie doktorsexamen framläggs till offentligt försvar i Hörsal F, Humanisthuset, Fredagen den 12 mars, kl. 10:00.

Avhandlingen kommer att försvaras på engelska.

Fakultetsopponent: Professor, Martin Bell,
Department of Archaeology, University of Reading, Reading, Great Britain.



Organisation,
Umeå University
Department of historical,
philosophical and religious studies
SE-901 87 UMEÅ
SWEDEN

Document type
DOCTORAL THESIS

Author
Johan Linderholm

Title
The soil as a source material in archaeology. Theoretical considerations and pragmatic applications.

Abstract

This thesis deals with questions on various applications using soils and sediments as sources of information in archaeological research. Human environmental impact on soils and sediments, in terms of pollution, is a well known phenomenon as the industrialisation intensified during historical times and onwards and has left strong pollutive marks. However, humans have always accumulated or emitted matter and various compounds in connection to their habitats for subsistence, but these earlier traces are not always detectable, depending on soil and sediment state of preservation. Bioessential elements are intimately linked to humans and their dwellings and especially phosphate has been evident in this respect. It was established already in the 1930s, that even Stone Age settlements could be located through elevated phosphate content in extensive soil phosphate mappings. This thesis is a compilation on results from several sites and excavations from the southern to the northern parts of Sweden. There is a wide variety of soil types and chronological setting in the material, from highly acid podzols to calcareous soils, and sediments dated to Younger Dryas to current top soils. Sites from the Mesolithic, Neolithic, Bronze Age, Early and Late Iron Age and Medieval are all represented. Methods that have been implemented are firstly various forms of analysis in regards to soil phosphate, magnetic susceptibility and organic matter. Furthermore, metal and non-metal elements have been considered, as well as lead isotopes. A multiproxy approach is applied in some examples where biological and chemical data is combined to interpret past events. In this thesis there are also five papers presented. The first paper deals with methodological issues concerning multi-element analyses of various soil samples (off-site to feature) from an archaeological excavation. The second paper is about the possibilities that may be used when analysing the soil organic phosphate in relation to prehistoric agriculture. Paper three and fourth are compilations of large scale contract archaeological project. These papers deal with theoretical, methodological and practical issues concerning environmental archaeology in relation to contract archaeology. Studies on landscape development and erosion are among the cases presented. The last paper deals with a late Mesolithic - early Neolithic settlement in Vuollerim, N. Sweden, and spatial dimensions on the human use of settlement (off-site to on-site) and house floors (intra-site), are discussed.

Keywords

Environmental archaeology, Geoarchaeology, Prehistory, Soil phosphate, Magnetic susceptibility, Soil chemistry, Site formation processes, Soil erosion

Language: English (Svenska)
ISSN: 0281-5877
ISBN: 978-91-7264-944-6
Number of Pages: 26 + 5 papers

Archaeology and Environment 25

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Theoretical Considerations and
Pragmatic Applications.**

Johan Linderholm

Environmental Archaeology Lab.

Department of historical, philosophical and religious studies

2010



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Printed by VMC KBC house, Umeå University
ISBN 978-91-7264-944-6
ISSN 0281-5877

Foreword

After the 10 years of battle at Troy and upon returning home to his beloved Ithaka, Odysseus was given, by Aiolos the god of all winds, a bag with all but the westerly wind entrapped, so that when sails were set for home the journey would be easy. As Odysseus and his crew sighted Ithaka, the bag was opened and unleashed a storm that tossed him and his men away on another 10 year escapade. Whatever went through the mind of Odysseus as the bag was opened I would like to know. Mixed emotions I would guess, since he was brought on a remarkably audacious trip and it took him some time to make it home. But that's life taking unexpected turns.

Before I recount my own Odyssey, an expression of gratitude for financial support is in place. The finalisation of this thesis was made possible through grants instigated through the Umeå University plan of action 2007-2009, "Projekt 11". Grants from the Kempe foundation and Göran Gustafssons Stiftelse för natur och miljö i Lappland, made various analytical efforts possible. The Wallenberg foundation and Gösta Skoglunds minnesfond made it possible to take part in several stimulating conferences, and this also applies for the Faculty of Arts.

Over the years I have been involved in many contract archaeological projects. As always, there are stories connected to all the various sites and their excavations. Each and every one of these places and projects would deserve a narrative, but that's another thesis, in another discipline. Nevertheless, since the last study in the thesis, the Vuollerim site, was in reality the first, a short narrative will be given here. My first visit to the Vuollerim area and the Raä 1292 site was as a undergraduate student, in late August of 1983, when finishing my last week of basic training in field archaeology. Here, I ended up in the south-east corner of one of the subterranean houses (Norpan 2), sieving during the days soil collected from a few square meters and in the evenings, cleaning and classifying findings and enjoying baked beans and salted pork as staple food. The archaeologists working here at the time, Lars Forsberg, David Loeffler and Ulf Westfal made quite an impression, and maybe this was the first occasion I got hooked on archaeology. During the months of May and June of 1984, I was given the opportunity to come back and work with soil phosphate studies. Throughout the sampling, I worked with local people that provided me invaluable knowledge on how to handle the invasion of privacy by mosquitoes. The ground was still frozen in parts of the area (in early June), which was a bit unforeseen and furthermore, a small but very active underground wasp nest was present inside of the remains of the house called Lasses hydda, which made sampling in this part of the house particularly problematic. We may do many things in the name of science, but we don't mess around with wasps, and these kinds of adversities never make their way in the scientific narrative. However, the second and major hook came later, in the embryonic stages of the environmental archaeology laboratory, when the dirt turned into soil.

Now, Odysseus was one of the smartest of the Greek heroes, whereas I'm not and without the help from my fellow travellers I surely would have been lost at sea long ago. To all of you I send my sincere appreciation and gratitude:

Firstly, Roger Engelmark, without whom navigation through this scientific odyssey would have been far more difficult, less interesting, less gastronomic and absolutely less fun.

Karin Viklund, for generously sharing competence, humour and consideration. We embarked on this venture in September of 1982 and now, quite many years later, we are still sailing the same old boat.

During my early years at the department of archaeology I was fortunate to have Evert Baudou as a most inspiring teacher and the seminars at the department were crowded, informative and stimulating. A similar atmosphere is something I wish for the coming doctoral students in Archaeology.

There is a bundle of people at the department of chemistry in Umeå that have been most helpful. However, a special mentioning goes to Erik Lundberg and Lars-Olof Öhman, for taking an interest in matters beyond their discipline.

Richard Macphail, Gill Cruise (and Flora) for hospitality and stimulating scientific cooperation over the years (someone still owes me a trip to Beaune!).

Paul Buckland for helping out with various matters of science and linguistics, especially in the last decisive stages of this work.

Anne-Charlotte Ek, for encouragement and for being Anta.

Johan Olofsson, for all the fun during the many field campaigns (and his impeccable sense of location), lab work and for helping me through the GIS maze. Phil Buckland, for patiently withstanding my computer needs and of course for his devotion and enthusiasm for the Swedish traditional cuisine and language. To all present and former MAL affiliates: Krister Efverström, Erik Eriksson, Stefan Gustafsson, Peter Holmblad, Nina Karlsson, Jan-Erik Wallin. Good colleagues simply make work more interesting and enjoyable! The same goes for Helena "Skylla" Andersson, Karolina Karlsson, Sara "Charybdis" Norberg, Sofia Sjöström, Åsa Zetterström, all who meticulously analysed loads of samples and kept the boat from sinking.

And of course I met some sirens on the way (quite ugly though), disguised under peculiar orchestral names such as Baggot Street and more... If I had known where this engagement would lead I would probably have put loads of beeswax in my ears and strapped myself to the ships mast. Still, we had so much fun and I owe them all to "play it simple".

My parents in law, for all the "babysitting" in times of need.

My mother, for never losing hope in my "homecoming" and for introducing me to all the classic stories in the literature. As for my father, Laertes in this short story, 20 years was to 10 years to many. He is greatly missed and I wish we could stand by the beech and just talk for a while. Still, he had faith in that I would get here in the end.

