Deep anthropogenic topsoils in Scotland: a geoarchaeological and historical investigation into distribution, character, and conservation under modern land cover

Joanne Thomas McKenzie

Thesis submitted for the degree of

Doctor of Philosophy

School of Biological and Environmental Sciences,

University of Stirling

2006

Statement of originality

I hereby confirm that this is an original study conducted independently by the undersigned and that the work contained therein has not been submitted for any other degree. All research material has been duly acknowledged and cited.

Signature of candidate:

Date:

Abstract

Deep anthropogenic topsoils – those augmented through long-term additions of mineral bulk among fertilising agents – retain in both their physical and chemical make-up significant indicators for cultural activity. This project researched the geographical distribution and historical context of deep anthropogenic topsoils in Scotland and the Isles, and used this information to investigate the impact of current land cover upon the cultural information they retain. In so doing, the project investigated the potential for conservation of this significant cultural resource.

A review of the historical information available on agricultural and manuring practices for Scotland identified several factors likely to affect deep topsoil distribution and frequency. These were: the availability of bulk manures to Scottish farmers, the significance of the seaweed resource in determining fertiliser strategies in coastal areas, and the influence of urban settlement and associated patterns of domestic and industrial waste disposal on the location of deep topsoils. Evidence for widespread deep topsoil development was limited.

The primary data source used – the First Statistical Account of Scotland – was manipulated into a spatial database in ArcView GIS, to which geographical data from the Soil Survey of Scotland and national archaeological survey databases were added. This was used to devise a survey programme aiming both to investigate the potential factors affecting soil development listed above, and to locate deep topsoil sites for analysis. Three sites were identified with deep topsoils under different cover types (woodland, arable and pasture). The urban-influenced context of two of these highlighted the significance of urban settlement to the location of Scottish deep topsoils.

Analysis of pH, organic matter, and total phosphorus content showed a correlation between raised organic matter and a corresponding increase in phosphorus content in soils under permanent vegetation. By contrast, soils under arable cultivation showed no such rise. This was attributed to the action of cropping in removing modern organic inputs prior to down-profile cycling. The potential for pasture and woodland cover to affect relict soil signatures was therefore observed.

Thin section analysis aimed to both provide micromorphological characterisation of the three deep topsoil sites and investigate the effect of modern land cover on micromorphological indicators. Distinctive differences in micromorphological character were observed between the rural and urban deep topsoils, with the latter showing a strong focus on carbonised fuel residues and industrial wastes. All sites showed a highly individual micromorphological character, reflective of localised fertilising systems. There was no correlation between land cover type and survival of material indictors for anthropogenic activity, with soil cultural indicators surviving well, particularly those characteristic of urban-influenced topsoils.

Suggestions for preservation strategies for this potentially rare and highly localised cultural resource included the incorporation of deep anthropogenic topsoil conservation into current government policy relating to care of the rural historic environment, and the improvement of data on the resource through ongoing survey and excavation.

Acknowledgements

My thanks go firstly to my supervisor Professor Ian Simpson for his sound guidance, practical support and unfailing patience for the duration of this project.

Many thanks to others at the University of Stirling: firstly to my second supervisor, Professor Donald Davidson, for generous help and advice whenever requested; to Dr. Sandy Winterbottom for GIS assistance, George Macleod for manufacture of thin section slides, to Scott Jackson and John Macarthur for IT support, to Dr. Paul Adderley for image analysis advice, to Helen Ewen for laboratory support, to Bill Jamieson for printing assistance, and to Dr. Lisa Cahan, Lorna English and Dr. Emma Tilston for much appreciated support with lab work. I would also like to thank Dr. Richard Oram at the AHRB Centre for Environmental History for his advice on the archaeology of Whithorn. Dr. Gerd Dercon is thanked for his help during his time at Stirling, especially for laboratory guidance at the start of the project.

This project was partly funded by Historic Scotland, who are to be thanked not only for a valuable financial contribution, but also for their provision of GIS data. I would especially like to thank Dr. Sarah Govan for her help and advice, especially in the initial stages of the project.

Thanks are also due to the Macaulay Land Research Institute, Aberdeen, for permission to use Soil Survey data in this study, and for access to the maps and diaries of the Soil Surveyors. Mr. Jim Gauld in particular is to be thanked for his help and advice with this part of the project.

I would also like to thank the Royal Commission for the Ancient and Historical Monuments of Scotland and especially to Dr. Piers Dixon, for providing FESP and Historic Land Use Assessment data and giving permission for this to be used within the project.

.

Many thanks are due also to Dr. Matt Canti of English Heritage for advice upon the interpretation of micromorphological features, and for the (very long) loan of reference slides.

I would also like to thank the many professionals and enthusiasts connected with archaeology and heritage management in all of the survey areas for their help and advice. Most importantly, gratitude is due to the landowners, farmers and local residents without whose co-operation this project could not have been completed:

Nairn: to Mr. J. Forbes, Mr. R. Allen, Jenny Rose-Miller at Nairn Museum and Bob Steward at the Highland Archives, Inverness.
Tealing: to Mr. & Mrs. Thompson of Tealing House, George Christie, and Willie Millar.
Unst: to Val Turner and all at the Shetland Amenity Trust, to Ian Tait at the Shetland Museum, Brian Smith at the Shetland Archives, George Petrie at SEERAD, Graham Fraser at the Shetland Agricultural College, Mr. Ali Smith of North House croft, Peter Peterson of Underhoull, Dennis and Ninian Johnson of New House, Brian and Margaret Hunter, Robert Hughson, and Dr. Manda Forster.
Tiree: to Tom Dawson of SCAPE, Dr. John Holliday, '*An Iodhlann*', Hugh MacInnes of Ruaig, Willie Macphail, Lachie MacFayden, Archie MacLean, and to the Factor's Office, Argyll Estates.
Solway Firth: to Jane Brann at Dumfries Council, Jen Butterworth of the Whithorn Trust, Jane Maitland at Dundrennan, David Deveraux of the Stewartry Museum, Kirkcudbright, Robert Stewart of Drury Lane Farm, and David Austin.

I would also like to thank the Inverness Field Club for awarding me their Research Bursary 2003.

Last but not least: to all colleagues in rooms 4B108 and 4V11, especially to Crona, Lisa and Helen, and finally to my husband Iain, for his assistance with the survey programme and much practical support besides.

Contents

Appendices

List of figures

List of plates

List of tables

1. Introduction

There is a significant body of work in the fields of both geoarchaeology and soil science indicating that anthropogenic soils – those created and/or altered by human activity – retain in both their physical and chemical make-up significant indicators providing a wealth of cultural information valuable to archaeologist and historian alike. Micromorphological features, lipid biomarker traces and relative levels of chemical nutrients such as phosphorus in anthropogenic soils all provide significant indicators for past human activities such as arable cultivation, animal husbandry and aspects of land management such as manuring. Evidence from the soil record has, over the last thirty years in particular, greatly improved our understanding of the nature of human interaction with the landscape and in so doing, has provided much of the basis for research themes of resource exploitation, the economics of land use, and societal structure within early communities (see for example Foster and Smout 1994; French 2003; Holliday 2004). In addition, the increasing role of ecological, especially soil-based, scientific data in shaping the archaeological narrative has prompted continuing debate upon the ability of current theoretical frameworks to integrate environmental and historical cultural information at the level necessary not only to construct holistic interpretations of these interdisciplinary studies, but also to frame effective culturally-sensitive environmental policies for the future (Hingley 1993; Govan 2003).

Soil-based chemical and physical indicators for cultural activity are, however, often subject to change and degradation through continuing activity upon and within the soil. In addition to the chemical and physical changes of soil pedogenesis, significant changes in the nature of land cover such as the planting of woodland, and the encroachment of urban development pose significant potential threats to the survival of anthropogenic soils. Additionally, and in contrast to buried soil profiles, relict *surface* anthropogenic soils – formed through anthropogenic processes no longer in operation but still present as surface soil horizons – are, as a result of their typical location within cultivable land parcels, likely to continue as a natural focus for present-day agricultural activities, including land management techniques such as intensive ploughing, the use of artificial fertilisers, and localised land disturbance such as fence and drainage construction.

This is especially true of those relict soils where anthropogenic activity has resulted in the topsoil depth being augmented as a result of the long-term addition of mineral bulk among fertilising agents, for example peat or turf. Deep anthropogenic topsoils - defined as having an effective topsoil depth of over 50 cm and often generically referred to as ‘plaggen’ soils – are recognised as prime retainers for cultural and archaeological information, yet also provide an especially fertile agricultural resource likely to attract intense modern-day cultivation. It is this class of anthropogenic soil which is the subject of this thesis.

Plaggen soils have seen considerable research into their chemistry, geography and anthropogenic history, most notably in the Continental European areas whose medieval land management systems give these soils their name (Section 2.1). Within the British Isles, however, there has been only limited research into plaggen-type deep anthropogenic topsoils. Much of this has been concentrated on Ireland, where extensive plaggen-type soils have been identified in the south-west coastal areas (Section 2.2).

Although there is evidence that similarly augmented relict anthropogenic soils are distributed throughout Scotland, previous research into Scottish deep topsoils has been strongly aligned with archaeological investigations and is thus predominantly site-based, concentrating in particular on the Northern Isles (Section 2.4). While these studies amply illustrate the potential of anthropogenic soils to complement a range of archaeological data sources, such as structural remains and surviving field systems, to become a valuable tool for historical geographical study, there has to date been little investigation into the distribution and frequency of these soils throughout Scotland, or their relationship to the wider, and later, historic landscape. Furthermore, although such projects have confirmed that these Scottish soils retain highly significant cultural indicators, no investigation into the effect of continuing agricultural activity upon the nature and quality of these indicators has yet been undertaken.

This aim of this thesis is twofold: firstly, to research the geographical distribution and historical context of anthropogenic deep topsoils throughout Scotland and the Isles; and secondly, to use this information to investigate the impact of land cover and modern-day agricultural activity upon the archaeo-historical information that these Scottish deep topsoils retain. In so doing, this project contributes to the development of conservation and management strategies for this significant soil cultural resource.

1.1 The potential threat to soil cultural indicators: modern land use and management

1.1.1 The general effect of agricultural activity

Archaeological sites and landscapes have long been understood to be damaged by agricultural activity – '*the biggest single threat*' (Thurley 2003: 24) to in-situ rural remains, many of which are unrecorded (Trow 2002).

Ploughing in particular has long been recognised as a major cause of damage on a number of levels. Ploughing damages archaeology and compromises its landscape context both above and below the ground: by cutting through and thus distorting or even destroying buried archaeology, by moving both artefacts and ecofacts out of context within an archaeological landscape (Wilkinson 1982), by gradually removing protective layers of soil, and by levelling out earthworks (English Heritage 2004a). Soil disturbance also alters drainage regimes and thus the conditions of the burial environment that ensure the preservation of organic remains.

Changes in plough technology and the economics of modern farming have, in recent years, exacerbated the problem. Despite a trend towards shallower ploughing in recent decades (Lambrick 1980; Hughes 1980), more efficient ploughs, which can cut more furrows at a time, need heavier tractors to pull them and thus tend to cut deeper into the soil (Geake 2003: 16). Large, industrial units with lower labour costs but more intensive cropping methods are more profitable than smaller farms. Converting from cereals to root crops makes it easier for small farms to make a living, but such crops require deeper ploughing (Nicholson 1980) and a stone free topsoil (Geake 2003) and are thus potentially more damaging to archaeological remains. Neither is plough damage limited to the plough layer: related cultivation techniques such as subsoiling, which improves drainage, can have a devastating effect on deeply-buried sites (Spoor 1980).

Forestry, especially commercially-managed plantations, poses another threat. Forestry ploughing is deeper and uses larger implements, causing increased damage (Hinchcliffe 1980) and the turning over of land to woodland can cause damage to subsoil archaeological features as land preparation, planting, and subsequent root growth disrupt stratigraphic relationships. Root systems alter the chemical balance of soil, producing exudates that may hasten the chemical deterioration of archaeological materials, and alter soil water levels which can destroy the anaerobic conditions which preserve, in particular, organic materials. The recent Monuments At Risk Survey for England '*demonstrated that one ancient monument has been destroyed every day between 1945 and 1995 and that forestry was a substantive contributor to this destruction*' (Trow 2001). The problem of increasing forestry cover is a particularly serious one for Scotland (Section 1.1.2).

Grassland, particularly unimproved permanent grazing land, is undoubtedly the cultivation method least damaging to structural remains, and action taken to preserve these in agricultural land has generally been to take such areas out of cultivation and into grass under a compensatory payment scheme (Hinchcliffe and Schadla-Hall 1980). Perversely, however, the lack of a crop on such land can lead to a general lack of care that may also affect archaeological remains. Careless use of farm vehicles, land drainage, encroachment of vegetation, erosion and burrowing animals are all threats to the historic landscape in this class of agricultural land (English Heritage 2004b).

Archaeologists have long been aware of these problems, and significant research has been undertaken into, in particular, plough damage, and how its effects might be mitigated (see especially Hinchcliffe and Schadla-Hall 1980), including experimental work (Reynolds and Schadla-Hall 1980). More recently, large scale survey projects have sought to investigate both the positive and negative effects of agricultural activity, such as the Norfolk Monuments Management Project, established in 1991 with an emphasis on identifying changes in land management that need not affect productivity (Paterson and Cushion 2003). Despite such projects, plough damage continues: the Portable Antiquities Scheme reports that almost all of the artefacts recorded since its inception come from ploughsoil areas (Geake 2003) and many significant archaeological landscapes are now described by archaeologists as 'plough-denuded', such as Wessex (French 2003: 173). There is, however, another side to the coin: ploughing in the Wessex region, for example, has been practised since the prehistoric period (Bonney 1980) and ploughing as an activity represents one of our main sources of information for past arable activity. In addition, not all plough damage is modern – in considering the question of plough damage it may be useful to reflect upon the medieval cultivation systems which, in the absence of heritage management schemes, have themselves certainly destroyed countless archaeological remains (Bonney 1980). It must be borne in mind that plough damage represents the continuation of those traditions that archaeological landscape study seeks to investigate.

1.1.2 The Scottish archaeological landscape

Cultivation practice, and the organisation of the agricultural landscape, differs significantly between Scotland and the rest of the British Isles. This is largely due to the nature of the farming landscape in Scotland: 85% of the Scottish landscape is designated as Less Favourable Area (see Coppock 1980), compared to approximately 15% of England. As a result, Scottish farming is predominately upland, and associated with pastoral agriculture (Wordsworth 2003). The benefits for the historic landscape are mixed. On one hand, plough damage may be considered to be less of a problem in Scotland; on the other, as farming subsidies are linked to arable productivity, Scotland has had the lowest level of agricultural support in the UK, and this includes spending on the rural development projects and agri-environmental schemes which now seek to include archaeological considerations within their remit (*ibid*.). Weak links between Historic Scotland and SEERAD (The Scottish Executive Environment and Rural Affairs Department) have compounded this problem, with the result that 'current environmental policy deals with ecology and biodiversity to the neglect of the historic environment' (Wordsworth 2003: 22).

Uniquely in the British Isles, there also exists in several archaeologically significant areas of Scotland a potential conflict between the needs of the historic environment and those of the traditional farming lifestyles which, in part, created it. The Crofting Commission, established in 1886, protects the interests of small-scale traditional farming – 'crofting' (Section 3.2.3) – in the legally defined 'crofting counties' of Shetland, Orkney, Caithness, Sutherland, Ross and Cromarty, Inverness and Argyll (Grantham 1996; www.crofterscommission.org.uk). The survival of a thriving crofting community undoubtedly has long-term benefits for landscape preservation strategies, keeping a population in rural areas and enabling maintenance of archaeological landscapes in both an environmental and historical sense. However, while good crofting practice is popular with both archaeologists and conservationists, the reality of the modern crofting economy is often one of overgrazing resulting from sheep overstocking, and a loss of traditional light cropping systems as grant aid systems encourage (largely unsustainable) attempts to raise yields through extensive use of artificial fertilisers (Grantham 1996). Potentially more serious a threat to archaeological remains in the crofting areas, however, is the Crofter Forestry scheme (www.crofterscommission.org.uk/ downloads/guidecroftforest.pdf: 2004), which encourages tree planting on small plots of 'inbye' land – i.e. the fertile infield areas within which the majority of evidence for past agricultural practices – and deep anthropogenic topsoils (Section 3.2.2.2) are likely to survive. In the interests of improving landscape diversity, providing local renewable fuel and creating jobs, forestry planting is being particularly encouraged in crofting areas with little or no woodland cover, such as Shetland and Lewis (Grantham 1996), which are rich in archaeological remains.