I've also been fortunate in that my spouse, Malin, has also been on board throughout this journey, sharing the joys and hardships. For us, this is not end of the journey, as we have many more Greek islands to discover. And who would be better to share these coming adventures with, than you? Finally, my two Telemakos in the tale, Agnes and Edvard, they boarded the ship in midterm and have been by my side ever since. I'm glad I didn't have to return to a couple of teenagers.

I made it to Ithaka last year, and as I swam ashore onto the pebbled beach, I felt reassured.

And now when this is done, there is a leaning tower in Pisa I need to climb.

Ithaka August 2009 and Umeå January 2010

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Papers I-V

Appendix, paper IV

"Science is about learning, not knowing"
Deena Dincauze

"Earth to earth, ashes to ashes, dust to dust..."

"Av jord är du kommen..."

"Markens minne är långt..."

"the Soil Memory goes far..." [author's translation]

Ur Förflutenhetens landskap...
Peter Englund

Introduction

Background

The Swedish author Wilhelm Moberg stated in his book from 1970, “A history of the Swedish people...” that, “the Swedish soil is our greatest national archive – an archive that has still only to a small extent been opened or studied” (Moberg 1970:32). He was probably not referring to the soil as such, rather to the items and artefacts found in the soil by excavating archaeologists. However, progress of soil research in relation to archaeology could be said to have given his statement a far broader meaning than was initially intended. Soils could easily be seen as archives in themselves, containing information on past human affairs and possible to “open to read” unravelling previous events.

Browsing through the literature, titles like “*Soils of the past...*” (Retallack 2001) or “*The Soils of the Tomorrow...*” (Dazzi, & Costantini 2008) show an all encompassing interest. Other titles like “*Soil and Soul: The Symbolic world of Russiannes*” (Hellberg-Hirn 1998) or “*Mother Earth: soil and people relationships...*” (Sampietro Vattuone et al 2008), gives another insight into the extent of this topic. The concept of soil has been used in political rhetoric, and is exemplified by the “*Blut und Boden*” that was encompassed by National Socialist Party in Germany during the earlier part of the 20th century; similar rather emotional nationalistic rhetoric is still occurring in many countries. Most urbanised people of today have probably lost this kind of physical-emotional relationship to soils, but not long ago the soil was the prime medium that people worked, manipulated and from whence they derived their living. Nevertheless, in a global perspective, a large part of human population is still highly dependent on this thin layer of mixed weathered rock, water, gases and organic matter, which makes up the soil that surrounds parts of the earth, and humans still have an on-going need for the soil as a growth medium for food production for the livelihood of future generations.

The degradation (or maybe destruction) of soils, through sealing and removal (Burghardt 2006), is an urban problem which one encounters working as in rescue archaeology. As land is being exploited for industries, roads and housing, top soil is stripped off or put under layers of asphalt, and what has taken a Holocene time perspective to build up, is gone in the grasp of an excavator’s tilting bucket. An increasing awareness on the importance of the soil in its several aspects is shown by the fact that researchers now are stressing that the soils in themselves are worthy of preservation for the future and soils can be considered as archives (Blum et al 2006). In soils, one could argue that a major part of the cultural heritage is preserved (or at least in a state of slow decay), and it is on a much larger scale than what can possibly be achieved by storage in museums. The importance of soils for human societies, as well as environments, is becoming more multifaceted.

There has been a long tradition of integrating information stored in soils and sediments into general archaeology but the interest and intensity has varied over the last decades. “A stand alone” situation in Swedish archaeological research has not been common, but as the sub disciplines environmental archaeology and geoarchaeology evolve, this will probably be very different in the future.

What about soils?

Being a most heterogeneous matter in nature, the soil is in general a rather complicated study object. As such, soils are studied in a variety of scientific disciplines; physics, chemistry, biology, geology, pedology, geography, agriculture, forestry research, and many more. This gives a multitude of various methodologies and analytical techniques applied in order to study various

phenomena in the soil. There are huge differences in how we relate to the concept of soil depending on scientific background, and the ways of viewing soils are several: as a sediment or as a growth medium for plants and organisms. Quaternary geology has a starting point in sediments and sediment formation, pedology is devoted to soil formation with specific focus on plant-organism interaction, general agriculture and forestry research are oriented towards matters of productivity, and geotechnology regards soils and sediments as building material (Retallack 2001). Adding archaeology to the list with its disciplinary requirements gives yet another angle, where the formation of sediments and soils must be understood from a human cultural perspective.

Since soils are heterogeneous in a global sense and show a high degree of local variation, soil classification is still not globally unified. Also the different needs of people to classify soils on a local level may complicate the matter further (Wells 2006). Several classification systems are at hand, the most general ones being World Soil Classification (FAO-UNESCO) and World Reference Base for Soil Resources (International Union of Soil Sciences). All these classification systems aim at an easy means of communication amongst scientists, to identify, characterize and name major types of soils" (ISSS working group 1998:21).

Some historical perspectives on Soils studies in Archaeology.

Within Scandinavian archaeology there has been a tradition of close cooperation especially with geology, and in matters dealing with dating and also with vegetational development and agriculture. In the mid 19th century a co-operation between the Danish archaeologist Worsaae, and among other scientists, the geologist Forchhammer was formed to solve the enigmatic sediment formation of the sea shell middens "Kökkenmöddingar" (Berghlund & Larsson 2005). Scandinavian archaeology has since maintained strong links with especially Quaternary geology.

In European archaeology, the interest in economic issues of prehistory and the emergence of landscape lead to an increasing interest in soils (e.g. Higgs 1972, Vita-Finzi 1978). This research orientation led to the development of environmental archaeology and geoarchaeology (cf. Davidson & Shackley 1976). An important contribution in writing soil science into an archaeological framework was made by Susan Limbrey, providing the book "Soil Science in Archaeology" (Limbrey 1975) as a benchmark. Later soil micromorphology became an integrated part of soil research in archaeology through the work of Corty et al (1989) and this field is still developing (Goldberg & Macphail 2006). The pedology angle appears to have been strong in the early stages of forming the field in Europe.

In America a parallel development, principally through the work of Karl Butzer (e.g. 1971, 1982), gave an ecological approach that later was transformed into geoarchaeology (Rapp and Gifford 1985, Rapp and Hill 1998). The link to geology appears to have been initially stronger in America, although the pedological approach is also present (Goldberg et al 2001, Holliday 1992, Holliday 2004, Mandel & Bettis 2001). Environmental archaeology, according to Butzer (1971) and later Dincauze (2000), could be considered to emphasise a more ecological and anthropological approach. In the British Isles, environmental archaeology has come to encompass a biological approach, with foci on plants and animals, whereas geoarchaeology, with its origin in geology and geomorphology, has landscape development and sediment studies as a point of departure (Bell and Walker 1992, Goldberg and Macphail 2006).

In terms of the landscape development, questions on soil erosion were recognized early in soil research as one of the most important factors in soil degradation. The starting point of human induced erosion became an important field in geoarchaeology and several studies on erosion were conducted in Great Britain. Shotton (1978) discusses late Bronze Age agriculture as a cause for erosion on alluviums lower Severn-Avon valleys, and the Brean Down project (Bell 1990)

provides another example of the understanding of the extent of early erosion and subsequent colluviation. In Bell and Boardman (1992) there are more examples to the early erosion also in a European perspective.

Concerning site formation processes Michael B Schiffer (1976, 1987) contributed important concepts by incorporating the human cultural impact into site formation and site taphonomy and their understanding. Schiffer's main line of argumentation, however, relies on a separate understanding of natural and cultural processes, which requires further discussion.

The main focus in all these mentioned streams of research has been on human and soil relations and human relation to the environment through history, and this is what gives environmental archaeology and geoarchaeology a given position in a wide meaning of the discipline of archaeology.

Soil Chemical studies

The history of chemistry in an archaeological framework is as old as the discipline of archaeology itself, particularly where problems with artefact authenticity and possible forgery was analysed by using chemical techniques (Craddock 1991). The Swedish chemist, Berzelius discovered the phosphate-molybdenum blue complex in the mid 19th century, and this made phosphate determinations in soils possible.

Basically the use of chemistry in archaeology can be divided into three parts:

- Chemical analysis of artefacts (provenience analysis or forensics)
- Conservation analysis
- Chemical analysis of biosphere material (soil chemical analysis of inorganic and organic matter)

As analytical chemical techniques have developed over the years, other applications in archaeological research have emerged. In the last two decades, use of organic chemistry and biochemistry (Hjulström 2008, Isaksson 2000) has been steadily increasing. The development of DNA polymerase techniques is in a state of increasing application, and where this technique will lead is still in the bud.

The strong link between human life and phosphate is well known (Thiessen 1995, Smil 2000), and the relationship between human activity and accumulation of phosphorus in soils was first recognised by Hugh (Russel 1957:145), who noted distinct phosphate accumulations adjacent to waterholes in Egypt in the early 20th century. Later, in Scandinavia, the pioneering research by Olof Arrhenius (1934, 1955) must be acknowledged. Arrhenius had a geographical approach to the analytical results and he could convincingly show that also older occurrences of human habitations could be recorded by analysing the soil phosphate content. His initial research dealt with Scanian soils, but he later also worked on Gotland and in several other places in Sweden.

In Danish and German research similar approaches were adopted by Christiansen (1940) and Lorch (1940). In Lorch's studies an anthropological model was presented for analysing sites of different economies by phosphate mapping. In Norway, Provan (1973) made an important contribution in a study on an agrarian Iron Age settlement, combining soil mapping and soil chemical analyses. In America, early work by Lutz (1951) and Sokoloff & Carter (1952), and later by Kondrad et al (1983) and Eidt (1985), showed the possibilities in using soil chemistry, and they were also able to show enrichment of nutrients in connection with habitations.

The current assortment of soil chemical studies in archaeology encompasses several lines of inquiry, both quantitative as well as qualitative, as the development of analytical techniques such as ICP-Massspectrometry and X-ray fluorescence has improved over the years (Wells 2006). Problems addressed range from usability of basic prospection methods to explaining complicated multivariate soil processes where humans have made their mark (Entwistle et al 1998, Entwistle et al 2000, Wells 2004, Wilson et al 2005 & 2008).

Aims and objectives

This thesis deals with questions on soils and sediments and their inherent information on human activities and behaviour and the ways of extracting information on these. The approach is mainly soil chemical/physical, but the concept of soil formation and its relation to cultural human impact forms an important foundation. Thus, the human dimension and presence is a central focal point here. Studies of the human-environment interaction and the organisation of human societies in time and space are addressed, where soils and soil formation are the most important archives and sources of information.

The time perspective of this work is the Holocene, although the time span of the sites in question mostly ranges from around 6000 BP to the present. Over time the traces of human impact will fade and become more vague as it closes in on the limits of detection, although in this thesis I try to show that this taphonomic limit is less of a problem, provided the soil archive is intact. Furthermore, I will show that soil data are applicable to study different prehistoric societies and economies, be it hunter-gatherer, pastoral and agricultural ones.

This thesis is a compilation of work done within contract archaeology projects as well as strictly research oriented ones. There are differences between these two approaches, depending on different goals, posed questions and time lag in project implementation. One important reason for taking part in contract archaeology projects is that large amounts of geoarchaeological source material can be generated through excavations and in order to be able to study this material, close cooperation and involvement is required wherever exploitation projects may lead.

Activities of prehistoric humans are preserved in soils in many ways, not least as chemical information, and soil chemistry gives a whole set of analytical parameters that can be used to address the problems above. I will argue that soils containing this type of information need to be, if not protected, at least given a similar weight as extracted artefacts upon removal.

By and large, this work has a methodological approach and many aspects of methodology have been developed, tried and applied during the course of the thesis. The application of soil chemistry into an archaeological framework is another quest and there are some central questions one could pose. Does soil chemical data provide information on prehistoric social organisation and economy? How does the prehistoric human use of space reflect in the soil system as chemical and physical properties? What possible inferences does the prehistoric human circulation of specific nutrients (phosphate) give for archaeological interpretations? Should soil chemical data be regarded "less" valid as evidence in an archaeological interpretative process? Are we forced to accept that the various sources of information which we have concerning prehistory reflect different angles on the past and can never to be truly complementary?

Studied sites

Material and studied sites derive from various locations in Sweden (see figure 1). Three of them (paper I, II and V) are the result of initially research oriented projects. Papers III and IV are the outcome of major contract archaeological investigations. Paper II, however, had a prolongation in the later work within the Vedabro bridge and road construction project (see below).

There is a wide variety in soil types and chronological setting in the material, from highly acid podzols to calcareous soils, and sediments dating from the Younger Dryas to current top soils. Sites from the Mesolithic, Neolithic, Bronze Age, Early and Late Iron Age and Medieval are all represented.

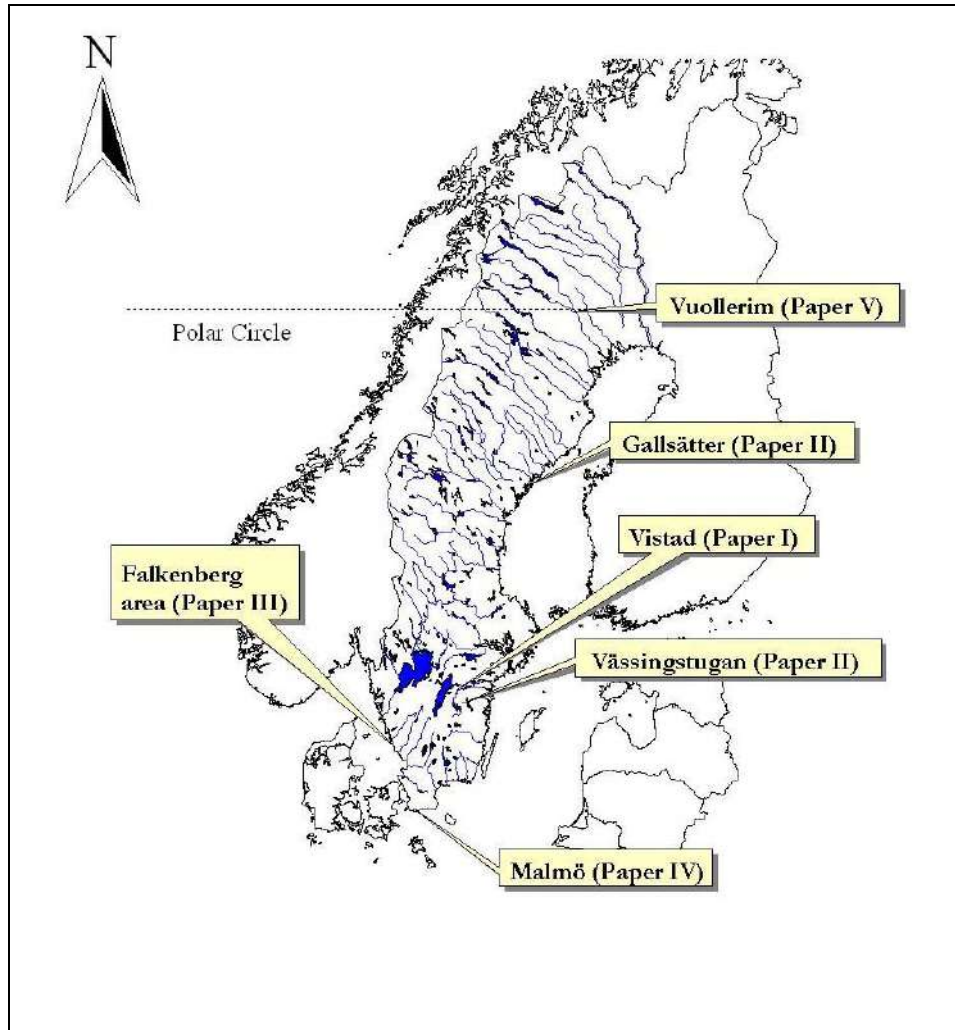
Paper I. Excavations at the Vistad site commenced during late 1980s and are directed by Thomas Larsson (Larsson 1993, Linderholm & Lundberg 1994). The site, situated in the south part of Östergötland, Sweden, has been dated to late Bronze Age. On this site, houses were identified with traits related to the Lausitz culture.

Paper II. The Vässingstugan site became a study object in association with the project “Kan man leva på en ödegård?” (Can you survive on a deserted farm? [author’s translation]), directed by Hans Andersson, Professor of Medieval Archaeology at Lund University. The Gallsätter site was partly dealt with in conjunction with the Veda-project in the early and mid 1990s (Engelmark & Linderholm 1996, Engelmark et al 1997, Lindqvist 1996).