Forestry is a potentially major threat to Scottish archaeological landscapes, and not just in the crofting regions. Historically, Scotland has had a low woodland cover: the earliest survey, dating from 1750, places about 4% of the Scottish landscape under woodland – one of the lowest percentages in Europe, and already achieved before the industrial era (Edwards and Smout 2000). After the First World War, with the establishment of the Forestry Commission, and encouraged by subsidies and tax breaks, this quickly rose to the 19% cover seen today (*ibid*.). Many of these new woodland areas are likely to have been established, therefore, not only upon ancient, but also post-1750 archaeo-historical landscapes. There is a strong conservation lobby for establishing new native woodlands throughout Scotland and, as hill farming becomes increasingly economically unsustainable, ensuring protection of the historic landscapes currently preserved on open moorland in response to the woodland lobby will become increasingly important (Wordsworth 2003). Although the need for this expansion to take account of the historic environment is recognised by the Scottish Executive (Yarnell 2003: 83), the stated aim for Scottish woodland cover to reach 25% over the next fifty years poses a challenge to, especially, protection of the wider archaeological landscape – the 'whole complex' of which soils and field systems are an integral part (*ibid*.: 84).

Unfortunately, it is possible that current agri-environmental policy, with its focus on the production of greener ‘energy crops’, including short rotation coppice, could further aggravate this problem (Trow 2001). This is undoubtedly an issue of some urgency, not least because the potential effect of woodland cover upon these less tangible elements of the archaeological landscape is not well understood: for example, the potential cumulative effect of tree cover combined with the loss of perceived positive effects of grazing in managed plantations, and the overall effect of scrub regeneration even in loosely-wooded areas.

Recent designations and developments in Scottish environmental policy have, however, proven beneficial for archaeology. The Argyll Islands, the Uists, Shetland and the Cairngorm straths have been designated Environmentally Sensitive Areas, policy for which assists farmers in adopting land management systems within which conservation interests – including the historic landscape – are integrated with the needs of agriculture (Macinnes 1993: 252). In these areas, this has included the adoption and/or or maintenance of traditional manuring practices such as the use of seaweed to fertilise the land (Grantham 1996: 233). Survey work undertaken for this project in 2002 noted extensive use of seaweed as a fertiliser on the island of Tiree (Section 5.2.4). Most significantly, initiatives associated with CAP (Common Agricultural Policy) reforms, such as the Land Management Contract Scheme, look set to further prioritise cultural heritage resources within farming policy (http://www.scotland.gov.uk/News/Releases/2005/08/ 25151946), Chapter 8.

1.1.3 Soils and the historic landscape: current conservation strategies

The last few decades in archaeology have undoubtedly seen awareness raised as to the threat to the archaeological landscape from agricultural activity. However, this concern has, until recently, been focused on the most ‘visible’ parts of the archaeological record – settlements, structures and artefacts. Fainter traces of cultural – mainly agricultural – activity, such as field systems and ancient tillage features, along with the human-modified soils found in association with them, have been largely ignored by scheduling and preservation strategies.

Over the past decade, this situation has changed. The increasing profile of scientific archaeological analysis has undoubtedly played a part in highlighting the importance of anthropogenic soils as an archaeological resource. However, more influential in focusing research upon – among other landscape features –anthropogenic soil amendment has been our changing perception of the historic past as preserved within a *landscape*, rather than through individual archaeological settlements or historical remains. While this perception is not new to archaeological thought, it has gained increasing prominence as a general theme for public debate and, as a result, policies that affect archaeological strategies. The notion of the 'landscape' or, more usually, the 'environment' as a holistic entity, to be perceived of and conserved as a system rather than as a series of separate concerns, is a thread which runs through current policy in conservation, rural planning, farming policy and archaeology alike. Thus, 'traditional' crofting methods of agriculture in Scotland are encouraged not only for the sake of preserving historical tradition, but for their promotion of species biodiversity as well as for the survival of rural communities (Grantham 1996).

Within archaeology, this concept of 'landscape' as a complex system has led to increasing prominence being given to interdisciplinary work which attempts to investigate not only the 'built' archaeological environment, but the land- and soil-scapes constructed around it. This has proven especially fruitful for soil-based geoarchaeological study, not only in an academic sense (as illustrated throughout this chapter) but in the area of national policy regarding the historic environment. DEFRA (Department for Environment, Food and Rural Affairs) isolate 'Soils, the Landscape and the Cultural Heritage' as a specific area for action within its First Soil Action Plan for England 2004-2006, launched in May 2004 (www.defra/gov/uk/environment/land/soil/ actionplan.htm), stating that '*Soils…must be considered as part of the totality of the landscape and the broader historic environment…Threats to soil and soil quality endanger the sustainability and protection of the historic landscape, and damage archaeological evidence preserved within the soil irreversibly*' (DEFRA 2004: 26-7).

1.1.3.1 MoLRS and Scottish historic landscape research

Within the archaeological community, the most valuable result of this concern to safeguard soils as part of the historic landscape has been the significant focus on survey and research into patterns of rural settlement in England, Wales and especially Scotland over the last decade. In response to a 1991 seminar (Hingley 1993) on the management and preservation of Medieval or later rural settlement features in Scotland (now, in the wake of numerous publications, known as MoLRS), Historic Scotland formed an Advisory Group to formulate policy and guidance on the protection, management and interpretation of the MoLRS resource (Macinnes 2003). MoLRS is now a mainstream field of Scottish archaeological study, with numerous research projects operating under its umbrella, focusing on the settlements, townships and often complex remains of their innumerable field systems, dating to the pre-Improvement period in Scotland (see www.molrs.org.uk/html/projects.asp; Atkinson *et al*. 2000; Govan 2003). This latter category is essentially a soil-based study area, and concerns the geoarchaeology, morphology and spatial relationships of past arable fields and their tillage features. The significance of the MoLRS research to the recognition of anthropogenic soils as an archaeological resource cannot be underestimated: in 2001, Historic Scotland indicated that, in their approach to scheduling 'particularly coherent field systems' they would consider scheduling examples of field systems isolated from settlements (Barber 2001: 5) – in other words, scheduling of anthropogenic soils would be considered.

An aspect of MoLRS-based research of particular relevance to this project are the two recent extensive spatial database projects undertaken by both Historic Scotland and the Royal Commission on the Ancient and Historical Monuments of Scotland (RCAHMS). The first of these is the Historic Landuse Assessment (HLA), devised in 1996 as a joint project between Historic Scotland and RCAHMS in order to create a method of assessing historic landuse patterns in Scotland by integrating Ordnance Survey, National Monuments Record, land cover and aerial photograph data into a GIS (Bruce *et al*. 1999; and see Section 4.1.4). This data has now been made available as HLMAP, a web-based presentation allowing users to view data by landscape type, category or period (see http://jura/rcahms.gov.uk/HLA/start.jsp). The second is the First Edition Survey Project (FESP), conceived as a response to growing concern at the lack of attention given to Scotland's medieval or later rural settlement (Atkinson 1995; Section 4.1.4). FESP is a survey of the unroofed buildings recorded on the first edition of the Ordnance Survey 6-inch map (1843-1878) and provides spatial information on the pattern of rural settlement and abandonment for the pre-Improvement period (Historic Scotland/RCAHMS 2002). The collation of these large bodies of extant archaeo-historical surveyed data into a GIS format has added over 20,000 new sites to the MoLRS database (Macinnes 2003: 3) and facilitated the mapping and interpretation of historic landscapes both for archaeological and cultural heritage management projects. These include the PASTMAP (www.PASTMAP.org.uk) national archaeological online database, which, among other uses, is offered as a tool for farmers to maintain compliance under GAEC (Good Agricultural and Environmental Conditions) rules regarding ancient monuments (Historic Scotland 2005). Data from the FESP and HLA projects have, with the generous permission of Historic Scotland and RCAHMS, been incorporated into the database which facilitates the first aim of this project: researching the distribution and frequency of deep anthropogenic topsoils throughout Scotland and the Isles.

Researchers in the field of MoLRS have commented that, given that MoLRS remains often encompass entire relict landscapes, the exploration of workable methods of protection and management of the MoLRS resource are a matter of some urgency (Hingley 2000: 14). The utilisation of MoLRS-based research in a project aiming to address one aspect of this issue – the soil cultural resource - provides an appropriate context for the potential application of any recommendations offered. In addition, as neither of these data sources utilise soils-based information, this project hopes to assess the potential for spatial resources such as these to widen their remit to include material of this nature.

1.2 The creation of soil cultural indicators: manuring

The cultural information retained by anthropogenic soils and threatened by agricultural activity as described above is a direct consequence of the fertilising materials added during similar such cultivation in the past. Soil fertilisation or manuring is an essential element of all agricultural systems, a process of replacement that compensates for nutrients taken from the soil through cropping. Successful manure application provides the necessary nutrients for crop growth, in particular the nitrogen, phosphorus and potassium that are today generally provided by artificial fertilisers. Manure application also supplies soil with bulk organic and mineral matter which retains water and – especially on loose sandy soils – provides essential cohesion. Organic additions also provide food for earthworms, which aerate the soil and facilitate root penetration.

As manures readily lose nutrients, either by fungal activity when the manure dries out or by leaching of the soluble constituents, an important part of the manuring process is the formation of composts. Composting is the mixing and storage of organic fertilising materials prior to addition to the soil, in such a way as to ensure that drying and leaching does not take place. The manure materials undergo decomposition before the compost is added to the soil, and, as a result, the fertilising nutrients are immediately made available to the crop. (Wilkinson 1982).

The importance of appropriate manuring strategies was recognised by the earliest agricultural writers, and treatises on fertilising methods survive from Roman writers such as Pliny, Columella and Varro (Woodward 1990). From the many later English and Scottish works dealing with manuring practice, we know that manure applications from antiquity through to the early modern period came from an extremely wide range of sources, their use largely depending on their availability within each agricultural area (Chapter 3).

The chemical and physical traces of these vital additions represent the best source of evidence for past agricultural practices accessible by soil analytical methods. Tillage, the other major agent of soil change associated with cultivation activity, while producing macro-features such as rig and furrow and being a vital to our understanding of landscape features such as field systems, is far less easy to identify and analyse in the sub-soil record (Carter and Davidson 1998; Lewis 1998). The action of ploughing mixes topsoil and sometimes subsoil horizons to produce, over time, a 'relatively homogenised' plough layer (Courty *et al*. 1989: 131), where the overall effect of repeated ploughing and manuring is to cause regressive pedogenesis – the simplification, rather than development, of horizon sequences (Davidson and Smout 1996). These processes themselves destroy the physical signs for tillage activity within the soil. Evidence for cultural processes in the anthropogenic deep topsoil record is therefore more likely to be seen in the remains of substances added to the soil, rather than physical evidence for tillage activity itself. This is especially true of deep anthropogenic topsoils. Aside from the obvious importance of fertiliser additions to the identity of soils characterised by intense manuring resulting in vastly increased soil depth, unlike non-augmented soils - for example the ard marks that, when cut into subsoil horizons, can survive to indicate agricultural activity - deep anthropogenic soils will have seen extensive, repeated tillage episodes which are likely to have destroyed evidence for previous plough events.

These factors have dictated the research design of this thesis, which uses the theme of manuring practice in Scotland, rather than topographic landscape study or an archaeological site-based context, as a starting point from which to formulate a series of linked objectives to achieve the dual aims of this thesis.

1.3 Aims and objectives of the project

The two aims to this research project, although comprehensible as discrete research exercises, are entirely complementary and are linked in this thesis to create a narrative progression. The first of these aims is the use of relevant historical, geographical and archaeological source data to investigate the distribution and frequency of anthropogenic deep topsoils in Scotland and the Isles. With the bulk of the archaeo-historical datasets able to provide information relevant to the investigation of deep topsoils relating primarily to the medieval and especially post-medieval period in Scotland, the project concentrates upon deep topsoil development of potentially later date than the primarily prehistoric deep topsoils so far identified in Scotland, and thus provides a body of research which complements that of the MoLRS study area discussed in Section 1.1.3.1.

The second aim of this thesis uses this body of research to devise a survey programme to identify previously unknown areas of deep topsoil currently under a range of different land cover types and, using samples taken from these, uses appropriate soil analytical methods to assess how modern land cover and land management practices may affect the survival of the cultural indicators these soils retain. From a conservation management perspective, these aims complement one other to provide a comprehensive overview of the distribution and potential rarity of these soils, plus the extent to which their cultural value may be being compromised by present-day land management techniques.

1.3.1 Investigating the distribution and frequency of deep anthropogenic soils in Scotland

The first aim of this project was achieved through two linked objectives, the first literature-based, and the second utilising techniques of spatial analysis. These two objectives identified a series of cultural, environmental and geographical factors which, it is posited, will have largely dictated the distribution and frequency of deep anthropogenic topsoils throughout Scotland.

The first objective can itself be separated into two parts. Firstly, the review and assessment of the available literature on deep anthropogenic soils (Chapter 2). This focussed on:

a. the most extensive and well-researched group of deep anthropogenic topsoils: those from the Continental 'plaggen' regions. This provided a sound characterisation of the nature and context of formation of these soils, and

b. those already identified in Scotland, largely as a result of site-based archaeological projects.

Secondly, a review and discussion of the data available for historical manuring practices throughout Scotland was undertaken (Chapter 3). This used the available historical source literature to characterise manuring practices throughout Scotland and their geographical variation, and, by considering these with reference to the known factors in deep topsoil formation discussed in Chapter 2, was able to identify the series of factors likely to have influenced Scottish deep anthropogenic topsoil formation, as stated above.

The second objective undertook to take the observations made in Chapters 2 and 3 a step further, creating a GIS database in which the historical source data reviewed in these chapters was integrated with relevant spatial data sources in order both to confirm and, hopefully, refine the hypotheses offered in the literature-based assessment regarding the distribution and frequency of anthropogenic deep topsoils in Scotland. The sources used were as follows:

a. Digital. Map of Scottish parishes, provided by Historic Scotland (Section 4.1.1)

b. Historical. The First Statistical Account of Scotland (1791-1799), supported by the County Agricultural Reports (1793-1814). Resolved to parish and county level, and the earliest Scotland-wide documentary data sources relating to agriculture and manuring practice (Section 4.1.2)

c. Geographical and soils-based. Spatial data from the Soil Survey of Scotland relating to topsoil depth in areas covered by the Soil Map series (Section 4.1.3)

d. Archaeological. Data from the First Edition Survey Project and Historic Landuse Assessment, as discussed in Section 1.1.3.1. (Section 4.1.4)

Chapter 4 discusses the creation of this ‘manuring database’ and its evaluation to provide further information upon the distribution and frequency of deep anthropogenic topsoils in Scotland.

1.3.2 Investigating the effect of modern land use on Scottish deep anthropogenic topsoils

The second aim of the project focussed on investigating the threats posed by modern land cover and land use to Scottish deep topsoils. This was, again, achieved through two linked objectives: firstly, a survey program undertaken to identify discrete areas of deep topsoil currently under a range of modern land cover types; and secondly, a program of analysis investigating differences in the expression of key soil cultural indicators under these different land cover types.

The first objective in this second part of the thesis - the survey program - was closely linked with those objectives undertaken in the first. The manuring database, created and evaluated in Chapter 4, was used throughout Chapter 5 as a basis for a survey methodology whose aim was not only to locate deep topsoils, but to further investigate the factors identified throughout the first part of the thesis as having a probable influence on the development of deep topsoils in Scotland. This was achieved by using the manuring database to select a series of five locations for auger survey which were representative of cultural and/or geographical contexts illustrative of these factors. From these, three sites showing deep anthropogenic topsoils under an appropriate range of modern land cover types were selected for sampling: arable, woodland, and grassland (Chapter 5).

The second objective of this part of the thesis investigated the effect of these different land cover types through a series of analytical techniques. These were:

a. analysis of soil pH (Chapter 6)

b. analysis of soil organic matter content (Chapter 6)

c. analysis of soil total phosphorus content (Chapter 6)

d. analysis of key soil micromorphological features (Chapter 7)

The discussion of the results of these analyses had two foci: first, the effect of modern land use and land cover on soil cultural indicators; and second, the variation in the nature of these indicators seen between sample sites. This latter carries the discourse present throughout the thesis into the scientific analysis – that a series of cultural and geographical factors have been identified which influence the frequency and distribution of deep anthropogenic topsoils throughout Scotland.