Paper III. From 1993 to 2004 several large-scale archaeological investigations were conducted in the surroundings of the city of Falkenberg, Halland, southwest Sweden. This led to several years of cooperation between the Swedish National Board of Antiquities (UV Väst) and the Environmental Archaeology Laboratory at Umeå University, and numerous site investigations were conducted (Rosén and Ryberg, 1998; Lundqvist, 1999; Ryberg and Wranning, 2001; Johansson et al., 2001; Carlie et al., 2004).

Paper IV. The Öresund fixed link project was initiated in the mid 1990s as the plans for building a bridge between Malmö and Copenhagen were realised. The first phase of the archaeological project was linked to constructions close to the bridge and was run by an industrial consortium named SVEDAB. The archaeological side in this project grew quite rapidly as the initial SVEDAB was merged with a later formed VGV project, which dealt with the construction of the highway surrounding Malmö city. This whole project operation was under the direction of the late Ingemar Billberg, Malmö Museum and Malmö Kulturmiljö (Billberg et al 1996 and Billberg et al 1998). The excavated material which has come out of these projects is vast. In this project, the most all encompassing empirical efforts in terms of environmental archaeology were made (Engelmark & Linderholm 2008).

Paper V. The investigations at Vuollerim were initiated in the early 1980s in relation to the Lule river project (Baudou 1997, Loeffler 1998, Loeffler & Westfal 1985). This project had a strong interdisciplinary ambition with contributing disciplines from archaeology, ecology and cultural geography, resulting in the discovery of the late Mesolithic – early Neolithic dwellings. The initial excavations were directed by Ulf Westfal during the 1980s. Investigations were resumed in the late 1990s under the direction of Kjell Knutsson, Uppsala University (Vogel & Knutsson 2000).



Geographical compilation of current sites in this thesis.

Theoretical considerations

Nature and Culture

In this work the meaning of nature - natural and culture - cultural has not in any way an essentialist meaning. Stroud (2003) discusses in the article “*Does Nature always matter. Following dirt through history*”, an environmental historian perspective on the environment (the “dirt” i.e. nature) as “source rather than subject”. She argues that the environment cannot be framed into categories like class or race and the analogue approach in historical studies is not possible. In this context, the word ‘nature’ refers to laws and models of nature (an apple hits the head whilst falling to the ground), which we as humans can do no more than try to understand and define. Culture on the other hand, is a word that has several meanings and definitions, and probably has more associations to the general public than nature. A simple way of looking at it seems to be that “nature is” and requires no human presence, but “culture” does, and as soon as humans are, there is no “nature”. However, to regard “nature” and “culture” as antagonistic dichotomies is not very fruitful since these concepts are no more than analytical categories and are in reality intertwined or entangled beyond any true separation.

Axel Steensberg (1986:174) defines the concept “culture” by its Latin origin, *cultivare*, meaning “to care for”. In terms of soil, this is most significant. Agricultural soils are soils that are being cared for and will remain cultural soils as long as humans ‘care’ for them. This is also relevant for any form of human society that manipulates the environment, be it as hunter-gatherers, pastoralists or tillers of the soil. The main issue is that a change or impact may be preserved in the soil matrix so that these phenomena are possible to analyse and observe. Whether the soil disturbance is a result of social, economic and/or ritual behaviour is of less importance; as long as they are detectable, they reflect past human affairs. Unfortunately, not all previous activities that end up in the soil will be preserved in this respect.

Whether it is possible to formulate general laws on cultural dynamics (similar to natural laws) in the quest for understanding humans in the past, as have been attempted by Binford (1983), Schiffer (1976) and others, has been and is a matter of debate (Hodder 1989 and 1991). These authors all argue that human action in the past is possible to understand although their reasons and ways of achieving this understanding are different (Binford 1983, Hodder 1986, Schiffer 1987). If all traces of material culture is gone, through c- and n-transformations (Schiffer 1976) or taphonomy and have returned back to its atomic or molecular ground state, does this mean that no archaeology can be done?

Element circulation.

What we deal with mostly when studying element circulation is biomagnification of certain elements (O’Neill 1993) and a trophic build up through the food chain. The opposite, depletion is more seldom a matter of interest. Our aim is to understand how elements qualitatively and quantitatively circulate and accumulate in the environment (soil system). This enables us to understand more on processes of site formation and more specific remains such as house floors, bodies and artefacts. Natural processes, like weathering and leaching of elements in the soil system or vegetation taking up nutrients from the subsoil differ from cultural processes, where human beings constantly manipulate the natural flow of energy and nutrients through the ecosystem and environment. Less mobile elements, such as phosphorus, become important in an archaeological perspective here since this leaves traces which are possible to detect after considerable amounts of time. Throughout the human history, the phosphorus flux has changed considerably and has gradually become intensified by domestication of animals, urbanisation etc. This is also valid for bioessential elements and other elements required for technology.

Sampling and soil formation; The clorpt concept

Soil formation and the development horizons in soil profiles may be applied both to understand the formation of natural as well as cultural soils. This framework is one key when dealing with and trying to understand prehistoric (or any other) human input or change of the soil chemical-physical system (Goldberg & Macphail 2006, Holliday 2004, Linderholm 2007). When Jenny (1941) introduced the concept of soil formation and the factors of influence and related processes, later formalised as the clorpt concept (climate, organisms, relief, parent material, time) (Birkeland 1999), he opened up a process related understanding in terms of how and why soils are formed in trying to define a function where the included parameters could be quantified:

$$\text{soil} = f(\text{climate, organisms, relief, parent material, time})$$

This equation was presented in order to understand the operational variables in the soil system in order to assess importance of each factor and thus achieving a fuller understanding of the soil formation processes and their complexity. Discussions on the weight of the different factors in the clorpt model hold that climate and parent material are prime factors in the soil forming process, but time has been given more weight. There has been an ambition within pedology to be

able to quantify the factors fully in order to solve the equation and this has received some critique. Furthermore, the clorpt model has received criticism for not being applicable on a global perspective (Birkeland 1999:144-145). Nevertheless, Holliday (2004:46) concludes that soils are environmental proxies and the processes forming the soils are of main interest, which makes a strong case for the clorpt model.

However humans are included in the factor “organisms and biota”, dealing with the exceptionally complex nature of prehistoric humans activities and their consequences for soil development, it is possible to consider humans (human activity, behaviour – culture) as a factor of its own. Within Swedish soil research humans were included in this function (in Swedish Jord = f (klimat, geologiskt underlag, topografi, växter och djur, tid - människan) by scholars such as Troedsson and Nyqvist (1973), Wiklander (1976), and Stålfeldt (1960). The human factor in soil formation, at least in parts, is quantifiable (Amundsen & Jenny 1991, Holiday 2004). Thus, it should be concluded that human behaviour, in the present as in the past, has relevance for soil formation, and clearly it should be regarded as a factor of its own in the clorpt model. A similar line of argument has been put forward by Wells (2006:126), and he considers the soilscape as being formed by humans through the combination of ideas, beliefs and practices, where the soil acts as reservoirs for shared ecological knowledge, entering a social dimension into the soil.

The most important aspect of the soil forming factor approach in archaeology-geoarchaeology is in relation to soil prospection, soil sampling and interpretation of chemical-physical properties. This is where modelling soils as a function of most important soil forming factors becomes practical, especially in geoarchaeological work (Amundsen & Jenny 1991, Goldberg & Macphail 2006, Holliday 1992 & 2004, Linderholm 2007). We work in present day soil but relate data to a pre existing situation. Every soil profile has to be evaluated “on-line” as sampling is conducted in a mapping situation and especially when encountering anthropogenic soils, every profile is “unique” and has a story of its own. The appropriate sample has to be extracted and subsequent data must be evaluated in relation to the shifting soil formation conditions. There are very few sampling situations where soil formation may be disregarded.

An example of how soil formation influences sampling is the early work of Arrhenius (1934). The reason for these studies’ success is partly because he worked in agricultural soils, with strongly homogenised Ap horizons, which was, in terms of sampling, a stroke of luck. Co-workers of Arrhenius did perform some sampling but parts were done by local famers that got instructions on how to do this. At least three sample points per hectare and a shovel depth of (top)soil in a brown paper bag thoroughly labelled and then sent back to the lab. If this work had been in connection with forest research with different soil types, I strongly believe that the outcome would have been different. Even so, Arrhenius himself was quite aware of soil formation and differences in soil chemistry and he would probably have compensated for such events. Arrhenius’ study did show just how powerful human impact in the circulation of phosphorus has been (and is), and the “robustness” of the approach.

Scandinavian surface soils are 10 000 years old at the very most and many soils are considerably younger due to land upheaval. This gives a comparatively quite fresh starting point of soil formation in relation to human impact. In the region of northeast Sweden (the Gulf of Bothnia) conditions are even more favourable in this respect. Following the former coast lines, humans have been active on the lands in the early stages of soil formation. Due to the low degree of urbanisation, many sites have not been subjected to any major later disturbances. This enables prehistoric “forensic” approaches and sites and soils may partly be regarded as “closed systems” in this respect. In certain favourable conditions this almost allows a straight forward interpretation of, for instance, soil chemical input.

Method

Sampling

The choice of sample to collect is firstly a matter of defining the sample. As discussed above, the concept of soil formation gives a theoretical framework to sampling definition and selection. However, depending on the state of pedogenesis, sedimentary complexity or intricacy, site related stratigraphical events, adaptive sampling is needed. In Sweden there are three main common soil types, podzols, cambisols (brown soils) and culturally maintained soils (i.e. plough soils), but 6000 years ago, the latter did not exist and cambisols were more common than today.

The general sampling approach in this work, in terms of soil grid mapping, has been developed quite empirically but is based on theories of soil formation. The aim is to sample horizons that will contain traces of the past activity in question. In general soil grid mapping, sampling of the illuvial B horizon in podzols and bottom Ap of plough soils have been conducted. As for podzols, B horizon sampling is performed because of the fact that over time, most surface matter ends up there. Sites younger than some hundred years will not be suitably sampled in this manner. As for the sampling of plough soils, the bottom part of the present day Ap has been considered, taking colluviation, etc., into account. Furthermore, the Ap horizon has probably, since the “deposition event”, been turned over more than once during the course of time. Nevertheless, the sampling procedure is done in order to try to minimize the impact of increasing pollution, etc., in later times.

Soil sampling can be performed in several ways but in large scale mappings of topsoil, gouges (gouge augers) or corers have been frequently used. In cases of major contract archaeology projects, where excavations is conducted in an assessment phase, with trenches over large areas, sampling may be conducted in the exposed sections, giving a good overview of long soil coherent profiles (paper IV). The profile visibility in the gouge, compared with the open soil profile/section, is something which has to be addressed, and this may affect the sampling result/quality (Canti & Meddens 1986), as may possible compaction effects. These problem may arise in using heavy equipment at greater sample depths (>1 m) and may be problematic in highly complicated stratigraphies. In most Swedish mapping situations this is less of a problem since soil are sampled at shallow depths.

Another technique used is the Kubiena box and this technique of sampling has advantages in some respects (Goldberg & Macphail 2006, Engelmark & Linderholm 2008). Apart from the possibilities of performing soil micromorphology studies, assessment of soil properties can be made in the lab; subsampling conducted in “optimal” conditions and the stratigraphic control may be very good. Also the box, if made from suitable material, can be saved as an archive for later studies when the original site and stratigraphies are excavated.

Soil chemical and physical properties

At the environmental archaeology laboratory, Umeå University, a five parameter analysis routine has been developed, adapted to soil prospection and bulk analysis of dwelling soils and features. Analysed parameters includes organic matter (loss on ignition, Carter 1993), two fractions of phosphate (inorganic and sum of organic and inorganic) (Engelmark & Linderholm 1996, Linderholm 2007) and magnetic susceptibility (MS- χ_{lf}) and MS550 (Clark 2000, Linderholm 2007, Engelmark & Linderholm 2008). These analyses give information on various aspects on phosphate, iron and other magnetic components and crude organic matter in soils and sediments.

Soil Phosphate

Soil phosphate analysis has been and still is the most common soil chemical prospection approach in archaeology. Different kinds of information may be extorted, depending on extraction methods used; several methods and techniques are available and have been applied (Holliday & Gartner 2007).

Analytical response in general depends on the matrix, meaning that qualitative aspects of elemental composition are often more defined/understood by the chosen method. This can be exemplified by the citric acid extraction of soil-phosphate. For acid soils (podzols-spodosols), it is on a theoretical basis possible to assume that mainly Fe-Al bound P (PO_4) is brought into solution since the complex formation between, for example, iron and citric acid is strong. Organically bound soil-P will probably not be hydrolysed under the circumstances.

The Citric acid extraction method (Arrhenius 1934) is used throughout this work. There are several advantages in using this. A lot of basic and empirical research has already been carried out by Arrhenius in the 1920s, and arguments involving safety, low price and speed of execution were put forward and these arguments still apply. Apart from basic quantification, one can get qualitative aspects of soil-phosphate. There are of course some disadvantages of this method. Weak acid extractions may be considered analytically less well defined than total dissolution methods and may be subjected to buffer problems in alkaline soil types. Furthermore, problems occur when trying to compare quantitatively results which used different techniques (Holliday & Gartner 2007).

Magnetic susceptibility

Magnetic susceptibility (MS) is a physical magnetic property that is connected to chemical properties, especially soil magnetic compounds, the various oxides of Fe, Mn, Ti-Fe, Cr-Fe, etc. (Thompson & Oldfield 1986). MS in archaeology is a well-established prospection technique and is also used in environmental and geological research, where the technique is used to identify pollution and sediment origin, etc. The magnetic susceptibility of soils is strongly related to iron compounds and may be used for studies of pedogenic processes (Paper III).

The iron chemistry of soils is complex and is dependant on factors like temperature, pH and redox potential, among others. In soils Scandinavian soils, compounds like goethite ($\alpha\text{-FeOOH}$) and hematite ($\alpha\text{-Fe}_2\text{O}_3$) are quite common and also maghemite ($\gamma\text{-Fe}_2\text{O}_3$) and magnetite (Fe_3O_4) occurs. Amorphous Fe hydroxides and ferrihydrite exist and are more related to reducing (wet) conditions in soils. When oxygen is encountered, these compounds transform to goethite ($\alpha\text{-FeOOH}$) and hematite (Schwertmann & Taylor 1989). Apart from giving direct spatial responses to human impact and habitations, MS is also possible to use for landscape reconstruction, and then especially when studying pedogenic processes related to changes in redox potential, for example, in or near wetlands or in riparian zones. This may be done by analysing the maximum conversion of MS of a soil substance. The maximum MS is analyzed by heating samples to 550°C in a furnace (MS550) (Clark 2000). One can argue that this temperature is not sufficient to provide a maximum conversion of the Fe-compounds in the sample. Clark recommends a temperature of 650°C and an addition of organic matter (potato flavour) to ensure initial reducing conditions followed by oxidation. However, soils usually contain organic matter in sufficient amount for the conversion takes place.

Metals and non-metals

Most bioessential elements are probably of interest in studies of traces of prehistoric human activity in soils and sediments, given that the elemental pathways through the soil system are known and compounds stay in the soil system over long time periods. In order to understand the

complexity of soil formation processes and the human inputs therein, other non-bioessential elements must also be considered, and it is important to analyse both components of natural and cultural relevance since these aspects are often combined. The multi element compositions of soils should be regarded as a multivariate problem that needs to be addressed accordingly.

Depending on level of concentration in the soil system, elements are divided into main components such as Al, Si, Fe, Ca, Mn, N, C and minor components like Zn, Cu, Mo, Ti, Zr. Phosphorus is intermediate here, since P in nature is generally a minor element, but may in soils subjected to substantial human impact, reach almost main component levels. This is one of the reasons why soil-P becomes so evident in human ecology.

In the study (Paper I and IV) different dissolution techniques such as total dissolution to various degree of extraction have been applied. The main analytical technique used is ICP AES or MS (Inductively coupled plasma – atomic emission spectroscopy or mass spectrometry) that offers the advantage of analysing several elements simultaneously.