Finally, Chapter 8 concludes by linking the series of investigations presented in this thesis – literary, spatial, and analytical – into a coherent consideration of the value of deep anthropogenic topsoils to the Scottish cultural resource, both in terms of their potential rarity, and the quality and range of information they can provide on aspects of Scotland's past. It is seen that the several factors identified as likely to influence deep topsoil development are of great importance both in determining the nature of this soil cultural resource and its potential level of survival within different Scottish regions. Against this is set the observed potential for modern land use to compromise this resource, resulting in a series of recommendations both for conservation of these soils and for future research potentially beneficial to increasing both understanding and protection of this significant cultural resource.

1.4 Key themes

As awareness of the part played by soils in archaeological landscapes increases, so will a concern for soil health in an archaeological context. This is a complex issue. Soils are dynamic entities (Davidson and Smout 1996) and their properties, including those which preserve cultural information, alter over time whether or not there is modern activity upon the land. The preservation of soil information is therefore not as simple as the preservation of structural archaeological remains: preserving soils 'in aspic' is neither possible, nor desirable for the environment - '*an ecosystem's destiny…is always to be in the process of becoming something else*' (Morris 2002).

Human impact, usually associated with degradation in the landscape, has substantially improved the majority of Scottish soils, and this continuing process not only makes it difficult to define the cultural and chronological limits of the soil-based archaeological record, but also makes gauging the effect of modern-day change on these relict properties a complex issue. More difficult still is the tracing of specific changes in the soil to one particular modern cause. Manuring activity is the most useful and reliable source of data on past farming practice, and also that most appropriate for study through the analytical methods used within geoarchaeology. To investigate the effect of modern land management and land cover on the soil-based cultural record through manuring indicators in deep anthropogenic topsoils is a solid approach.

More challenging has been the concept of achieving this by relating explicitly historical data, such as documentary sources, to the soil record. But although these may provide only indirect evidence for past soil modification, this thesis demonstrates that such sources can be an equally coherent basis for enquiry. Furthermore, as current thinking on the potential threat of modern land use to the archaeological landscape highlights, documentary and cartographic historical sources are an essential part of contemporary efforts to record and protect the more elusive elements of the wider historic landscape. So far, large-scale manipulations of historical records to provide 'gazetteer-style' resources relating to the historic landscape are lacking (Bangor-Jones 1993: 40).

Such historic contextualisation is also a vital consideration in considering the impact of modern land cover on this cultural record, and how its effects can be mitigated. The issue is one of cultural resource management: is soil cultural information being lost through current land management techniques, and if so, what might this loss mean for the historic landscape? Could soils from certain regions or archaeo-historical contexts be considered more culturally significant than others and therefore more worthy of conservation? In this, context is everything: two soils of comparable depth which have different input histories must be seen as equally worthy of investigation. This project, in assessing the distribution and frequency of these soils as a function of their historic context, hopes to provide a meaningful statement on the conservation methodologies most appropriate for these soils. The detailed archaeological and historical contextualisation of each fieldwork site in this project illustrates the difficulty of defining the nature of such an unquantifiable cultural resource, and such assessments require not only the interpretation of a set of analytical results, but in addition a 'deft integration of both environmental and cultural information at a variety of spatial scales' (Crumley 1994: 9). This thesis aims to present an interdisciplinary body of work which does this: combines historical, archaeological and scientific research to give a meaningful insight into the position of deep anthropogenic soils within the Scottish landscape.

2. Previous research into deep anthropogenic topsoils in Europe

In this chapter the characteristics of, and the processes which result in, anthropogenic deep topsoils are discussed, with reference to previous research into these soils in a range of geographical and environmental locations in Europe. This chapter aims at an overview of the state of research in this area, introducing the most significant European locations featuring deep anthropogenic topsoils, their physical and chemical characteristics, and, most significantly, the many and varied agricultural practices which contribute to their formation.

The chapter divides into three main sections. The first of these discusses previous research into deep topsoils outside of Scotland. This focuses primarily upon the Continental North-West European areas which have not only seen by far the most research into deep anthropogenic topsoils, but also provide the most appropriate comparative dataset to provide historical, geographical and environmental context for this investigation into these soils in Scotland.

The second part of the chapter examines the current state of research into those deep anthropogenic topsoils so far identified in Scotland itself. This makes for a very different discussion: where the Continental soils show a relatively strong association with the agricultural intensification of medieval Europe, in Scotland these soils are associated with prehistoric to modern contexts. Likewise, where the Continental soils are notable for their extensive spread through several countries, deep anthropogenic topsoils identified in Scotland have been – so far – relatively small in extent and largely restricted to the Northern Isles. With common themes of manure input, archaeological context and potential outside influence linking the soils seen in these different areas, this section approaches the Scottish soils context first and chronology second, with a discussion of first the Orkney and then the Shetland deep topsoils.

These discussions therefore not only provide a review of deep anthropogenic topsoil research that informs the remainder of the thesis, but also an introduction to many of the key themes explored throughout. These include the indispensable role of specific manure types in creating deep anthropogenic topsoils, the influence of the relationship between urban and rural areas upon manuring strategies, the potential anthropogenic complexity of soils formed through gradual accumulation of material over long periods, and the way in which the formation of deep anthropogenic topsoils is governed by, and in turn can inform upon, specific agri-economic and even social factors in the regions in which they survive. These are seen to be truly ‘cultural soils’, key to understanding landscape history.

These many and varied factors which govern the formation of deep anthropogenic topsoils leads into the final section: how to classify these soils? This is a debate which has not been entirely resolved within either archaeology or soil science. Within geoarchaeological study, the question of classification is closely related to that of historical background, making for a complex and unavoidably ambiguous discussion, within which terminology has not yet been agreed. Within soil science, classification is predicated by the chemical and physical composition of a soil, and to a lesser extent its geographical situation, and this latter discipline has achieved little consensus on the classification of deep anthropogenic topsoils.

While classification is not a central theme of this thesis, the objectives of this research project make it possible to comment on the relationship between these factors, and thus the issue of classification of deep anthropogenic topsoils. The final section of this chapter discusses the varying classifications of anthropogenic deep topsoils within the main classification systems used in soil science, and introduces the suggestion that will be explored further in the rest of the thesis: that a system which considers input choice and historical and/or archaeological context as the defining factors in the classification of these deep anthropogenic topsoils is able to examine the pedological, geographical and social context behind the formation of such soils, and therefore place investigations within a meaningful archaeological framework. From this, issues of preservation and management – the central theme of this thesis - can be more intelligently explored.

2.1 The plaggen soils of Continental North-West Europe

The earliest and still the most extensive body of research into deep anthropogenic topsoil formation comes from Continental North-West Europe, from Germany, Belgium, Denmark, and especially the Netherlands (Stoklund 1999: 210). These are the *plaggenbodem* (German *plaggengronde*) or ‘plaggen soil’ regions, from *plagge*, meaning ‘sod’ (Siderius and de Bakker 2003: 525) – large areas of extensively augmented anthropogenic topsoils, formed by a system of land management characteristic of these regions which is thought to have its origins in the Late Bronze Age (Blume and Kalk 1986, cited by Blume 1998: 2) and which continued throughout some of these areas until the advent of chemical fertilisers (Pape 1970: 253).

The plaggen manuring system pared sods of turf from areas of ‘waste’ – uncultivated – land, and then either used these as bedding material in stock pens and stables (where they would become impregnated with dung) or composted them with dung separately before applying the resulting mix of mineral and organic material as fertiliser to the fields. This intensive addition of bulk matter contained large amounts of relatively insoluble mineral material - the system required approximately 5-10 ha of waste land to supply 1 ha of arable land (Blume 1998: 2; Stoklund 1999: 210), though amounts varied due both to the type and the quality of turf and the crop for which the manure was intended (Slicher van Bath 1963: 258). The result of such intensive additions to the soil was the development of extremely deep anthropogenic topsoils – the deepest can be over 1.2 metres (van de Westeringh 1988: 11), though the minimum depth for a plaggen soil is generally accepted as 50 cm (de Bakker 1979: 138). An estimated 221,000 ha of land within the Netherlands has been augmented to at least this depth by plaggen manuring, and a further 196,000 ha to between 30 and 50 cm (Pape 1970: 230). Data is less extensive for other plaggen regions, but coverage is also likely to be extensive: a study in the district of Osnabruck (North-West Germany) alone recorded more than 400 km^2 of plaggen-manured soils (Blume 1998: 3).

Almost all of these plaggen topsoils are located on sandy soils, usually within the coastal regions around the North Sea - of the Pleistocene sandy soils that cover one third of the Netherlands, over 30% have been augmented by plaggen manuring (Pape 1970: 230). In North Germany and West Jutland, substantial areas of moorland were brought into cultivation through the plaggen system (Poulsen 1997: 140): land reclamation and an associated increase in population density are strong features of the plaggen areas – at their deepest around larger settlement areas, they gradually thin towards more distant areas of poorer soil (Pape 1970: 237). Place names commonly reference the plaggen system: in the Netherlands, while field and farm names in the low-lying polders are commonly associated with water management, on the higher, sandy plaggen areas such names are chiefly related to soil fertility (Siderius and de Bakker 2003: 529). The legacy of the plaggen system thus remains an evocative expression of the particular concerns of rural life and agricultural practice in these areas.

For the archaeologist, the plaggen areas are characterised by the presence of artefacts and ecofacts testifying to their anthropogenic origin – charcoal, pottery, bone, burnt loam, bleached sand grains and sand strata, and especially pollen. Pollen survives extremely well in humic, comparatively acid plaggen soil conditions, and the use of pollen diagrams to date and investigate plaggen deposits is well-established (Bakels 1988; Groenman-van Waateringe 1988; Mucher *et al*. 1990; Spek 1992). Plaggen soils are also characterised, and indeed partly classified, by their colour: either black or very dark brown (de Bakker 1979: 134).

The plaggen manuring strategy was an effective means of maximising yield from chemically and physically poor soils (van de Westeringh 1988: 7), for although the addition of plaggen did not greatly raise the chemical fertility of the land (largely as the heath and moorland areas from which the mineral additions were taken was also chemically poor), the physical increase in topsoil depth conferred several advantages. The humose topsoil created a favourable moisture regime, in which sandy soil would rarely become too wet or too dry (the plaggen areas could withstand considerable drought), and within which soil oxygenation and root penetration were good. In addition, the thick dark topsoil would absorb heat quickly, enabling crops on plaggen soils to start their growth season early (Pape 1970: 234).

Historical, archaeological and ethnological research has provided considerable detail on the specifics of the plaggen manuring system in various Continental regions, its place within the changing strategies of European agricultural development, and its relationship to environmental and economic factors. These are discussed in the following sections.

2.1.1 The introduction of the plaggen system

Although a range of dates are quoted for the development of plaggen soils in individual regions, the wider chronology of plaggen soil introduction and development in Continental North-

West Europe is still a subject for debate. The earliest ‘safely proved’ plaggen soil has been dated to the Bronze Age (Blume 1998: 2). Isolated investigations have also demonstrated that turf manuring systems were in use in some areas of Denmark, the Netherlands and Norway from the eighth to ninth centuries AD (Myhre 1985: 77; Groenman-van Waateringe 1988: 55; Poulsen 1997: 120). However, the most reliable source for plaggen soil dating comes from the pollen record, which suggests that that plaggen manuring on a large scale did not start until around the tenth century AD, and did not reach a level of widespread use until the twelfth or, more probably, the thirteenth centuries (Mucher *et al*. 1990; Spek 1992). Archaeological dating methods support this: a palaeoecological investigation into plaggen soils in North Brabant, the Netherlands, found that associated potsherds dated to the ninth to tenth centuries only at the base of the plaggen sequence (and could therefore have lain on the original, non-augmented soil surface for centuries prior to being amalgamated into plaggen manures) whereas the regular distribution of ceramic material within the true plaggen soil dated to the tenth to eleventh centuries (Bakels 1988: 48).

These dates broadly link the expansion of the plaggen manuring system with a key period of agricultural development and intensification in Continental North-West Europe which reached its apex through the twelfth and thirteenth centuries. Plaggen creation is popularly viewed as a response to the challenges facing farmers in these regions at this time, facilitating advances such as the introduction of permanent cropping and the expansion of rye cultivation (Mucher *et al*. 1990; Stoklund 1999: 210, and see particulars of the Danish system discussed in Section 2.1.2) not only by maximising arable yields, but by assisting in the reclamation of moorland for cultivation (Poulsen 1997: 140). A second possible impetus for the widespread adoption of plaggen manuring during this period is the climatic anomaly which resulted in considerable drought through the tenth and eleventh centuries in these regions, and which itself had an influence on the changing agricultural strategies of the period (Heidinga 1988: 23-5).

However, the most recent investigation into the chronology and development of plaggen type soils may indicate a far longer period of development. As part of an interdisciplinary landscape project, pedological, palynological and micromorphological methods have been used to investigate the development of a ‘Celtic’ field system (dating from roughly 1100 BC – AD 200) in the Drenthe area of the Netherlands (Spek *et al*. 2003). This well-preserved field system is comprised of a network of fields enclosed by sandy 'ridges', shown by an extensive auger survey programme to preserve relict cultural soils of 10-20 cm thickness in the fields, but similar deposits of 60-70 cm thickness within the ridges. Analysis of the sequence of soil horizons within both the ridges and the arable soils themselves indicates that the large soil ridges were created in the later Iron Age and early Roman periods by the large scale transportation of soil material, both from the arable fields and from the surrounding area. These deep topsoil ridges were then themselves heavily manured and cultivated (*ibid*.: 167). These early dates suggest that the origin of the well-organised, large-scale plaggen manuring system may be very ancient indeed.

2.1.2 The plaggen system: historical and ethnoarchaeological research

Recent work has illustrated the wealth of information available on the plaggen system. In Denmark, an interdisciplinary ethnarchaeological and ethnohistorical project aiming to reconstruct the 'traditional heathland agriculture' of the region has been undertaken by geographers, geologists, botanists and ethnologists as well as archaeologists (Gormsen 1991; Stoklund 1999).

Between 1000 and 1100 AD, Danish agriculture, as in other Continental European areas, underwent a period of intensification characterised by technological development and land reclamation, during which time a clear distinction emerged between the farming strategies employed in the western areas of Jutland, and the eastern areas and their accompanying islands (Poulsen 1997). Unlike the more productive eastern areas, West (and areas of Northern) Jutland were characterised by poor, sandy soils, upon which sparse grass and heather heathland had steadily expanded since Neolithic times (Andersen 1990, cited in Gormsen 1991), and within which farm settlements clustered within river valleys (Gormsen 1991: 109). Fields were small and unfenced, and initially cultivated using a long fallow period of three to six years, a system called *graesmarksbrug* in Danish (Poulsen 1997). During this period of intensification, however, this system gradually changed, and the extensive heath areas of the west began to be utilised in a turf-based (or peat-based, in areas of moorland) intensive manuring system which allowed the arable 'infield' areas to be cultivated for long periods without fallow. The precise period of this development is not known. Documentary evidence can only date the development of this system to prior to the sixteenth century (Stoklund 1999). The earliest Danish ‘dung fork’, from the town of Lund, dates to the thirteenth century, but surviving examples of the more diagnostic turf- and peat-cutting spades only survive from later centuries (Lerche 1970).

There is archaeological evidence, however, that turf manuring may have been used around the town of Ribe as early as the ninth century (Poulsen 1997), and this more closely fits the period which saw what is widely (but not universally – see Hoppenbrouwers 1997: 95) accepted as likely to be strongly connected to the development of plaggen manuring: the introduction of rye as a major crop (e.g. Pape 1970; Heidinga 1988; Myrdal 1997). Rye became widespread in Denmark during the period 900-1100 AD, especially in moorland regions unsuited to the cultivation of oats. This development was probably also connected to the introduction of the mouldboard plough, used for ridge and furrow cultivation which created better drainage, essential for the growing of winter crops such as rye, and also allowed more effective ploughing in of manure. The earliest surviving plough of this type from Denmark has been dated by radiocarbon to 1285 AD, though field system evidence suggest that its use began at perhaps two centuries earlier (Poulsen 1997).

Plaggen manuring in this region was long-lived: the most detailed surviving record of the system in these areas comes from a farm diary written from 1829 to 1857 by a farmer in Staulund, Western Jutland (Gormsen 1991: 111). On the island of Laeso in the north, compost turf-and-dung dunghills were in use by ‘conservative farmers’ as late as 1949 (Stoklund 1999: 211). Both oral and written tradition has therefore contributed greatly to recent Danish research into the detailed workings of the plaggen system, and the level of organisation associated with it.

Work on plaggen manure creation in West Jutland would start during the summer period between sowing and hay-harvest, when farmers would use this ‘quiet’ period to cut sods on the heath and transport both sods and underlying earth from these marginal areas to the farm (Gormsen 1991: 109). The turf sods, or *traek*, would be laid out, on edge, to cover the farmyard itself, over the area through which the cattle would be brought home twice a day for milking. The dung and urine dropped by the cattle would therefore be absorbed by the *traek*, which would at the same time be trodden flat and mixed with the dung by the cattle themselves over an extended period, until the resulting mixture was ready to be organised into a dunghill (Gormsen 1991: 110; Stoklund 1999: 210). Farmers who stabled their cattle would construct their dunghills from alternate layers of animal manure from the byre and layers of turf (Stoklund 1999: 210). For these dunghills, however, the farmers would recycle turf already composted from use either in the fields or the farm. A complex recycling system saw turf dykes reused as dunghill material after about 6-8 years of use, and turf sods which were habitually stacked around the outside walls of houses for insulation were likewise re-used. Dunghill content was generally 5-6 times more turf and earth than animal dung (*ibid*.), and ashes from sods that were burnt on the hearth were also recycled into a separate ash midden before being incorporated into the larger midden, which would be constructed out of the farmyard, near to the fields where the manure would eventually be spread (Gormsen 1991: 110). Such ashes would also originate from the heath: heather turves were habitually preferred to peat as they burned slowly, thus keeping the fire going throughout the night (Lerche 1970: 151).

A slightly different method of dunghill construction is known from oral tradition describing the nineteenth century plaggen manuring system of the northern island areas (Stoklund 1999). Turf sods were cut from the heath and stacked in a heap near to the dunghill. The heap, usually a few metres square by a couple of metres high, would be stacked in such a way that it would collapse in on itself as the turf decomposed. The sods were then known as *hakkemog*, or ‘chopping muck’, and the *hakkemogspold* (‘chopping muck heap’) would be left for at least a year to decompose, occasionally being chopped and mixed with a spade, before being used in the construction of a new dunghill. This was a precise operation. A thick layer of chopped sods would be laid first to form the base of the dunghill, which would be covered by a layer of manure from the byre. This would be covered by a layer of *hakkemog*. Alternate layers of dung and *hakkemog* would then be laid until a dunghill of appropriate size was erected. Neatness was important - the dunghill was expected to be of a regular shape – ‘as if it was made in a cheese form’ (*ibid*.: 211).

Research in other plaggen regions supports these descriptions of a labour-intensive and highly organised system, within which farmers apparently took care not only to acquire specific ingredients but also to mix and decompose them in what, we assume, were perceived to be the best ways for creating the most potent and/or suitable manures for a variety of crops. Different 'recipes' for plaggen manure creation using the pens (and thus the manure) of different stock breeds are recorded: '*the sheep-cot; deep stables with litter and heather sods: cleared out once or twice a year. Young cattle; deep stables with litter and sod, cleared out every year. Dairy cattle; the dung is brought regularly to the dung heap; on this heap earth, sand or clay, from locations unsuitable for meadow grass…*' (Van de Westeringh 1970, in Mucher *et al*. 1990). Evidence for the collection of manure from sheep (normally left to graze on open moorland) is seen from elsewhere in the Netherlands: sheep were brought in overnight and housed in folds strewn with heather sods specifically so that their manure could be collected (Hoppenbrouwers 1997: 102). In Germany, nineteenth century sources describe how in the summer months, heather turves were cut to a specific size of 40x100 cm, and stripped up into a roll for transportation using a tool not unlike a scythe (Meyn 1858, in Blume 1998: 1). Different turf sources were understood to have different manuring properties: heather turf was usually used (Pape 1970: 241), but grass turf was also widely used, as although it was said to less easily bind the dung together, it more intensely improved soil fertility (Meyn 1858). Forest litter was used in more wooded areas in the Netherlands and Belgium (Conry 1974: 323), and occasionally *Sphagnum* peat litter (more moisture absorbent than heather peat, which was avoided), and sometimes sand. This was often dug out from the subsoil of higher areas of grassland and sometimes from the subsoil layer of the plaggen soil itself (Pape 1970: 241).

Although concentrated in the Continental areas discussed, plaggen manuring systems have in recent years also been discovered further afield. In south and west Norway, plaggen-type cultivation is documented from the nineteenth century, with small enclosed areas of arable land 'manured with a mixture of cow dung, soil and turf from the surrounding heath land' which caused a deep topsoil to develop (Widgren 1997: 186) and allowed the fields to remain in permanent cultivation (Myhre 1985: 69). Archaeological and palynological evidence, however, indicates that some of these plaggen soils began to accumulate in the eighth century and that plaggen cultivation was the norm for the fourteenth and fifteenth century farms that now survive as deserted remains – plaggen soil fields in these areas, identified by the high lynchets that were formed around them, are known as *Gamleageren* – 'the old field' (Widgren 1997: 186). Excavations at Rogaland, West

Norway, show an association between high soil phosphate values (indicative of manuring) and areas of thick relict field soils, defined by lynchets and up to 60 cm thick (Myhre 1985). It is likely that a similar method for the creation of plaggen manure was used in these areas – the mixing of turf and humus with animal manure before application to the fields (various citations in Myhre 1985: 876) – but traditional accounts describe an interesting variation on this system which was used in the Nordhordland area of West Norway. This was called *moldbruk* – 'mould manuring' – and consisted of bringing earth from the outfields to special 'mound houses', where it would be mixed with animal manure and household waste before being applied to the fields. Earth would also be spread on floors used by animals in order to be dunged and trampled before being spread, in a similar fashion to that documented from Western Denmark (*ibid*.).

More recent studies have also identified plaggen-like topsoils in Northern Norway, in the Lofoten archipelago (Simpson *et al*. 1998c). As in the traditional plaggen regions, these topsoils are located on relict arable land in sandy soil areas. However, these north Norwegian soils differ somewhat in physical structure in that they appear to be associated with terracing activity which is at least partly responsibly for the accumulated depth of topsoil (*ibid.*: 1188). These soils result from 'a combination of soil movement and accumulation' coupled with deliberate fertilising activity through the addition of turves, likely recycled from either midden or building material (*ibid*.: 1189). The recent discovery of such soils from outside of the recognised 'plaggen regions' is a reminder that the extent of this manuring system throughout Europe is as yet unlikely to be fully understood.

2.1.3 Urban wastes and the plaggen system

There is a strong similarity in both archaeological and ethnological accounts of the materials and methods used to create plaggen manure throughout all the known plaggen soil regions. Turf and dung, from various sources and used in various proportions, form the backbone of the system. However, it is unlikely that many rigid rules would have existed within a system whose purpose was the maximising of available resources, and plaggen soils were thus made up of many other materials. Some of these have been mentioned above, such as ashes from the hearth, recycled building materials or old field dykes. Marl (soil consisting of clay and carbonate of lime) is also known to have been applied to plaggen soils (Hoppenbrouwers 1997: 103).

More significantly, historical sources indicate that from the fourteenth and fifteenth centuries onward, with the ongoing progression of agricultural intensification, intensive manuring systems throughout the majority of the Continental regions came to depend heavily on urban manure sources such as industrial wastes and ashes, and especially nightsoil (de Vries 1974: 150-151). By the mid seventeenth century most cities in the Netherlands operated franchises for the collection of industrial and domestic refuse and its sale to farmers. By the mid eighteenth century, eleven specialist nightsoil shippers operated from Leiden alone, and farm diaries and land contracts show that urban manure purchase was common, with supplies often obtained from cities some distance away (*ibid*.). Nineteenth century writings comment on the massive size of the manure stores near Dendermonde, where nightsoil from Dutch towns was taken by barge before being distributed (Slicher van Bath 1963: 256). The practice of intensive manuring, then, was a central part of what became a flourishing cycle: intensification and the development of new crops, and a resultant raise in productivity which supported an increasing and progressively urbanised population, the waste from which in turn was channelled back into the system of rural production. In the city of Groningen, this seemingly paradoxical connection between urbanisation and the ongoing development of the plaggen manuring system are seen particularly clearly. Here, urban expansion drove not only the draining and exploitation of large peat bogs adjacent to the city, but also the subsequent colonisation and cultivation of the sandy, unfertile areas left exposed by the peat stripping. To encourage settlement in these areas, the city offered free nightsoil to colonists. The uptake was so large that an import bounty for manure was offered, which encouraged boats shipping peat from the region to return with nightsoil from other areas of the Netherlands (*ibid*.: 150). The effect of these manures on the organisation of the system is likely, if anything, to have increased the rate at which accompanying bulk material was added to the soil: historical sources note that the richness of human manure required its composting with proportionally larger amounts of mineral than required for dung (Somerville 1796: 35).

2.1.4 Land tenure and the plaggen system

It has been noted (de Vries 1974: 149) that the farmers of the Continental plaggen areas managed, largely as a result of the interrelationship between town and country discussed above, to break the 'vicious circle' seen to curtail agricultural expansion in times of population growth, where demand for grain causes arable to expand into pasture areas and thus limit the fertiliser supply which could maintain such demand (Slicher van Bath 1963: 18). The plaggen soils are evidence of the fact that within medieval Western Europe, the farmers of these regions were uniquely successful in this respect. Why? One theory is that farmers in the plaggen areas were in an unusually strong position, both politically and legally, to exploit such avenues for growth. Unlike the feudal system in operation in other regions at this time, the governmental system of the northern Netherlands was based on voting rights through land holdings, a system by which the bulk of the population was enfranchised (de Vries 1974: 26).

What appears to have been more significant, however, are the regulations governing tenure for leased land seen in the Continental plaggen regions. Of particular interest is the custom known as '*beklem-regt*', variants of which are seen all over north-western Europe, but which is particularly associated with the Dutch province of Groningen, well known for its extensive plaggen soils (*ibid*.: 16). The *beklem-regt* was a purchased right of occupancy of a land parcel, at a fixed rent which the proprietor could not raise, and which, once purchased, would pass to the tenant's heir. The tenant could let, mortgage or even sell this occupancy without the proprietor's consent; however, upon doing this, a fine of one or two years' rental would be incurred, and division of the holding by sale or inheritance was prohibited. Although in theory the 'lease' was renewed periodically and the *beklem-regt* could at this time be revoked (as it could should the tenant wilfully depreciate the holding), in practice this rarely happened, mainly as the proprietor would have to compensate the tenant to the value of the house and farm-buildings (de Laveleye 1878: 273).

It has been noted that the balance inherent in this system acted to promote significant investment in improvements to the land: crucially, the tenant was not penalised for improving leased land through increases in rent, nor was the investment lost at the end of a fixed term (de Vries 1974: 202). In addition, the prohibition on farm *division* under this system in itself encouraged land improvement: as a tenant could only pass the *beklem-regt* to one heir, high productivity was vital to ensure a cash inheritance for other family members. It has been suggested that this regulation, in preventing land-holdings being split into ever smaller portions, promoted land improvement far more than did outright ownership (*ibid*.: 276). In the plaggen soil regions, a level of autonomy facilitated by security of tenure therefore appears to have allowed peasant farmers to invest in bought manures, thus improving their lands to the point at which they could take advantage of market demands, for example by taking risks on new crops (de Vries 1974: 147).

2.1.5 Plaggen manuring: sustainability and land cover change

Although highly integrated and economically effective, it would appear that the plaggen system was, over time, less environmentally sustainable. There is strong evidence that the plaggen system denuded heathland and can be held partly responsible for long-term ecological damage in the plaggen regions (e.g. Stoklund 1999: 212). In addition, evidence for conservation of this essential manuring resource is patchy and somewhat contradictory. There were certainly rotation systems in place to promote heathland regeneration between turf cuttings – in the Netherlands, for example, heather sods were only cut after intervals of 6-8 years in one location, and 12-15 years in areas where the cutting had been deep (Pape 1970: 239). Sovereign regulations also covered the cutting of sods, especially in grassland, in an attempt to achieve a balance between manuring and grazing rights (Blume 1998: 1). However, it seems that in some areas there was little regulation for either grazing or cropping, such as in Western Denmark, and once turf cutting removed the sand from the heath, it could take as long as 100 years to regenerate properly (Gormsen 1991). The heathlands of Western Denmark did indeed become barren, and were the subject of large-scale land reclamations for agriculture in the nineteenth century (Odgaard 1988: 311).

Although the question of the impact of modern-day land cover and cultivation upon the Continental plaggen soils has so far not been investigated in any depth, studies have indicated that cover change does have a morphological effect upon the plaggen layer beneath. Darkening of the top plaggen horizon as a result of modern manure addition has been noted in soils in the Netherlands (Niemeier and Taschenmacher 1939, cited by Conry 1974: 324), as has extensive bleaching of the plaggen layer when afforested, sometimes to such an extent that the soil may be unrecognisable as a plaggen soil (Pape 1970: 238).

Overall, the plaggen manuring system represents the most important archaeological and environmental resource retaining cultural information pertaining to a period in which agricultural strategies in Continental North-West Europe changed drastically, moving from a system of large-scale fallow rotations to annual cropping over smaller arable units, increased use of manures, spade instead of ard cultivation, and increased productivity. In this, it resembles aspects of the farming system in Scotland throughout the pre- and immediately post-Improvement era, as highlighted by Dodgshon (Widgren 1997: 186). Using plaggen soils to study these agri-economic developments helps them to be viewed within the environmental and geographical context which, in every region, exerted a strong modifying influence on farming methods (Slicher van Bath 1963: 4; Myhre 1985: 69). The body of work on the European plaggen soils outlined above is therefore a most important source for understanding the wider social and agri-economic context of the cultural information retained by deep anthropogenic topsoils in Scotland.

2.2 Deep anthropogenic topsoils in Britain: Ireland

The majority of research into anthropogenic deep topsoils in the British Isles has been in Ireland, where extensive plaggen-type deposits up to 85 cm deep have been identified in the south-west coastal regions (Conry 1971; Conry and Diamond 1971; Conry and Mitchell 1971; Conry 1972, 1974; Conry and MacNaeidhe; 1999). Although similar in depth and physical appearance to the plaggen soils of Continental Europe, both historical and geoarchaeological research has shown that Irish deep anthropogenic topsoils differ from the soils of the plaggen regions in very significant respects, and that these differences are intrinsically linked. Socioeconomic as well as topographic differences between the agricultural situation of Ireland and that of the plaggen regions have given rise to a very different class of soils.

Deep anthropogenic topsoils in Ireland are, firstly, the result of a distinctly different set of manure materials: mainly, intensive applications of calcareous sea-sand. Although this was sometimes mixed with dung, peat mould, grass sods or seaweed, there is little evidence for the application of these mixed manures or for composting techniques, in the manner of the Continental plaggen system, until the twentieth century (Conry 1971: 407). Rather, evidence from eighteenth century sources bemoans the lack of efficiency with which animal manures are collected and used within the 'well littered' farm yards (Young 1780, cited in Armit 1998: 41). Research suggests that the majority of known Irish deep anthropogenic topsoils were created by the addition of large amounts of sea sand, applied directly to the fields (Conry 1971: 406).

Like the Continental plaggen soils, the development of deep anthropogenic topsoils in Ireland is linked to the intensification of arable production, and the development of new farming technologies (Armit 1998). However, in Ireland the development of these topsoils appears to be linked more to population pressure and a pressing need to bring into cultivation previously marginal areas of land, rather than a desire to increase productivity. In addition, unlike in the plaggen soil areas, restrictions and prejudices against the use of turf as a manure source seem to have resulted in the majority of deep anthropogenic topsoils developing in response to these agricultural pressures in areas where sea sand, the preferred resource for deepening and fertilising the soil, was freely available (Conry and Mitchell 1971).

Between 1735 and 1841 the population of Ireland rose from 3 million to 8.2 million (Armit 1998: 39). Although this puts the widespread development of the Irish soils much later than that of the plaggen regions, however, there is also evidence that soil modification in Ireland may have started possibly as early as the first, and certainly by the thirteenth, century (Conry 1974: 320). By the second half of the eighteenth century, in the face of this population expansion, extensive previously wasteland areas such as blanket bog and marsh were brought into cultivation. Although land reclamation in the eighteenth century in Ireland was mainly achieved through such technologies as drainage schemes (*ibid*.), paring and burning (Lucas 1970) and later, the use of lime (Armit 1998), there is also some evidence that soil deepening was used as a way to mitigate the effects of boggy land. Cultivation ridges in particular were recognised as being ideal for potato cultivation in wet areas. Using allochthonous soil material to create extra ridge depth in certain areas was, and still is in some areas of Ireland, an integral part of the creation of ridges (O'Danachair 1970: 53). In addition, earth and clay were sometimes spread as part of the reclamation process (Armit 1998: 42). However, the use of turf sods for this and for manuring purposes was controversial. Evidence that sod cutting was discouraged is first seen in a twelfth century commentary listing fines levied for this practice (Lucas 1970: 99). Although this aversion to turf cutting is linked to the practice of paring and burning (the stripping and drying of surface sod which is then burned and the ashes used to fertilise the stripped area), in the nineteenth century turf cutting even for manuring purposes was still discouraged, with the practice of removing 'bog-stuff' from moorland to spread on cultivated fields blamed for making cultivated land itself 'moory' (Armit 1998: 42).