Mapping

We have to assume that the spatial dimension of human activities, in landscapes, on sites or dwellings, leads to changes in the soil that may be analysed through the concept of regionalised variables (Davies 1986). This enables us to generalise and to use geostatistical concepts (Lloyd & Atkinson 2004). Basically this means that soil or sediment properties of one point have some predictive power on nearby points. This is true so long as the soils properties are not “too different”, and can be considered to relate to the same phenomena. In cases where *catenas* are present or when there are clear shifts in soil types (podzols to ploughsoils), this approach is less applicable. Working with comparable context is of course preferable, but rarely something one can expect to find in real world situations so one is forced to adopt a pragmatic approach.

How the spatial studies and mappings are conducted is a question of scale and representativity. The human action radius, in the landscape, in settlements and houses is not haphazard, but is rather governed by various traits of human behaviour (Chisholm 1972) and also by biomechanics (there are limitations to how fast and how far humans physically can reach due to the nature of our musculature in our bodies). However, this has relevance for choosing density in grid sampling since the grid density depends on the scale of the spatial activity one wants to reflect. The metric system (SIS) gives “natural” intervals of 1, 2, 5, 10 and 20 m as base grids. Working in other system will give different preferred intervals as discussed by Clark (2000:158). Prehistoric humans would probably have one or two things to say about our scientific endeavour forcing our grid onto our predecessors’ use of space. Either system is not related to the biomechanical aspect. In reality, one has to balance the amount of samples between project economy and spatial precision needs. One metre grids are often too ambitious and costly in relation to the patterns emerging, and 10 000 samples on a hectare is simply too much, but in cases of intra-site analysis 2-5 metre will be sufficient, both in terms of statistics and picking up the human dimension when acting in nearby spaces. A twenty metre grid gives quite stable results on the hectare scale, for instance, suitable for a general reflection of agricultural dwellings, but there will be a need to increase the grid density as more specific spatial questions are posed.

Experimental archaeology

Experimental archaeology may give just as important possibilities of analogy modelling as ethnoarchaeological studies in understanding the archaeological record (Steensberg 1986). There are examples of where soils have been examined in an experiment in archaeology. The Overton Down earthworks showed several important aspects on the formation on soils and sediments in

archaeological contexts (Bell et al 1996). Furthermore, the agricultural experiments at the Butser Hill farm have given interesting results in the analysis of soils and sediments from the floors of stables, etc. (Macphail et al 2004). At the experimental farm at Baggböle, Umeå, field experiments on cereal cultivation was conducted (Viklund 1998). Here, soils from the various fields and plots, which had been subjected to different treatments, were analysed and used in the understanding of the state of soil phosphate in prehistoric fields in present day podzols (paper II).

In terms of soils, an experimental approach gives possibilities to test different analytical techniques on material in different stages of manipulation. This also gives the possibility of having control, to certain degree, on the inferred changes to the soil system. By doing process oriented experiments we may create analogies to the past that no longer exist.

Discussion

Soil chemical and physical properties and archaeology

One of the major criticisms of the use of soil chemical data (soil chemical mapping) in archaeology is the achronological aspect of the data, especially when a prospecting situation goes on to try to explain specific "crime-scene" archaeological events (what has happened). In this case soil chemical data are forced into an artefact position. Thus, a contextual view and approach is advocated. A lot of the things we humans do, given time, end up as traces in the soil, be it biological, chemical or physical traces. The main part of these traces closes in on the molecular level, simply because thermodynamics and taphonomy will bring matter to the lowest and stable energy state. Hence, these traces must be studied accordingly.

Donald Davidson (1988:20) states that "*the chemical loading by anthropic processes on sites ought to be investigated with exactly the same emphasis as other artefactual remains*". To what extent this is done in contemporary archaeology is a matter of discussion, but I believe that the last 20 years have led to some efforts in this respect, although we are a long way from fully encompassing it. However, chemical loading represents the lowest form of order in terms of entropy and represents very modest remains of previous people's activities (paper V). The fact that soil chemical data rarely are chronologically distinguishable is considered to be their greatest weakness, but I would argue the contrary. It is simply a matter of what degree of precision is needed related to the interpretations in question. The "average" everyday use of a dwelling is better reflected by these low order remains, taking into account that their formation process and flow through the system is known. In terms of archaeology, the soil is not to be treated as a discrete entity since soil (chemical) data rather reflect ongoing processes. The soil is a matrix and system that is constantly changing, but the rate of change differs.

Soil studies are in general, non (or at least less) -invasive compared to any excavation effort. This is important to note, since archaeological investigations in general actually destroy the source material. Not taking the soil information into account is like throwing out the baby with the bath water along with the bathtub. However, soil data (chemical or physical) are not to be regarded as additional artefacts to be added to the analytical tool kit. The formation and context of soil formation is very different from the biography of any artefact. On the other hand, not taking into account the multitude of human cultural manipulations and behaviour expressed in soil property data is just as bad. The soil information may have strong explanatory power that enables temporal interpretations of human activities and behaviour.

Soil, conservation or protection?

Scientists regard the soil in many ways depending on their theoretical, factual and methodological starting point. To reduce soils to mere sinks for artefacts or the fossil record (organisms) is of course a matter of wasting important information on past human affairs. Soils and their formation are certainly archives, preserving and reflecting remains of human, plant and animal life pathways, both in the present as well as in the past. Being reservoirs of information on past cultural and natural phenomena, soils make up a part of our heritage, and as cultural-natural heritage, soils themselves have to be cared for.

Within natural heritage management, discussion is focused on the conservation of ‘natural’ soils whereas ‘cultural’ soils have been, to a much lesser degree, taken into account since soils are by definition handled by natural heritage agencies (c.f. Taylor et al 1996). In this volume, Davidson & Smout (1996) show convincingly, the scale and extent of human impact on Scottish soils during the last 400 years. It is unfortunate that it seems as if stakeholders from cultural resource management were not present or took little part in this discussion. The protection of soils and sediments are problematic since they may lack affiliation to monuments or artefacts (which is the common legislative reason for protection), but still they may contain other types anthropogenic information (cf. Barham & Macphail, 1995).

Human use of landscape and land management has contributed to formation of different soil types, including the *Calluna* podzols, plaggens, Amazonian terra preta and dark earths (Goldberg & Macphail 2006). How long culturally managed soils will survive without management is not easy to assess. Terra preta soils still exist but were formed over long time periods and may represent an almost irreversible change of the soil system, even though they exist in rainforests, where soils normally are nutrient poor. *Calluna* podzols, on the other hand, needs intensive grazing and have to be burned in cycles. If not managed, shrubs and trees will invade the landscape and modify the soil.

Soils might conserve materials put into the system, but how do we then conserve soils? To “conserve soils” could be regarded as a contradictory statement, at least in a long term perspective, considering the consistent and inevitable changes that the soil forming processes bring about. What state of preservation should we focus upon? Formation of specific landscape types and forms depends on existing soils and sediments, but their maintenance is as much a cultural task, since humans are, and have been, frequent players in forming soils and landscapes. Soils provide the historical background to acquire knowledge on future soil management, where we still have to learn from the past.

The Swedish Environmental Protection Agency EPA, (The Environmental Objectives Secretariat) has listed 16 Environmental Objectives and none of these are exclusively related to soils. The Swedish National Heritage Board has embraced these goals in parts but the specific soil aspects are few and mainly regarded from biological and conservational points of view (http://www.raa.se/cms/extern/samhallsbyggnad/hallbar_utveckling/miljomal.html (2010-01-27)).

Furthermore, these issues are discussed in an international perspective by Montanarella (2006). In this article he points at the successful actions in the US, through the US Soil Conservation Act that was implemented in the mid 1930s, as a response to the “dust bowl” erosion. The EU showed initially a low concern regarding soil protection, but this has apparently changed in current directives. The European Commission states regarding soils:

“Erosion, loss of organic matter, compaction, salinisation, landslides, contamination, sealing... Soil degradation is accelerating, with negative effects on human health, natural ecosystems and climate change, as well as on our economy.” http://ec.europa.eu/environment/soil/index_en.htm (Last updated: 05/03/2009) (2010-01-17)

However, the primary focus in this policy document is on preserving soil productivity even though there is an awareness of the archive ability of soils. In contrast, in the German Federal Government - Soil Protection Report (2002), it is clearly stated that the soil has a function as an archive for natural and cultural history and protective measures are needed to maintain the soil sustainability.