The result of these restrictions, and also the lack of an efficient system for maximising manure collection (perhaps linked to the poverty endured by many small farmers in Ireland at this time) is that despite these large-scale reclamation activities, the deep anthropogenic topsoils found in Ireland are not found throughout the main agricultural areas, and nor are they linked exclusively to areas of structurally poor soil, as in the sandy Continental plaggen soil areas. Rather, they are found associated with the coast for another reason: to be nearer to good sources of sea sand, and are thus found on a wide range of soil types and parent materials (Conry 1971: 404).

Within these specific areas, however, there is slightly more indication of the existence of a plaggen-style system of manure preparation. There is evidence that in these areas, farmers also used their bulk matter - sea-sand - as animal bedding (Conry 1971: 407) though, as said, not until significantly later than that recorded in the plaggen system. It also appears that in some of these deep topsoil areas, attention was paid to the collection and composting of manure materials. Although eighteenth century sources state that sea sand was seldom mixed with other materials prior to being spread on the fields, there is also evidence from County Wexford that farmers 'ploughed a compost of sea sand, seaweed and sometimes earth and the scrapings of ditches into the soil' (Frazer 1807, in Conry 1971: 408). There is also evidence that sea sand was mixed with peat or turf mould in the farmyards 'for the cattle to trample on' (Devon Commission 1845, in Conry 1971: 408). Like the Continental plaggen deposits, the Irish soils also deepen relative to population density (Conry 1971: 404), indicating their association with increasing productivity in these areas, and possibly therefore a level of organisation in the system, although this does not seem to be anywhere near the scale associated with the Continental plaggen regions. However, despite this, it is the Irish soils that are chemically more favourable for agriculture, largely as a result of this calcareous input. The Irish deep anthropogenic topsoils have a high pH, phosphorus content and high levels of plant micronutrients such as calcium and magnesium (Conry and MacNaeidhe 1999: 88). Deep anthropogenic topsoils created through calcareous sand additions are also known from discrete areas throughout Devon and Cornwall (Staines 1979, in Guttmann 2001).

Should the Irish soils be described as plaggen soils? The answer should surely be no, in a chemical, morphological, and perhaps most importantly, historical context. Despite some similarities in their date and construction technique, deep anthropogenic topsoils in Ireland are a distinct entity, illustrating the exploitation of natural resources in the face of specific economic and population pressures seen in Ireland at the time of their formation.

2.3 Urban deep soils

Deep anthropogenic soils are common to most urban areas with a long history of occupation, and have been found to be widespread during many large-scale urban archaeological excavations, both in the British Isles - e.g. at Carlisle, York, Canterbury, Gloucester and especially London (Macphail 1983: 245), and in various European cities in France, Belgium, Germany and Italy (Macphail *et al*. 2002). Commonly called ‘dark earth’, these loamy soils are characterised by their very dark colour, their homogeneity and frequent anthropogenic inclusions such as ceramics, and can often be several metres deep (Macphail and Cruise 2000: 9).

In London in particular, dark earth deposits characteristically overlie, and seal, Roman occupation layers, often immediately sealing a truncation of the latter part of the Roman occupation sequence, and are themselves sealed by Medieval deposits (Yule 1990: 620). Therefore, although dark earth deposits may date to the late Roman, Saxon, Viking and early Medieval periods in the British Isles, there has been a tendency to equate dark earth with the immediately post-Roman

‘Dark Ages’ and thus with abandonment, ruralisation and impoverishment, and furthermore, to identify any poorly-stratified dark soil deposit with these processes (Macphail *et al*. 2002: 350).

Over the last twenty years, micromorphological analyses in particular have led to a greater understanding of the nature of dark earth deposits in urban areas (e.g. Macphail 1983; Macphail 1994; Macphail and Cruise 2000). As a result of these investigations, dark earth is recognised as commonly falling into two broad categories. The first is characterised by organic-rich, often waterlogged deposits containing very frequent anthropogenic indicators such as pottery, tile, mortar and other building materials and organic waste materials such as bone and shell and represents long-term, continuous urban refuse disposal, occasionally even showing tip lines indicative of episodes of dumping. The second, however, is a more well-drained, homogenous deposit thought to have been deliberately dumped, possibly taken from other urban contexts for the purpose of so-called ‘garden’ cultivation within the urban area, an activity indicated by the characteristic presence of severely abraded ceramics (Macphail 1983: 245). There is also evidence that some of these cultivated soils were deliberately fertilised by the addition of organic materials (*ibid.*: 250). Dark earth, therefore, whilst still potentially representative of a period of change within urban settlement, is by no means indicative of abandonment (Macphail *et al*. 2002: 356). This has been further emphasised through micromorphological investigations into several dark earth type deposits indicating that deep, homogenous deposits seen within an urban sequence may also be a result of biological and pedological reworking rather than anthropogenic activity. While high levels of organic matter promote bioturbation, the presence of building debris such as mortar, brickearth and stone may act as a parent material source, facilitating the natural processes of weathering and soil formation (Macphail 1994: 18; 20).

Dark earth deposits of both types have been recorded from numerous Scottish urban excavations, notably from the medieval burghs of St. Andrews, Dundee, Forfar, Perth, Aberdeen, Inverness and Dumfries (Murray 1982; Bowler *et al*. 1995; Coleman 1996; Mackenzie 1998; Cachart 2000; Carter 2001). Although waterlogged, organic, artefact-rich strata indicative of dumping have been recorded (Bowler *et al*. 1995: 995) research into deep anthropogenic soils in Scottish historic towns has focused on the ‘garden soils’: similar to the ‘cultivated’ category of dark earth deposits seen in other urban excavations in the British Isles, but in a medieval context.

Micromorphological investigation into the nature of the Scottish urban ‘garden soils’ has, however, indicated that rather than being composed of soils redeposited from a primary urban context distinguished by a high content of potsherds etc., these deep topsoils may have been formed using a system not dissimilar to that of plaggen manuring (Carter 2001: 87). Investigations at St. Andrews demonstrated that the bulk of material comprising the augmented topsoil was similar in texture to that of the original topsoil layer, and that urban anthropogenic material such as refuse and building debris were largely present only in the uppermost cultivated layer. The dominant input was interpreted as turf and/or topsoil from ‘an unidentified local source’ (*ibid.*: 90).

The development of garden soils in the medieval burghs has been traditionally associated with a period of urban decline, in a similar manner to the dark earth deposits recorded south of the border. So called because of their association with the ‘backlands’ of properties within the burgh area which later used these deep topsoils for small-scale market garden cultivation, the presence of garden soils has been taken as evidence for previously urban areas being used as animal pens and the like (Murray 1982: 248). Yet the presence of garden soils in so many of the Scottish burghs makes this unlikely, as there is no evidence that the late medieval period saw the wholesale decline in economic activity that this would suggest (Carter 2001: 90). More recent studies have, however, posited an alternative model explaining the development of these deep topsoils – that the difference between the obviously ‘dumped’ deep anthropogenic deposits in the burghs and the more ‘agricultural’ soils is not one of use but of preservation. It is argued that in a similar process to that noted for some dark earth deposits (Macphail 1994), the more well-drained soils have promoted the rapid destruction of organics and high invertebrate activity that has homogenised stratified horizons. This has destroyed the physical evidence for the thriving burgh - the wooden structures, pits and ditches that would have given a more accurate urban context to these (undoubtedly still cultivated, albeit on a small scale) topsoils (Carter 2001: 91). Despite their similarity to plaggen soils as regards the addition of turf, ‘garden soils’ from Scottish medieval contexts are clearly distinct from these in both an economic and historic sense.

2.4 Deep anthropogenic topsoils in Scotland: previous research

Anthropogenic deep topsoils in an agricultural context were first recorded in Scotland in the Insch valley, Aberdeenshire (Glentworth 1954), and plaggen-type deep topsoils resulting from turf-ash manuring were identified in 1974 on the remotest of all Scottish communities, that of the island of St. Kilda (Hornung 1974; in Meharg *et al*. 2006). However, it is only in the last two decades that research on deep topsoils has developed in Scotland and, in contrast to the more wide–ranging studies on the Continent, Scottish anthropogenic soil studies have on the whole been connected with archaeological investigations and are thus predominantly site-based, concentrating in particular on the Northern Isles (e.g. Davidson and Simpson 1984; Dockrill and Simpson 1994; Davidson and Carter 1998; Simpson *et al*. 1998a; Simpson *et al*. 1998b; Simpson *et al*. 1998c).

This focus has helped to define the nature of investigations into deep topsoils in Scotland in two significant ways: firstly, these (often multiperiod) site-based investigations have allowed a solid archaeological and chronological context to be applied to the soils with which they have been associated; secondly, these studies have been characterised by the use of an especially wide range of geoarchaeological analytical techniques, usually within multi-analytical programmes which have provided great detail on the formation processes and spatial organisation of these soils. These have included magnetic susceptibility study (Dockrill and Simpson 1994), radiocarbon dating (Simpson 1995), total and fractionated P content (Guttmann 2001), particle size analysis (Simpson 1997), micromorphology (Simpson 1997), stable isotope analyses (Simpson 1997; Simpson *et al*. 1999) and lipid biomarker analysis (Simpson *et al*. 1999), as well as traditional survey and excavation processes. The result of these investigations is an in-depth understanding of the formation processes and context of deep anthropogenic soils which are, however, largely restricted to discrete and often small areas, mainly within the Northern Isles. Understanding the place of these soils within a Scotland-wide historical and archaeological context is, therefore, still to be achieved.

2.4.1 The Orkney Isles

2.4.1.1. Plaggen-type manuring in the Late Norse to Medieval period

The first significant investigation into deep arable anthropogenic topsoils in the Northern

Isles was prompted by the mapping by the Soil Survey for Scotland (1981) of a ‘deep phase’ of loamy topsoil, generally in excess of 75 cm and reaching a maximum depth of 1.15 metres, located in discrete ‘patches’ within coastal areas of the West Mainland of Orkney and the island of Stronsay (Davidson and Simpson 1994: 68). A programme of auger survey and geoarchaeological analyses established that these soils were greatly enhanced in phosphorus compared to the expected background level for the freely to imperfectly drained podzol that they were formed upon, and that their location and relative depth were related to the location of Norse-period farm remains and place name elements in the landscape (Simpson 1985; Simpson 1997). Radiocarbon dating of selected examples of these deep topsoils sited within the infield areas of Norse period farmsteads within the Marwick basin, West Mainland, places the start of deep topsoil formation in this area to within the mid- to Late Norse period, roughly the late twelfth to early thirteenth centuries AD (Simpson 1993: 185), contemporary with the period which is believed to have seen the widespread adoption of the plaggen manuring system in Europe (Spek 1992; and see Section 2.1.1). Geoarchaeological analysis also indicates that these deep Orkney topsoils are similar enough in composition to be considered analogous to the plaggen soils of Continental Europe and were formed through the use of a very similar set of farming strategies, a conclusion supported by archaeological and historical evidence (Simpson 1997: 375, Simpson *et al*. 2005: 376).

Particle size analysis coupled with micromorphology of the Marwick soils suggests that the increase in topsoil depth was the result of the application of grassy turves, sourced from the hill land beyond the deep topsoil area (Simpson 1997: 369). Total phosphorus and stable carbon isotope analyses, coupled with the identification of fungal spores in thin section, identified a high level of organic input, probably in the form of animal manures, with a minor seaweed component. More recently, analysis of the lipid biomarkers and secondary bile acid compounds of these organic manure components identified that their animal origin was ruminant and pig (Simpson *et al*. 1999). As seen in the Continental plaggen soils, the intensity of this organic content, and the depth of topsoil overall, decreased with distance from the farmstead (*ibid.*: 373). At Marwick, organic input also decreased down-profile, perhaps indicating that reliance on animal manures increased over time, and that livestock supported by the farm increased. Furthermore, although the level of organic input was highest in the deep topsoil area, notably high levels of these chemical indicators were also observed in adjacent, non-deepened areas still within the farmstead – possibly an indication of the folding of animals overnight in enclosed pens or fields from which their manure could then be collected for use as fertiliser (generally referred to in the Northern Isles as *teathing* or *tathing*). This is also a feature of the plaggen manuring system in several areas (e.g. Van de Westeringh 1970, in Mucher *et al*. 1990; Hoppenbrouwers 1997). A preference for hill turf for composting, rather than grassland – thus preserving the latter for use as winter fodder (*ibid*.: 373) - parallels the separation of heathland and pasture for these purposes on the Continent (Pape 1970: 241).

More recent investigations have established that plaggen manuring was not limited to the Orkney Mainland. Similarly augmented deep anthropogenic arable topsoils have also been identified in the far north of Orkney, associated with the Norse site of Quoygrew on the island of Westray (Simpson *et al*. 2005). Here, extensive fish-midden deposits, a farm mound, and areas of deep anthropogenic soil (to a maximum depth of 95 cm) indicate a complex sequence, within which the deep topsoils appear to be the later addition (*ibid*.: 364).

The Quoygrew soils show an almost identical micromorphological profile to the Marwick deep topsoils, indicating a manuring system which stripped turf from uncultivated land and composted it with a variety of animal manures before applying it to the arable area (Simpson *et al*. 2005: 373). Like the Marwick soils, place name evidence associates the deep soil areas with Norse period farming – the Quoygrew field name ‘North Tun’ is likely to be derived from the Old Norse *tunmal*, indicating an assessed area of land permanently allocated to one farmstead (*ibid*.: 359).

With a primary input system of turf and manure, the deep anthropogenic topsoils identified with the Norse period in Orkney can be deemed true plaggen soils in a way that the deep anthropogenic arable topsoils of the Irish coast, for example, cannot, both in composition and, perhaps more importantly, date. Historical records for this period relating to Orkney indicate that the Orkney plaggen manuring system may have existed within a highly organised and well-integrated arable system that can be identified with a general intensification of arable production, thus contributing perhaps to our understanding of the economic position of Orkney farmers in Europe at this time. There is mention in the Icelandic ‘Sagas’ of this period of grain being exported from Orkney, suggesting that a production surplus was being maintained by at least the twelfth century (Simpson *et al*. 2005: 376) and it has been suggested that the plaggen manuring system was introduced directly to Orkney through the monastic community based on the Isle of Birsay in the West Mainland: the Birsay monastery was a part of the archbishopric of Hamburg-Bremen, Germany, an area where plaggen manuring was practiced (Guttmann 2001: 207). This potential connexion between plaggen manuring techniques and monastic agricultural activity is discussed further in Section 2.4.3.

Despite these pointers toward general arable intensification as represented by the plaggen manuring system in Orkney, there is also evidence to suggest that the location of these deep arable topsoils may reflect farming strategies that were primarily a response to local conditions. The patchy distribution of the West Mainland topsoils has been explained with reference to the location of seaweed resources: seaweed is identified as the preferred fertiliser in Orkney during this period, largely because of its suitability for sandy soils (Fenton 1978: 274). The plaggen soils of Marwick are located in areas with poor seaweed resources (Simpson 1997: 366), and thus turf manuring in these areas may therefore have been a ‘second best’ strategy. This interpretation is supported by the perceived relationship between farm mounds and seaweed resources in other areas of Orkney. Farm mounds – physical accumulations of material made up of the debris resulting from long-term farming settlement, such as cattle bedding materials and domestic wastes such as ash – are seen in Orkney to be closely associated with areas of fertile calcareous soils with abundant seaweed resources (Simpson 1985; Davidson *et al*. 1986). The hypothesis is that at these locations, fertile soils and easy availability of their perceived best fertiliser made the re-use of organic and mineral wastes as manure, and the creation of deep topsoils, unnecessary.

At Quoygrew, the deep topsoil areas are located upon what would have originally been thin, poor soils, and while their amendment through adoption of a plaggen-type manuring system represented a considerable effort, this was apparently not undertaken until later in the occupation of the site. This, and the fact that the more fertile and easily worked machair soils near to the site were not brought into the plaggen system (Simpson *et al*. 2005: 373), despite the fact that they may have benefited from the extra structural stability this would provide, indicates a very localised solution to raise productivity, intended perhaps to fulfil only limited requirements. There is evidence that arable production in West Mainland was also not being pushed to the limit. Micromorphological evidence from Marwick indicates that cultivation was of moderate intensity, probably via the Orkney one-stilted plough, rather than the spade - more labour intensive but offering higher returns (Simpson 1997: 375). The modest population of West Mainland Orkney at this time has been suggested as a reason for this (*ibid*.: 378). The Orkney plaggen soils, though the product of a similar farming regime to that seen on the Continent, are possibly representative of a slightly different economic and cultural situation, perhaps even of particularly localised practices.

Like the Continental plaggen soils, the Orkney deep anthropogenic topsoils at Marwick continued to be amended into the late nineteenth and early twentieth centuries, until the introduction of alternative fertilising methods (Simpson 1993: 9). The plaggen system may also have been indirectly responsible for land degradation, also noted in the Continental areas: arable production at Quoygrew appears to have been abandoned after severe sand blows, possibly exacerbated by the removal of turf from nearby areas (Simpson *et al*. 2005: 373).

2.4.1.2 Prehistoric deep anthropogenic topsoils: Toft's Ness, Sanday

Anthropogenic arable topsoils which pre-date the Norse period have been identified as a result of archaeological investigations in several locations in Orkney: at Spur Ness, Toft's Ness, and the Bay of Stove on Sanday (Dockrill 1993), Links of Noltland (Clarke *et al*. 1978), Knap of Howar on Papa Westray (Ritchie 1983) and Skaill, Deerness on the Mainland (Gelling 1985, Limbrey 1975) (all cited in Guttmann 2001: 34). Little geoarchaeological investigation has been carried out on the majority of these topsoils, but the relative lack of depth of many of these indicates that all were either formed through manuring practices that differed substantially from that recorded for the Norse period, or cultivated for a significantly shorter period.

The exception to this is the site of Toft's Ness, on the island of Sanday in Orkney, which has been the subject of extensive geoarchaeological study (Dockrill and Simpson 1994; Simpson 1998; Simpson *et al*. 1998b; Bull *et al*. 1999). The Toft's Ness site consists of a buried landscape of Neolithic and Bronze Age settlement remains and associated arable soils, covered by machair and wind-blown sand (Dockrill *et al*. 1994). Anthropogenic soil 35-75 cm deep was dated through radiocarbon and stratigraphic association to the late Bronze Age occupation of the site (Simpson *et al*. 1998a) – contemporary with the earliest recorded Continental plaggen soils (Blume 1998: 2).

Geoarchaeological investigations into the nature of the deep anthropogenic soil at Toft's Ness, however, have concluded that there are major differences between the components of this soil and those of the plaggen regions. Although analysis of the deep soil at Toft's Ness indicated that it had been manured using a turf-based input (Simpson *et al*. 1998a: 739; Bull *et al*. 1999: 550), lipid biomarker and associated bile acid analysis identified the prime organic manure input to be human in origin, with no evidence for the use of animal manures (Bull *et al*. 1999). Micromorphological analysis indicated that, instead of being composted with dung, the turf input into these soils was often burnt (Simpson 1998: 894). Hearth ashes and the presence of other domestic waste materials such as bone, in conjunction with the presence of human excrement, indicates that the strategy for fertilising the Toft's Ness Bronze Age soils was probably the application of domestic midden material along with low-level burning, possibly associated with vegetation clearance (Simpson *et al*. 1998: 739).

It would appear that these soils are indicative of a very different agricultural system in terms of fertiliser choice and available resources. Archaeological investigation into the arable soils associated with some of the prehistoric sites listed above has indicated that midden material is a major component of them all (Guttmann *et al*. 2006: 87). Animal dung does not appear to be used as a fertiliser until the Iron Age in the British Isles (*ibid*.: 90), indicating a less intensive agricultural system with less of a livestock presence, and in certain areas, perhaps, one in which only completely waste materials could be spared for use as fertiliser. In many areas, including the Northern Isles, dung was a precious fuel source in areas short of peat or wood, used up until the nineteenth century (Fenton 1978: 206-9).

2.4.2 Shetland: multi-period evidence

Deep anthropogenic soils connected with arable activity in Shetland are less widespread in comparison with Orkney, particularly the later, Norse-period soils which appear analogous to the

Continental plaggen soils. However, the investigations which have taken place have perhaps contributed more to our understanding of the development of these soils in the Northern Isles and the transitions in their associated manuring traditions over time. Although there is evidence for deep anthropogenic soils at, for example, South Nesting (Dockrill and Simpson 1994) and Hill of Taing (Dockrill *et al*. 1998), two discrete locations have been the focus for deep anthropogenic soil study in the Shetland Isles. Between them, they cover the period from the Neolithic until the middle of the twentieth century. These are the multi-period settlement mound of Old Scatness on the southern tip of the Mainland of Shetland, and the island of Papa Stour off the mid-west coast of the same (discussed in Section 2.4.3).

2.4.2.1 Old Scatness: the development of prehistoric manuring strategies

An extended excavation programme at the site of Old Scatness has not only revealed evidence for continuous settlement spanning the Bronze Age to the early modern period, but also a series of deep anthropogenic soil and midden sequences which can be directly related to on-site settlement phases: significantly, the Bronze to Iron Age transitional period, of which the latter represents the most substantial period of occupation at Old Scatness, represented by a well-preserved broch tower. These stratigraphic relationships have enabled the construction of an extended chronosequence of anthropogenic soil formation and associated agricultural practices not possible elsewhere (Simpson *et al*. 1998b: 112). Bronze, Iron and post-Iron Age anthropogenic soils at Old Scatness have been investigated using particle size, phosphate and soil micromorphological analyses which have largely confirmed the variation in fertilising materials used in these different periods seen in other anthropogenic soils in the Northern Isles, but have provided more detail on how, and perhaps why, these changes took place.

The Bronze Age cultivated soils at Old Scatness are characterised by the presence of domestic waste, such as bone, as seen at Toft’s Ness. However, at Old Scatness, evidence for turf-based material is lacking, while peat fuel waste – charred peat fragments and peat ash – is seen (Simpson *et al*. 1998: 122; Guttmann *et al.* 2006). This would appear to confirm that the Bronze Age manuring strategy, as indicated by the Toft’s Ness evidence, was to utilise any and every waste material as fertiliser. Toft's Ness lacks peat deposits, while at Old Scatness, peat is a key resource. An alternative viewpoint is that in the Bronze Age, midden waste was recognised as the *most* suitable fertilising material, an approach which could be seen to have its antecedents in the Neolithic at Old Scatness, where there is evidence that arable plots were deliberately sited on midden heaps, with no attempt to fertilise or cultivate surrounding land (Guttmann *et al*. 2006: 87).

In the Iron Age, a change in the utilisation of these resources is seen. Consideration of micromorphological features and relative phosphate levels within the Iron Age anthropogenic soils at Scatness show that although domestic waste continued to be used, there is a gradual shift to the use of animal manures, and along with these, the incorporation of turf-based material into the soils (Simpson *et al*. 1998c: 121). Complementing this is evidence that peat-based floors were constructed within the house structures and periodically cleared and renewed (Guttmann *et al*. 2003: 28). These could either have been living spaces, or byres: either way, archaeological and micromorphological evidence combine to suggest the development of a 'proto-plaggen' system where specific inorganic bulk materials were recycled as fertiliser from within a structure (Guttmann *et al*. 2003: 29). Micromorphological evidence also suggests an intensification of cultivation during this period (Simpson *et al*. 1998c: 121), at the same period within which the more efficient rotary quern was introduced. Midden deposits from this same period, however, show decreased phosphates, and evidence that the ashy domestic waste materials that were previously spread onto the fields were now being left in the midden (Guttmann *et al*. 2006: 78). These indicators for intensification of production alongside the deliberate selection of specific fertilisers and the rejection of others indicates that the Iron Age may have provided a basis for the home-grown development of a specialised, plaggen manuring style system as seen in areas of the Northern Isles such as Marwick during later periods. At Old Scatness, however, evidence of continuing development in manuring practices is complicated by the fact that environmental conditions deteriorated at the site during the Norse/Medieval periods – there is evidence for increasing sand blow, and despite continuing intensive arable practice similar to that seen in the Iron Age, including the utilisation of calcareous sand as a fertiliser (Simpson *et al*. 1998c: 122) cultivation appears to have gradually declined (*ibid.*: 123).

2.4.3 Monastic agriculture and deep topsoils: the 'Papar' locations

One of the most interesting aspects of deep anthropogenic topsoil research in Scotland has been the association between a number of these soils and areas of monastic activity, specifically that of the '*papar'*, or Celtic missionary priests of the pre-Norse period (Simpson and Guttmann 2002; Ballin-Smith *et al*. 2005).

This association has led to an alternative hypothesis regarding the development of deep topsoils in Scotland: that, rather than developing out of the prehistoric manuring strategies discussed above, turf-based manuring systems were introduced to areas of Scotland as a result of missionary activity to the islands from the early Christian church in Ireland, originating at Iona (Simpson and Guttmann 2002). Written sources indicate that the Irish missionaries were sophisticated agriculturalists, and the monastery at Iona is one of the few locations in which deep anthropogenic soils have been recorded in Scotland outside of the Northern Isles (Barber 1981). Its soils show similarities to those at Marwick (Simpson and Guttmann 2002: 65) and possibly date to the seventh century AD, contemporary with Irish missionary activity.

Beyond Iona, evidence for the spread of monastic missionary activity during this period is seen chiefly through place-names: known to the Norse as the '*papar*', the many, usually island locations associated with these individuals are distinguished by a related name or prefix, for example Papa Westray on Orkney and Papa Stour on Shetland, the island of Pabbay on Harris in the Western Isles, and the many instances of settlements named Papil, Papley, or Paible throughout both the Northern and Western Isles (see Crawford 2002). A number of these, such as Papa Stour and Pabbay Harris, are known to have deep anthropogenic topsoils. An interdisciplinary project, combining archaeological, historical, place-name and geoarchaeological evidence is currently underway to explore the nature of the *papar* influence in these islands, and its possible relationship with the adoption of plaggen-type manuring activity in these areas (*ibid*.).

At the forefront of research into this connection is the island of Papa Stour. Off the west coast of mainland Shetland, this island has been described as 'a splendid microcosm of a landscape system' (Davidson and Simpson 1994: 67). Although a peripheral area of modern Shetland, Papa Stour was a major settlement area in the Norse period and an important sea-route stopping point (*ibid*.). Papa Stour has extensive areas of deep anthropogenic soil which, according to archaeological and historical evidence as well as recent oral accounts, are the result of a plaggen manuring system analogous to that seen on the Continent (Davidson and Carter 1998: 828) and at Marwick, Orkney (Simpson 1997). These are situated both within localised infield areas and the *kailyards* or kitchen-gardens adjacent to the farmsteads (Guttmann 2001: 81) and were formed through applications of turf pared from the hill, composted through the byres in which cattle were housed overnight, along with other materials such as seaweed (Davidson and Carter 1998: 828). Archaeological evidence has indicated that this mode of cultivation is likely to have been initiated in the Norse period (*ibid*.: 829); however, uniquely among plaggen soil areas in the Northern Isles, the relative isolation of Papa Stour ensured that elements of this manuring system continued until at least 1967, and have therefore been recorded in great detail by ethnographers (see Fenton 1978).

This combination of extensive deep topsoil areas and reliable data on soil additions has meant that research on Papa Stour has concentrated largely upon experimental investigations, particularly into the survival of micromorphological evidence for tillage and manuring (Davidson and Carter 1998; Adderley *et al*. 2000). Alongside this, investigation into the role of the *papar* in instigating intensive manuring in Papa Stour is currently exploring the historical context of these soils, specifically the potential role of such outside influence in the key transitional period identified in deep topsoil formation in the Northern Isles: the change from domestic waste use and small-scale cultivation to the adoption of the depth-creating, turf-based compost manuring strategies that appear to be associated with (as in other European areas) agricultural intensification.

It should be noted that not all deep anthropogenic topsoils seen in a monastic context are linked to *papar* place names. The potential link between the Orkney Marwick deep topsoils and the nearby monastic community of Birsay, linked to the German archbishopric of Hamburg-Bremen, has already been mentioned, and deep anthropogenic topsoils have also been identified at Fearn Abbey, Easter Ross (cited in Davidson and Simpson 1994: 73). Interestingly, the development of the *beklem-regt* – the system of land tenure identified as a potential factor in the success of plaggen manuring techniques on the Continent – has also been attributed to early monastic land tenure regulations (de Laveleye 1878: 272).

2.4.4 Deep anthropogenic soils in Scotland: the contribution of this project

Investigations into deep anthropogenic arable topsoils in Scotland so far present a complex picture, with both similarities and differences to the plaggen manuring system as described from Continental Europe. Although those that are contemporary with the European plaggen soils show similarities in input system, few have been identified, and this hampers interpretation of their wider historical context. Those that date from significantly earlier periods appear to represent a fundamentally different agricultural system, which may or may not be a direct precursor to these later, 'true' plaggen soils.

Research has also suggested that, far from being a widely adopted system, even Norse period plaggen manuring in the Northern Isles may at least partly represent localised responses to problems of availability of fertiliser resources (e.g. Marwick), rather than a process of widespread intensification as seen on the Continent. The relative isolation of the deep anthropogenic topsoils identified so far also makes it unclear how, and from where, plaggen manuring was introduced in Scotland. While we can infer a certain level of organisation from the makeup of a deep anthropogenic soil, without a larger sample set, it is difficult to comment on the wider economic significance of these soils in Scottish agricultural history. Was intensive manuring a catalyst for intensification, or a response to needs, e.g. as a result of population pressure?

One of the ways in which this thesis hopes to contribute to this discussion is by researching the information available for intensive manuring systems from historical sources. The pre-Improvement documentary sources accessed for this project represent the most extensive datasets on manuring practice for the period following that which saw the development of the Late Norse topsoils, and directly relate to the latter period of development of some of the same. It is therefore hoped that by exploring evidence for the continuation of these manuring systems into the historic period across a wider area of Scotland, and into areas for which we have no field evidence for deep anthropogenic topsoils, this project may elaborate on aspects of the review provided above, exploring the extent to which deep anthropogenic topsoils were a feature of the Scottish landscape, their pattern of distribution, and their relationship to specific agricultural systems.

2.5 Classification of deep anthropogenic soils

The final section of this chapter on previous research into deep anthropogenic topsoils examines the question of their classification, a theme that has run through the above discussion. Classification is a prerequisite to understanding the nature of these soils and their relationship to the historic landscape: for the archaeologist, an urban soil is in a fundamentally different class to one from a rural context, and a settlement deposit represents a different set of processes to an arable one. Such classifications have informed the discussion above. Yet the various soil taxonomic systems in use have so far achieved little consensus in their classification of anthropogenic soils. Due to the fact that an overall system of soil classification has not yet been accepted – a matter of concern for soil science in general (Nachtergaele *et al*. 2000) – inter-regional, and interdisciplinary geo-archaeological studies are hampered by the fact that analogous anthropogenic soils are classed differently in different regions. These differences are discussed below.

2.5.1 Deep anthropogenic topsoils in current classification systems

How do the various classification systems of the different world regions recognise the deep anthropogenic soils discussed above, and do they prove useful in a geoarchaeological context?

Some, such as the Soil Survey for Scotland soil classification systems – do not even fully recognise anthropogenic soils (Guttmann 2001: 30). The Soil Survey for England and Wales, although classifying separately soils 'with a thick man-made A-horizon' (Avery 1990: 50-51), merely distinguish between 'man-made' (divided into 'sandy' and 'earth' soils) and 'disturbed' soils - of limited relevance in an archaeological context, except perhaps in a consideration of land reclamation processes (Davidson and Smout 1996).

A more useful approach is the 1960s classification devised by the American (USDA 1960) and Dutch (de Bakker and Schelling 1966) taxonomists. These recognise plaggen soils as a distinct soil group ('*plaggepts*' or '*Enk*' Earth soils respectively), created through long-continued manuring processes, defined by depth (over 50 cm) and by input, with both systems specifying mineral and especially organic inputs, such as the classic heather sods of the plaggen regions. The plaggen group is then subdivided according to colour – brown and black. This has archaeological as well as scientific relevance, for the colour of the soil is related to its input history and is therefore a useful classifier for the geoarchaeologist (van de Westeringh 1988: 11). The criteria of these subgroups have, however, excluded some anthropogenic soils from these classification systems, despite comparability in form and function (Spek 1992: 80). The Dutch *Tuin* ('garden') soils, which are formed by the addition of organic manures, mud and dune sand to the soil surface, are not considered plaggen soils on the basis of their more clayey texture (Conry 1974: 325), despite their depth and colour. The American classification system, meanwhile, stresses the importance of properties within the soil order rather than those indicating the anthropogenic origin of the deposit (*ibid*.), which for the geoarchaeologist is to fundamentally misclassify these soils.