As forestry management accelerates, in Sweden and other countries, forest fertilization and the use of large scale mechanised tilling or ploughing for the planting of trees for instance, has not only a destructive physical impact on the cultural heritage remains, but will also introduce other top soil disturbances with consequences for the soil archive. The physical disturbances are evident in short term perspectives, but the long term consequence as for the chemistry of human influenced soils is not thoroughly investigated. Soils, however, have to be utilised by society, and the assessment and evaluation of when and where to allow exploitation of soils, is ultimately a political matter, but such decisions need to be closely related to current and future scientific knowledge.

The importance of soil studies for humanity is obvious, since all terrestrial food resources are derived from soils. Thus knowledge of past and present, and predicted future use, of soils is essential for human survival. Sustainable agriculture is presently a frequently studied topic and stand as a contrast to the modern highly mechanised, chemically dependent and energy intensive ways of producing food crops. Consequently, studies of prehistoric and historic agriculture and past management of soils have an obvious relevance for the present day as well as for the future.

Sammanfattning (Summary in Swedish)

I denna avhandling behandlas marken, jord och sediment, som informationskälla inom arkeologin, främst genom att använda kemiska och fysikaliska analyser. Centralt begrepp för diskussionerna är jordmänsbildning och betydelsen av denna för att kunna utläsa människans påverkan av marken över tid. Förståelse av jordmänsbildningsprocesser har stor betydelse inom miljöarkeologin för hur markprovtagning genomförs och hur kemiska/fysikaliska data kan tolkas. Studierna behandlar prospektering med hjälp av markkemiska och -fysikaliska metoder, främst fosfatanalys samt magnetisk susceptibilitet och hur dessa metoder går att använda inom arkeologisk forskning. Framför allt har dessa två analysmetoder använts för att lokalisera förhistoriska bosättningar, men metoderna kan användas för rumsliga analyser av både boplatser och mindre aktivitetsområden som hus e.dyl. Man kan även använda analysmetoderna för att undersöka landskapsförändringar och landskapsrekonstruktioner.

I avhandlingen betraktas mark, jord och sediment som ett arkeologiskt källmaterial i sig självt. Vidare diskuteras hur bruk av mark, jord och skog påverkar våra möjligheter att använda marken som källmaterial om förhistoriska människors aktiviteter.

Fem olika *papers* ingår i avhandlingen och de behandlar hur mark och jord kan analyseras för att belysa olika aspekter på mänskliga aktiviteter och detta oberoende av omständigheter som ekonomiskt näringsfång eller tidsålder. Exempelen som tas upp är bland andra boplotsundersökningar från stenålder till medeltid och från olika delar av Sverige.

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Paper summary

The summary of paper IV is slightly extended, for the convenience of English readers. Furthermore, in the Appendix, selected figures from paper IV are presented with captions in English, in colour and graphically enhanced.

Paper I

This paper deals with the elemental composition, metal and non metal, of soils from a late Bronze Age site, where soil material from off-site (background), on-site and various features have been analysed with Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES). Analytical considerations regarding dissolution techniques, total dissolution and acid extraction are discussed. The paper is structured according to a chemometric research design where PCA is used for data evaluation. It could be established that several elements were enriched in the site soils and in various features (P, Zn, Cu, Mn and Ca), and a statistically valid classification of the sample groups could be obtained. Moreover, it was concluded that different dissolution techniques had limited importance in terms of classifying types of soil with a varying degree of human impact.

Paper II

This paper has a prime focus on phosphorus circulation in an agrarian context with examples from the Iron Age to the medieval period. In this paper, the possibility of analysing the organic phosphate content in soils is discussed and also the stability of such compounds over time. In this study, it is concluded that the organic phosphate compounds in podzols and acid brown soils are quite stable over time and may be used to study the application of manure in medieval and earlier time periods.

Paper III

This paper deals with questions on soil chemical and physical prospection in archaeology analysing phosphate content and magnetic susceptibility of soils and sediments. The study is a part of a major archaeological project that was conducted some ten years ago (1997-2002). The investigated area is located south and east of the city of Falkenberg (west Sweden) where the sites are localised along a road construction. The studied sites cover a time period from the Bronze Age to the early medieval period. In this paper, the importance of understanding soil formation is discussed in relation to sampling and data evaluation. Several areas were identified, where *Calluna* podzols had been dominant, often at valley bottom or slopes, where colluviation had preserved them from later agricultural destruction and these were important for landscape development.

Results show that there is a relationship between the soil phosphate input and population increase over time. This is also caused by changes in the phosphate circulation and a change in cultivation technique, where handling of manure is intensified. Settlements contracted to smaller hilltop locations during the Iron Age due to a changing climate and landscape. Magnetic susceptibility is shown to have as strong an information potential as soil phosphate as a general prospection method in landscape reconstruction and occupation site evaluations.

Paper IV

This paper consists of a synthesis of parts of the environmental archaeology that was conducted in connection with the fixed link project in the Malmö area, Scania, south Sweden. An English summary is given at the end (pp 78-81). The synthesis has a strong environmental archaeological approach and seeks to combine chemical, physical and biological data in a comprehensible picture of past events. In this paper several methodological aspects on how to extract information from soil and sediments is discussed and also the way in which these data can be used as a proxy for analysing human activities in the past is considered.

The initial chapters provide a background to the Öresund fixed link project and the environmental archaeology engagement. Various aspects of working with environmental archaeology in contract archaeology projects are considered. The following chapters deal with theoretical points of departure. Studies of any landscape where humans have been present must embrace a holistic view including economic, social and ritual dimensions. The landscape is the context in which humans form their societies, and these are not possible to understand if knowledge of this context is lacking. The varying levels of scale (off-site, on-site and intra-site) are discussed and how these must be adapted to material of choice and methods of analysis are considered. The choices of scale in relation to sampling have strong relevance for where interpretations of environmental data may lead. In the chapter “*Interpretation and taphonomy*”, the formation and post depositional processes affecting the archaeological record are discussed, and how these relate to soil formation considered. Within the chapters “*Material and methods*”, “*Sampling*” and “*Methods of analysis*”, the various categories of sediments and soils and features that have been analysed, ways of sampling and the different techniques for analysis are presented. A general discussion on environmental archaeology and the use of proxy data is put forward. Also, a discussion on problems and possibilities regarding interdisciplinary studies and working in contract archaeology and ways of reconciling the various interests are discussed.

In the following chapters “*Fragments of past landscapes – Case studies*”, a number of thematic cases are introduced. From these chapters a selection of the themes-cases are presented in more detail, mainly those dealing with soil, erosion and settlements. They are presented in this summary as follows:

1. A case study regarding erosion, agriculture and settlements (Figs 13-17)
2. Method study regarding erosion, chronology and environmental pollution (Figs 18-21)
3. Farmstead, hinterland and environmental impact (Figs 22-27)
4. Analysis of chronology and environments on the local level (Figs 28-32)

Figures related to these themes are also found in the Appendix.

1. A case study regarding erosion, agriculture and settlements (Figs 13-17)

Colluvial deposits reflect the occurrence of erosion and they thus contain an inherent history of varying complexity. The analytical techniques applied here are soil properties such as magnetic susceptibility, content of metal and non-metals, lead isotopes (Pb) and ¹⁴C dating of humic matter and soil micromorphology. The initial and prime interest for investigating colluvium was to initiate a prospection approach for finding sites, not possible to detect by ordinary field walking. However, the erosion history is interesting enough in itself.