The classification that most clearly recognises not only the chemical and physical soil properties, but also the anthropogenic context of the soil is the German system (Muckenhausen 1962). The German class of '*Terrestriche anthropogene Boden*' (terrestrial man-made soils) is divided into 3 'Types', '*Plaggenesche'* (plaggen soil), '*Hortisol*' (old garden soil) and '*Rigosol*' (a very deep mixed soil, the result of, for example, vineyard cultivation). There are many subdivisions, created as a result of soil surveys for agriculture, forestry and viniculture, below these divisions (Beckel 1962). It is possible to see how the divisions here – plaggen, garden soil – may be used to apply meaningful classification to some of the soils discussed above, such as the garden soils seen in urban contexts (Section 2.3). Such differences, though not subdivided as such, are recognised within the most recent FAO classification of 'Anthrosols' which, alongside anthropogenic horizons arising from processes such as sedimentation as a result of irrigation activity (*irragic* horizons) and paddy-field cultivation (*anthraquic* horizons) acknowledges the difference between the *plaggic* horizons arising from the addition of plaggen-type bulk manures, and *hortic* horizons formed through the application of 'household wastes and manure' (FAO 2006: 71). In addition, the FAO system recognises the fundamental difference between plaggen-type 'organic-plus-mineral' manuring strategies and the predominantly mineral additions used to create deep topsoils of the kind seen in Ireland, identifying the latter as '*terric'* horizons (*ibid*.: 72).

Conry (1974: 319) suggests that the restrictive and possibly divisive aspects of deep anthropogenic soil classification may be rectified by dividing these topsoils according to whether they are the result of a *raising* or a *deepening* of the soil. Plaggen deposits, containing bulk organic matter, *raise* the existing surface to form a *deep* anthropogenic topsoil. Topsoils such as the *Tuin*, however, are formed through the addition of largely organic manures which, although darkening the soil, do not raise the soil profile. Rather, the deepening is a result of the cultivation methods used. This more useful classification, which by referring to the soil formation process allows more meaningful comparison between these related soils to be made, does not, however, solve the problem of classification beyond this point. Some true plaggen soils formed by both mineral and organic addition are classed as 'deepened' due to biological activity, depending on the underlying soil material (van de Westeringh 1988: 16). Secondly, such a system would not successfully classify for the geoarchaeologist the range of deep anthropogenic soils described in this chapter. As a result of a wide range of formation processes which varied over different historical periods, many deep anthropogenic topsoils are probably the result of a mixture of deepening and raising processes. In the absence of prior evidence for the kind of application system used, it is also difficult within localised anthropogenic deposits to decide whether the topsoil has in fact been deepened or raised. Comparisons of metres O.D. measurement for B horizons over adjoining areas of deep anthropogenic and shallow soil profiles could answer this for discrete deep topsoil deposits, but would prove time consuming and difficult to undertake on a large scale.

2.5.2 Recommendations for classifying deep anthropogenic topsoils: inputs and context

Discussed with reference to, above all, their archaeological and historical context, the deep anthropogenic soils discussed in this chapter fall quite naturally into a range of categories: soils associated with arable activities; soils located in urban contexts; soils formed by the application of different manures to the soil, often in specific combinations. If these are the demarcations of most relevance to the geoarchaeologist, how is a classification using these indicators best created, and can this be integrated with the scientific requirements of soil classification system?

This chapter has demonstrated that, firstly, deep anthropogenic soils are to be found within what can be viewed as a range of 'categories' indicative of varying physical processes of development. Secondly, it is observed that the prefix 'deep' notes the defining feature of these soils rather than ‘deepened’ or, as is sometimes used in relation to plaggen soils, ‘raised’. As has been indicated above, it is likely that many of these soils have been created through a combination of raising and deepening processes. Previous work on Scottish soils has demonstrated the wide variety of processes responsible for their formation, and to classify them as either ‘raised’ or ‘deepened’ when their variability throughout Scotland is still so poorly understood does not seem appropriate.

This chapter has demonstrated that the most significant aspect of deep anthropogenic soils is their *input* history, in both a geoarchaeological and historical context. Input variation is already recognised as a key variable in separating the subgroups of deep anthropogenic soils defined within existing classification systems, influencing colour, texture and chemical composition. Input choice can be as much a reflection of soil environmental as economic conditions, indicative of the underlying chemical and physical soil condition of the locality, and the soil properties requiring enhancement in order to maximise fertility. Preserved traces of past anthropogenic inputs above all represent the available store of retained cultural information within an anthropogenic soil.

It is argued in this thesis that within the varied categories of deep anthropogenic soil, the primary factor in their classification in both an historical and geoarchaeological sense should be the nature of their inputs. This philosophy is embraced more fully in the following chapter and the research context it provides for the first objective of this project: the analysis of the historical source data for the variety of inputs into these soils and how they were utilised by Scottish farmers in the past. Through this, an elementary classification of deep anthropogenic topsoils in Scotland according to their primary inputs can in effect be constructed, and integrated with geographical data in order to locate deep topsoil areas. A knowledge of variation in patterns of soil input may also be able to inform upon the relative vulnerability of a soil to the effects of different modern land management systems and land cover, with particular suites of soil cultural indicators created by specific input regimes likely to exhibit differing responses to land cover effects.

Although the definition of a classification system for deep anthropogenic topsoils is not an aim of this thesis, the above summarises the approach taken in this project to the issue of classification of deep anthropogenic topsoils, and therefore the contribution of this thesis to the ongoing issue of deep anthropogenic soil classification.

3. Historical evidence for manuring practices in Scotland

The review of geoarchaeological and archaeo-historical research presented in Chapter 2 has indicated that manuring regimes leading to the development of deep anthropogenic topsoils were in operation in the some areas of the Northern Isles of Scotland in a form comparable to those of the Continental European plaggen regions as early as the twelfth century AD and as late as the early twentieth. While geoarchaeological investigations indicate that the prehistoric period in these regions saw the development of plaggen-type manuring strategies, indicating that Scottish plaggen manuring techniques may have developed indigenously, independent of those of the Continental European regions, there is also evidence for a link between the spread of monastic activity and the development of such topsoils in both the Northern and the Western Isles. But what of the centuries between these dated examples, and what of Scotland outside of these island regions?

This chapter focuses on the history of arable farming practice throughout Scotland, with particular reference to manuring strategies and materials, from the period immediately post-dating the initial Norse-period development of deep topsoils at Marwick, Orkney, up to the early modern period to which the latest plaggen soils at Papa Stour have been attributed. The chapter reviews Scottish agricultural and manuring practice during the historic period, and through this identifies a variety of factors which would have been likely to encourage, or acted to inhibit, the development of anthropogenic deep topsoils in different Scottish regions.

This serves several purposes. Firstly, this chapter continues the ‘chronology’ of the development of Scottish farming practice begun in Chapter 2, adding historic period data to the archaeological-based evidence for prehistoric farming, and thus completing a picture of Scotland’s agricultural and manuring history from the earliest episodes of cultivation to the introduction of the artificial fertilisers that superseded intensive, plaggen-style manuring regimes. Secondly, this chapter brings together the available historical and ethnographic evidence for the range of manures used by farmers throughout Scotland during this period, the farming strategies of which they were a part, and the geographical and chronological variation of these. This complements the geoarchaeological evidence presented in Chapter 2 for manuring materials and strategies and their relationship to known episodes of deep anthropogenic topsoil development: does the historic evidence point to similar manuring strategies being used throughout Scotland in the medieval and post-medieval periods, and therefore to the possible development of deep anthropogenic topsoils outside of a largely pre-historic Northern Isles context?

Thirdly, and very importantly, this chapter illustrates the differences between archaeological and historical data sources, and the implications of this for investigating the distribution of deep anthropogenic topsoils in Scotland. The construction of this chapter differs greatly from that of Chapter 2, for the sources of evidence provide a very different dataset. Some of this is positive: the historical source data consulted for this period, for example, provides a far broader geographical and chronological dataset for manuring practices than that provided by the micromorphological or geochemical evidence from Toft's Ness or Papa Stour. On the other hand, the historical accounts cited in this chapter do not often progress beyond very generalised information for manuring practices, and can therefore only provide indirect sources of evidence for the location of deep anthropogenic topsoils.

Such ambiguity is also a feature of the numerous research projects into rural settlement which, largely undertaken during the last decade under the aegis of the MoLRS interest group, represents the main body of archaeological research into farming history for this period in Scotland. In stark contrast to the well-researched, and often well-preserved archaeological landscapes of the Norse period Northern Isles, evidence for medieval and later rural settlement remains elusive throughout the rest of Scotland, to the extent that Norse archaeology has developed as a field set apart from MoLRS in general, despite its Medieval context (Lelong 2003: 8). Documentary research indicates that a tendency towards re-use of structural materials (Macinnes 2003: 3; Dodgshon 1993a: 423) and a level of flux within a farming settlement that may have led to frequent shifting of house sites (Dodgshon 1993a: 419) are likely reasons for this lack of preservation on, especially, the Scottish mainland.

More pernicious however, from the point of view of investigating the development of deep anthropogenic topsoils in this period, is the constant re-use and re-organisation of the rural landscape, to the extent that alteration in soil depth is presented against a background of repeated cultivation regimes which can only provide a generalised chronology for deep topsoil development. Individual cultivation regimes are difficult to pick out from the complex picture of overlapping field systems and settlement remains which characterise the MoLRS survey work undertaken so far (e.g. RCAHMS 1993: 14-16; Dixon 1994: 32), and until very recently, the notion that real information may be being lost as a result of this has been somewhat masked by the tendency, even encouraged by the acronym MoLRS itself, to see this 'medieval and later' landscape as representative of a single phase in the development of Scottish agriculture (Lelong, cited by Dalglish 2003: 485).

Current thinking on archaeology's approach to the problem of characterising the piecemeal evidence of rural settlement for this period has correctly recognised that to see pre-Improvement settlement and landscape patterns as representative of a fairly static socioeconomic situation is a false premise (Dalglish 2003: 492). More recent MoLRS-based research projects are addressing this issue, and there has been a clear shift in research design methodology away from solely survey-based field projects and towards a more landscape-oriented approach, such as that seen for the Ben Lawers Historic Landscape Project, which is combining documentary research, field survey and excavation with palaeoecological and soil analysis to investigate patterns of rural settlement on the north side of Loch Tay (Turner 2003: 31). Investigations into manuring traditions are an integral part of the land use element of the Ben Lawers project.

A fourth aim of this chapter, then, is to give an insight into the often problematic nature of the MoLRS body of research introduced in Chapter 1, and the difficulty of utilising this often survey-based resource to investigate the distribution of deep anthropogenic topsoils in Scotland.

Finally, this focus on the use of historical data to investigate agricultural and manuring techniques in Scotland acts as an introduction to the two key documentary sources used in this thesis: the County Agricultural Reports and the First Statistical Account of Scotland. As the two most extensive and finely-resolved datasets providing information on agricultural change and development in the post-medieval period, these sources provide the backbone for the manuring database, the creation of which is described in Chapter 4. By integrating geographical and archaeological source data with these historical datasets, the manuring database creates a tool by which the factors identified and discussed in this chapter as potentially affecting the development of deep anthropogenic topsoils throughout Scotland can be investigated in more detail. Chapters 3 and 4 are thus closely related: this chapter provides an historic and intellectual context for the manuring database, introducing not only the research milieu from which the source material for the database is drawn, but also some of the difficulties inherent in its use. Set against the archaeological source data presented in Chapter 2, we are introduced to the challenge presented by the integration of cultural and environmental information that is a key aspect of this thesis.

This chapter begins by introducing the range of source data and commentary available for the historic period which relates to agrarian practice, including the County Agricultural Reports and First Statistical Account. It then discusses the key developments in agricultural organisation, and their variation through regions with differing geographical and economic circumstances, identifiable in post-medieval Scotland from documentary and (mainly survey-based) archaeo-historical evidence. In relating these to evidence for manuring practice, a number of factors which may have impeded, as well as encouraged, deep anthropogenic topsoil development in Scotland are identified. The final section provides an individual assessment of the use of each of the core manure types recorded in Scotland, from dungs and bulk manures to seaweed, lime and 'exotics', examining more closely the factors identified above, associated with each of these materials, which may have affected the development of deep anthropogenic topsoils in Scotland.

3.1 Source data for the historic period

Documentary sources providing information on the activities of rural communities in Scotland are, with the limited exception of early monastic records (Dixon 1994: 30), rare for the fifteenth and sixteenth centuries, only becoming more widespread toward the latter half of the seventeenth century (Dodgshon 1998a: 2). Early Governmental records such as those concerning property transfer commencing in 1617 (Shaw 1980: 7) and the poll tax returns of the 1690s (Devine 1994: 4) provide early, though often scant, data on leaseholding tenants in rural communities.

This same period, however, saw early attempts at the more eclectic form of statistical data gathering which was ultimately to come to fruition in the First Statistical Account, such as Sir Robert Gordon of Straloch's commentaries for Bleau's *Atlas Scotiae* of 1662 (Sinclair 1826: 68), Andrew Melville's preface of the same, and the parish-level chorographical collections attempted by the 'Ecclesiastical Survey' of 1627 and 1690 (Withers 1995: 376). Such works are significant in that they illustrate the development of the intellectual approach to statistical enquiry seen in the Statistical Account: with the compilation of national knowledge seen as a means of promoting national identity, these works include localised detail on peoples and places alongside economic, political and topographic data (*ibid*.). A similar approach is seen in the other significant group of documentary sources of the pre-Improvement period which provide information on rural and farming life: the publications of travel writers such as Munro (1549), Martin (1695) and that describing the celebrated journey of Samuel Johnson and James Boswell (McGowan 1966).

Graphic sources are also relatively scarce for this period: Scotland shows a dearth of detailed estate plans for the sixteenth and seventeenth centuries (Baker and Butlin 1973: 12) and although the earliest plans of Scottish rural settlement survive from the 1560s, the vast majority date from the eighteenth century (Dixon 2003: 55).

Detailed and wide-ranging information on farming practice in Scotland only becomes available from the Improvement period of the eighteenth century, most significantly as a result of the detailed and country-wide surveys carried out for the County Agricultural Reports (1785-1814) and First Statistical Account (1791-99), but also through other records such as Webster's population enumeration of 1775 (Gray 1962: 148). Largely as a response to the recommendations of the Improvement writers, large scale estate surveys were commissioned by many landowners toward the latter part of the eighteenth century, in the interest of improving agricultural productivity, such as the report by Blackadder for North Uist (1800) and Turnbull's survey of the Argyll estate (1763) (cited in Withers 1995). Individual, farm-level accounts, prompted by the public interest in agricultural development seen in this period, begin to fill out the record supplied by the Improvement literature, such as those collected by John Ramsay which document the introduction of lime as a manure to the Carse of Stirling (published 1888, cited by Symon 1959: 113). Detail on the specific circumstances of data collection and organisation of the County

Agricultural Report and First Statistical Account projects is provided as part of the manuring database methodology in Chapter 4.

Into the nineteenth century, alongside an increasing number of such contemporary accounts relating to farming, plus the Second Statistical Account of 1850, individual estate papers also begin to provide a detailed and continuous record of farming activity, such as the Breadalbane Collection, the Seaforth Papers and the Clanranald Papers (Gray 1962: 151). Into the twentieth century, a continuing record of socioeconomic survey work is seen, focused on the perceived 'marginal areas' of Scottish agriculture (e.g. Darling 1944).

In recent decades, a large body of archaeo-historical literature researching change and development in Scottish agricultural practice has been produced (e.g. Shaw 1980; Devine 1994; Dodgshon 1998a) which has complemented a strong tradition of ethnographic research, mainly focused on the Northern and Western Isles (e.g. Fenton 1978; 1985; 1986). Current thinking, spurred in part by the growing focus on rural settlement studies in archaeological research, has criticised the approach taken by, especially, ethnographic researchers, as tending to characterise pre-Improvement rural society as static, representing unchanged, ancient traditions, and has argued for a more holistic theoretical approach in which documentary sources can be critiqued in the light of more recent archaeo-historical investigations (e.g. Dalglish 2002).