Landscape change has been significant throughout history. Figure 14 shows a composite map, combining different landscape maps from the 19th century, the reconnaissance map and the map of meadows and wetlands. The landscape presented here is quite different from the present and points out where colluvium is likely to be located. The colluvium on the slopes of the sites 14B-15A turned out to be almost 3 m in depth. Figure 15 (see Appendix) gives a synthesis of chemical

and biological data that were analysed from one stratigraphic section (S1) from the site Robotskjutfältet 14B. This particular stratigraphy was studied in more detail than the other ones. The attention to this sequence was drawn by the fact that the phosphate content showed a peak at the bottom and in the middle of the colluvium implying probable dwelling phases. Thin section samples were produced from these parts of the profile. When combining the soil micromorphology result with the sediment chemistry, these phases were identified to be a result of habitation in periods of stable sediment conditions. The phases were dated to the late Neolithic and from the late Iron Age to the early medieval period. During the latter period, cultivation seems to have been dominant and the upper ^{14}C dates may well indicate the introduction of the mould board plough as erosion after this intensifies. The curves of MS550 (high), Fe and Mn (low), show clearly that reducing conditions had prevailed at the base of the sediment, which also coincides with good pollen preservation. Pollen data represent a shorter time period and show increasing deforestation and an increase in pasture in the latest phase in the diagram.

The colluviation process is quite consistent in the local landscape. Figure 16 shows this consistency in soil data and ^{14}C dates, demonstrating a simultaneous colluviation process across the landscape.

2. Method study on erosion, chronology and environmental pollution (Figs 18-21)

In order to obtain several chronological markers in the analysed colluvium, various approaches have been applied. Apart from ^{14}C dating of humic matter, analysis of lead isotopes and other elements such as the metals Pb, Cd, Zn and Cu was implemented. Cadmium (Cd) and arsenic (As) turned out to be important for relative dating of the later phases of the colluvial sediments, because of their massive introduction in human environmental circulation in later times through artificial fertilisers.

Figure 18 shows a compilation of the organic content and ^{14}C dates from seven of the more intensively analysed colluvium from five different excavated sites. Overall, there is a decrease in organic content with depth. In basal sequences where the organic content increases, these originated in former wetlands, which was the case in colluvium at 14-S1, 15A-K2 and 15H-K1. In the case of 17-P2, possible remains of an earlier Cambisol-Brown earth is visible.

In figure 19, the same set of colluvium is presented as in figure 18, but here focusing on Pb and $^{206/207}\text{Pb}$ isotopes. There is an increase in the total Pb concentration towards the younger parts of the colluvium. Sediments with elements of former wetlands show different signatures depending on the Pb affinity to organic matter.

The lead isotope signatures of the colluvium are consistent with lead isotope studies of lake sediments and show a decreasing $^{206/207}\text{Pb}$ quotient, meaning that the level of contamination increases towards the present. In three cases it might be possible to follow the recent improvement in terms of lowered lead emissions (Södra Sallerup 15A-K2, Fortuna 17-P2 and 17-P6). If the sample resolution had been higher, it probably would have been possible to pinpoint the Roman Iron Age increase in Pb, providing additional support for the ^{14}C dates. As for the total Pb concentrations, reducing conditions and presence of organic matter affect also the $^{206/207}\text{Pb}$ quotient (i.e. Södra Sallerup 15H-K1).

Figure 21 provides an overview of the Cd and As signatures through the analysed colluvium. There is an apparent gradient, from higher top soil values, to lower values at the base of the colluvium. This reflects primarily the last century mineral phosphate fertilisation, but also deposition of atmospheric dust. The sediment from Södra Sallerup, 15H-K1, is anomalous compared to the others, depending on the wetland nature of the sediment, with high organic

content and reducing conditions. The extreme high level of Cd here is probably of lithogenic origin.

3. Farmstead, hinterland and environmental impact (Figs 22-27)

This section of the paper deals with land use and landscape reconstruction in relation to Iron Age settlements by analysing phosphate circulation and various aspects of magnetic susceptibility. Prior to this study, there had been discussions as to what degree soil phosphate analysis was applicable in relation to archaeological research in Malmö (Björhem & Säfvestad 1993). The soil studies of settlements in the area of Fosie 11 showed a distinct correlation between settlements of some duration and increased soil phosphate content. At the site Fosie 11A soil phosphate data gave several different aspects use of space on the on-site level (figure 23, see Appendix).

However, the most important feature is the possibility, given by the MS550/MS quotient, in terms of locating former wetlands or areas with a comparably high groundwater table (figure 25, see Appendix). Combining this with soil-P content gives quite solid evidence on former land use, even in present day soils. When MS-data after ignition are considered the results indicate areas with chemically reduced condition interpreted as wetlands (higher groundwater level and higher organic content, figure 26, see Appendix). MS data are in good agreement with old maps of meadows and wetlands and suggest areas beyond these. A proposed model of land use, based on the combined soil data and soil properties is presented in figure 27 (see Appendix). One may conclude that the landscape of the Malmö area had been significantly wetter during the Iron Age.

4. Analysis of chronology and environments on the local scale (Figs 28-32)

This section deals with the local level of representation (micro- to meso- perspectives), where point specific accumulation of proxy information is considered, such as wells and ponds. The representivity of the local spatial scale is discussed. The first case considers the micro scale and uses a well from the Iron Age site Lockarp 7B. The figure 29 (see Appendix) compiles chemical and biological data from a stratigraphy from the well feature A14495. Wells are considered to represent very local biota and are even more local in terms of soil and sediment properties. In the figure a range of properties are combined that gives a credible scenario to the various stages in the history of construction and destruction of the well, as suggested by the sediment phases outlined on the right.

The second case uses a local sediment infill from Södra Sallerup 15H, representing a larger catchment than the first case, still representing general site activities in the surroundings. In figure 31(see Appendix), a synthesis of chemical and biological data from a stratigraphic section through an occupation layer area is presented. A local but extensive erosion-colluviation had been initiated already in the early Bronze Age, and as suggested by pollen data, pasture dominated. Since this is a local water hole it is possible to suggest trampling as a trigger source.

Paper V

In this paper a case is presented with soil chemical and magnetic susceptibility prospection from a late Mesolithic site, in Vuollerim, Northern Sweden. Firstly, the landscape development and soil formation during the period before, during and after the dwelling period is discussed and the consequences hereof considered. The investigation focuses on mapping of soil properties such as soil phosphate content and magnetic susceptibility, where mapping are performed at off-site to intra-site levels of scale. A geomorphological background is given and postglacial landscape development is discussed, putting the site in relation to the setting of landscape development.

Results from this investigation bring forward different aspects of the dwelling area and how these subterranean houses were used. Analysis of soil phosphate content show a strong spatial correlation to areas around the various houses on the site, whereas the magnetic susceptibility show some problematic features as background signals are quite high in the area. Intra-site studies performed in and around one of the subterranean houses show distinct patterning, related to social organisation and use of space. The soil magnetic susceptibility measurements were in these magnetite-rich sediments particularly challenging to evaluate and to pinpoint the human impact. However, possible interpretations are suggested that include both natural and cultural reasons for the acquired data.

Obtained soil data are discussed in relation to ethnoarchaeological observations which give insights into the complicated mix of processes generating the archaeological and soil record *sensu lato*.

List of papers

This thesis is based on the following papers, which will be referred to in the text by their Roman numerals.

I. Linderholm, J & Lundberg, E. 1994. Chemical characterisation of various archaeological soil samples using main and trace elements determined by Inductively Coupled Plasma Atomic Emission Spectrometry. *Journal of Archaeological Science*. 21:303-314.
doi:10.1006/jasc.1994.1030

II. Engelmark, R & Linderholm, J. Prehistoric land management and cultivation. A soil chemical study. 1996. In: Mejdahl, V. & Siemen, P. (ed.) *Proceedings from the 6th Nordic Conference on the Application of Scientific Methods in Archaeology*, Esbjerg 1993. *Arkæologiske Rapporter* nr. 1, 1996:315-322. Esbjerg Museum.

III. Linderholm, J. 2007. Soil chemical surveying: A path to a deeper understanding of prehistoric sites and societies in Sweden. *Geoarchaeology*. 22(4):417-438.
DOI: 10.1002/gea.20159

IV. Engelmark, R & Linderholm, J. 2008. Miljöarkeologi. Människa och Landskap – ett dynamiskt förhållande – Projektet Öresundsförbindelsen. (Environmental Archaeology. Man and Landscape – a dynamic interrelation. The Öresund Fixed Link Projekt). Malmö: Malmö kulturmiljö.

V. Linderholm, J. Soil prospection: chemical and magnetic susceptibility attributes from off-site, on-site and intra-site perspectives. A case study from a late Mesolithic- early Neolithic dwelling in northern Sweden (submitted to *Geoarchaeology*).

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