Documentary sources specifically relating to manuring practice are a feature of, though often not central to, all of the periods listed above. There are significant early writings, such as Napier's '*The New Order of Gooding and Manuring of All Sorts of Field Land with Common Salts*' (1595) and later, Donaldson's '*Husbandry Anatomised, Or, An Enquiry into the Present Manner of Tilling and Manuring the Ground in Scotland*' (1697), but the majority of these date to the Improvement period and many are treatises arising from the General Agricultural Report series, collating material from the English as well as Scottish surveys, for example Young's '*An Essay on Manures*' (1799). Although providing a valuable adjunct to the large-scale Improvement surveys, reports of this kind generally reproduce material from the surveys themselves, and while they provide interesting examples of some of the propaganda against traditional manuring methods seen at this time, these accounts can as a result provide a distorted picture of the extent to which traditional bulk manures were utilised in the areas they discuss. Later, post-Improvement period studies, such as Falkner's *Muck Manual* (1843) have not been consulted for this project.

3.2 The development of Scottish farming in the historic period

3.2.1 1200-1600: a history without runrig?

Pre-Reformation period data on arable cultivation methods in Scotland are scarce. A brief glance at the historic picture for the period during which the Norse period deep topsoils at Marwick began to be formed shows a Scotland not yet united as a single country: indeed, at this time the Northern Isles were themselves governed by Denmark (Fenton 1978: 1). In the twelfth century, mainland Scotland was peopled by five distinct ethnic groups with origins in Scotland itself, Ireland, Cumbria, Northumberland and Scandinavia, of which we have archaeological evidence for a tradition of deep topsoil manuring from only the latter (Simpson 1997). Through the following centuries, however, these groups coalesced, under the control of a single monarchy dominated by the Irish settlers, into a nominally united country distinguished by a central church structure, a network of royal burghs and a functioning legal system (Smout 1969: 18-29). Despite this, differences prevailed between the power structures and social traditions of the predominately Celtic-origin groups of the high north-western third of the country (the 'Highlands') and those of the Norman-influenced 'Lowlands'. By the fourteenth century, Scottish society was essentially divided into two 'kingdoms', as war with England finally united the Lowlands into a centrally-organised feudal society, and the fall of the Norse in the western coastal areas ushered in the era of 'Clan' rule, in effect a second royal house, in the Highlands (*ibid.*: 39-42).

This historic divide, whilst central to understanding later differences in agricultural regimes between north and south, may have made little difference to farming practice in the twelfth to thirteenth century. The limited evidence available indicates that during this period, where differences between the Highlands and the Lowlands existed, they seem to have been based upon terrain rather than differences in social organisation. The unit of settlement common throughout the country was a largely nucleated village, generally representing a single farming unit and thus determined in size by the area its inhabitants could keep under cultivation, known variously as the farming township, *farmtoun* or *fermtoun*, or *kirktoun* or *clachan* if it happened to house the parish church, and a *milltoun* if the mill were located within. *Cot-touns*, settlements consisting not of a farming unit but housing for *cottars* – the landless poor, who would be employed on a farming unit nearby – were also known (Shaw 1980: 80; Smout 1969: 111). *Baile*, another general name for such a farming settlement, is indicative of a farm-unit held in joint tenancy (Dalglish 2003: 82). The land cultivated by the farmers of these touns was not theirs, but held by members of the ruling classes - in the Lowlands, the laird of the estate, to which the farmers paid a yearly rental. In the Highland regions, the clan chiefs, by whom the peasant farmers were ruled, demanded similar tribute.

Extant settlement evidence for early farming townships are rare in the archaeological record, due partly to the widespread removal or reorganisation of such settlements during the Improvement period, but also to the general effect of land re-use, especially in the Lowlands (Dixon 2003: 63). Such variations in form as can be defined appear to have been dictated by the relative reliance on arable or pastoral farming of the settlement itself. Arable farmtouns were confined to available cultivable land, whilst pastoral-based settlements tended to be more dispersed (Smout 1969: 113) but despite the identification of the latter with the Highland regions (Barrow 1962: 123) and the strongest arable base being in the Lowlands, a mixture of settlement forms appears to be seen throughout Scotland. Strongly nucleated villages comparable to those of the Northumbrian region are identifiable through place-name and archaeological evidence from the twelfth century in the south-east Scotland (Barrow 1962: 124; Dixon 2003: 54), but upland summer grazing sites, or *shielings*, more commonly associated with Highland settlement patterns, are also known from the twelfth century in the southern uplands (Barrow 1962: 126).

Even more fragmentary are data sources for the systems of land division and cultivation, and thus manuring, within the farming townships during this early historic period. The earliest system of land organisation for which there is evidence is that of ‘mass tenure’, in which the tenants of a farming township held and cultivated the land in common, shared the produce communally, and paid their rent as a lump sum (Smout 1969: 113). Though primitive, the strength of such a system was the sense of common interest it preserved in the land, important in regions such as the Western Isles, where raiding from neighbouring clans was widespread up to the early seventeenth century (Shaw 1980: 86).

Although the origins of the more sophisticated ‘runrig’ system of land division, and the ‘infield-outfield’ system of cultivation - the cornerstones of the Scottish agricultural system prior to the Improvement – likely date from this period, prior to the fifteenth century, there is no reference to either term (Dodgshon 1980): instead, a complex and varied Latin-based terminology for field division is seen (Barrow 1962). Despite this, field evidence suggests that the rig division, by whatever name, was well-established as a basic field-system unit in the twelfth century (Dixon 1994: 30). However, what such early rig divisions represented in terms of farming practice is still a subject for debate (see Dodgshon 1993a; Dodgshon 1993b; Dodgshon 1998a; Donnelly 2000) and is considered further throughout the following section.

3.2.2 The pre-Improvement system: runrig division and infield-outfield cultivation patterns

The division of arable land by means of the runrig system, and the infield-outfield structure of crop rotation and land use, are recognised as having been near-universal in the farming regimes of Scotland prior to the reorganisation of land tenure and the enclosure of arable areas seen during the Improvement period. Although subject to numerous variations in structure, and not necessarily practiced together, runrig and infield-outfield were for the most part the common agricultural system in use in both Highland and Lowland Scotland during this period, and these patterns of land use and division are thus central factors in the organisation and distribution of manure resources.

3.2.2.1 Runrig and ridge-and-furrow cultivation

The runrig system sub-divided the unenclosed arable land cultivated by a farming township into a series of separate strips, known as ‘rigs’, each of which was allocated to different individuals for cultivation, most characteristically in a rotation system organised in such a way as to ensure both a fair division of the most productive lands and a necessary communality of effort among the farmers of a township (Smout 1969: 113; Whittington 1973: 536; Fenton 1976: 8). Without such communal effort, a township could not have operated, dependent as the system was on resources that would have been both limited and beyond the resources of individual farmers, such as ploughs and plough-teams (Fenton 1976: 7).

The land strips in the runrig system were cultivated by means of a ploughing method which involved ploughing the land into a series of wide raised ridges on which the crops were grown, while the furrows between them created a drainage system for surface water. The ‘ridge and furrow’ ploughing technique was standard from the earliest period of runrig cultivation in Scotland up until the nineteenth century, when tile drainage systems made straight ploughing possible on the majority of Scottish arable soils (*ibid.*: 5). Rig typologies vary according to date, soil type and terrain (see Halliday 2003), but within the runrig system, the raised rig became a permanent fixture delineating separate cultivation strips, and was therefore re-ploughed on the same position every year, which action would serve to increase the height of the rig and the depth of the furrow (Fenton 1976: 5).

Ridge and furrow are distinctive features of the MoLRS landscape, form a key part of numerous MoLRS landscape surveys (e.g. RCAHMS 1994a; 1994b; 1994c) and have been the subject of much typological research (e.g. Dixon 1994; Halliday 2003). But rig systems are a multi-period, much re-used land formation which are difficult to date, except merely to the pre- or post-Improvement periods (RCAHMS 1994a: 14). Neither can the physical evidence of ridge-and-furrow cultivation provide much of an indication of the system of land tenure within the pre-Improvement farming township, for a layout of runrig strips could be organised in many different ways. ‘Periodic runrig’ saw strips reallocated, usually on a one to three-year rotation, but under the ‘fixed runrig’ system they were permanently allocated to a single holding (Smout 1969: 113). The County Agricultural Report from Perthshire (1799) describes this process, ‘*by which every field of the same quality was split into as many lots as there were tenants on the farm*’ (see Whittington 1973: 540). We can however assume that the ridge-ploughing of these fields would still have been a joint responsibility. Further complications are seen, for example in Angus, where some farms were split by rental into north, south, east and west quarters, each of which was occupied by a single tenant for one year, after which they moved to a different quarter (Smout 1969: 114).

Systems of land leasing also varied in this period, from the co-joint tenancy (where all tenants rented communally) as described above, to individual rent agreements among farmers in one township. In this second system, though activities such as ploughing would most likely have been communal, the division of the rigs of land would not necessarily be equal (Whittington 1973: 542). While documentary sources can illustrate this variety of land division systems, such interpretation is generally beyond the reach of archaeological survey work. The picture is further complicated by the convincing argument that, contrary to the commonly held belief that the enclosure of township arable lands was a product of the Improvement period, the extant remains of several Highland townships indicate that a system of field enclosure may have *pre-dated* the runrig system in certain areas (Dodgshon 1993a; Dodgshon 1993b).

It would seem that, as discussed in the introduction to this chapter with reference to the MoLRS resource, investigating the mechanics of land use (including systems of manure application) is not possible through examining the field pattern of surviving rig strips that form a main part of survey work into rural settlement of this period.

From the point of view of manuring practices, what we may also be able to conclude is that the mechanics of ridge-and-furrow cultivation would seem to be a disincentive to the use of bulk manures to create deep anthropogenic topsoils. With a deep topsoil ‘profile’ already created for the crop to be sown upon through the movement of soil to form the ridge, there would appear to have been no need to add manure beyond the level needed to fertilise the soil. Certainly, the historic period deep anthropogenic topsoils identified in Orkney are located on generally free-draining soils that were not cultivated in a ridge-and-furrow manner (Simpson 1997), and whilst the deep anthropogenic topsoils formed on the runrig strips of land in Papa Stour, Shetland, are at least partly located on poorly drained soils (Davidson and Carter, 1998: 828), ethnographic evidence indicates that these soils were spade-cultivated (*ibid*.).

Likewise, it is unlikely that the action of ridge-and-furrow cultivation would itself have contributed to the development of a deep anthropogenic topsoil. Topsoil ‘deepening’ could conceivably have been achieved by using this method to turn up successive layers of subsoil which would then, through a combination of manuring and cultivation episodes, become part of the topsoil. However, eighteenth century accounts of ridge-and-furrow ploughing technique make it clear that the furrow should not be cut into the subsoil, and should be cut narrow and shallow in areas of thin topsoil to make the most of the restricted soil surface area (Dickson 1770: 283). The tillage method used throughout the majority of Scottish areas does not, therefore, appear to encourage the development of deep anthropogenic topsoils, nor is it particularly associated with a specific manuring regime. For a more detailed investigation of manuring practices during this period, it is necessary to discuss the system through which the crops themselves were cultivated: the infield-outfield system.

3.2.2.2 Infield-outfield cultivation

The arable land cultivated under the runrig, and later, systems in Scotland was divided into two main categories: the infield (also known as *tillage*, *croft-land* or *mucked-land*) and the outfield (also known as *in-bye* or sometimes *folded-land*). These divisions were based on the quality of the land for cultivation, the infield being the most fertile land within the township, which could stand more intensive cropping and was invariably under constant cultivation, and the outfield a less productive, yet still cultivable category which would generally be held in a field-by-field rotation of cropping to fallow period (Smout 1969; Whittington 1973; Fenton 1976; Dodgshon 1980).

Invariably a part of a mixed arable and pastoral system, the infield and outfield were not the only categories of land within this cultivation regime: just as vital to the running of the system were the grazing lands (or *common grazing*, or in Shetland, the *scattald*), usually held in common ownership even after the permanent division of arable land after the Improvement period. The structure of a typical pre-Improvement period farming township can be summarised as follows: firstly, the *settlement* itself, which would not necessarily be nucleated in structure (see Dodgshon 1993b) but would be located on or near to the best arable land, which would be kept under permanent cultivation as *infield*. As the division between infield and outfield would be largely dictated by factors such as terrain, drainage etc., it would have been common for blocks of infield and outfield land to be intermingled within the central township region (Smout 1969: 118). The majority of *outfield* land, however, would tend to be further from the centre of cultivation, perhaps further upslope, or, as seen in the Hebrides, located on areas of peatland which had been brought into cultivation (Smith 1994: 31). In coastal townships, the infield land would tend to be located nearest to the sea, often on the fertile 'machair' (the extensive areas of low-lying sandy pasture that are a feature of, especially, the coastal areas of the Western Isles) and close to the seaweed resources which were a primary manure source (Shaw 1980: 88).

As these arable areas were unenclosed, at least during the pre-Improvement period of infield-outfield cultivation, it was vital that during the growing season, the livestock of the township were kept away from the fields under crop. This was achieved by the appropriation of an area of uncultivated waste, or pasture land beyond the township boundary, as the *common grazings* to which livestock were restricted during the growing season, and which were separated from the township by a *head dyke*, constructed from stone or turf, which prevented stock from entering the arable land. An additional land-use element seen especially in the Western Isles is the *shieling*, or upland area of extra summer grazing (Smith 1994: 47). Shielings were common in areas with large tracts of hilly upland pasture, and in many areas the summer would see the wholesale movement of the livestock of the farming township, usually accompanied by the women and children, to spend a three- or four-month sojourn at the *summertoun* of the shieling (Fenton 1980: 98). Transhumance of this sort can be traced beyond the twelfth century in Scotland, and is a feature of pastoral systems in many parts of the world (e.g. Simpson *et al*. 2004). The Northern Isles, with a lack of upland pasture resources far from the township base, does not seem to have had such a tradition, but in both the Northern and the Western Isles a similar method of utilising far-flung pasture land is seen in the summer movement of stock out to uninhabited islands (Smith 1994: 22; Nicolson 1978: 53). These additional pastures were a vital part of the system, taking pressure off grassland both in the common grazing and within the township itself.

The structure of these land-use divisions varied: in the more fertile areas of the Lowlands, infield and outfield land tended to occupy most of the township, and were fairly equally balanced in acreage (Dodgshon 1980: 76). Such *touns* would therefore be almost entirely reliant on common grazings outside the township for their pastureland. In regions where soil drainage was poor, such as the Highlands and areas of the Islands, blocks of infield and outfield would be interspersed with large areas of pasture, creating a tripartite land system within the *toun* (*ibid.*: 77). Smaller-scale divisions of land within the township were also common, such as the *kailyards*, or small areas of land allotted to tenants for use as kitchen-gardens (Shaw 1980: 84): kail, documented from the fifteenth century in Scotland, was a dietary staple (Fenton 1978: 101). Known as *tounmals* in the Northern Isles, these individual portions of land annexed to the house could be up to half an acre, and would include not only an area of *kailyard*, but grassed areas where the milking cows would be tethered during the period when the remainder of the stock were confined to the common grazings. Where houses were close together, these *tounmals* often formed a contiguous strip separating houses in the township from the fields (Nicolson 1978: 51; Fenton 1978: 25). In a consideration of manuring practices in the infield-outfield system, the function of these small areas should not be ignored: accounts pertaining to *tounmals* in Orkney in the seventeenth century indicate 'lovingly manured arable plots' (Smith 2000: 32). Other small but cultivated areas enclosed from the infield-outfield system are the *plantiecrues* of the Northern Isles: small, high-walled enclosures within which young cabbage plants were brought on before planting out (Fenton 1978: 103).

Pastoral farming as represented by the infield-outfield system was complex, organised around not only the need to keep animals from the growing crops, but also the need to maximise manure collection. In the winter, the animals would graze on the unplanted open fields within the township, dropping their manure on fields that were to be cultivated. Where the outfield lands were concerned, the distribution of this manure resource would be controlled by enclosing the animals in temporary folds upon that area of the outfield that was next to come into cultivation, a practice known as *tathing* or *teathing* (Fenton 1976: 13). It was common for cattle (and often lambs – e.g. FSA V: 378) to be housed at night, and the manure generated through this was subject to various treatments to maximise both the amount and potency of the manure prior to distribution (discussed further in the following sections). Once the crops showed, the animals would be relegated to the common grazings, and even here there is evidence that manure was harvested and utilised. Opportunistic cultivation is recorded as taking place at the shielings, within areas in which the cattle were brought together at night (Fenton 1980: 102) and rural settlement survey at Braes of Doune, southern Perthshire, shows evidence for rig-cultivation around extant summer shieling huts

(RCAHMS 1994c: 16). Improvement period agricultural writers for Perth note the manured '*heath*… (that) *became as green as a meadow, to the extent of several acres around the huts…afterwards converted into regular farms*' (Robertson 1799: 339).

How and where was this manure used in these patterns of cultivation in the farming township, what other fertilising materials supplemented it, and would these uses have been likely to lead to the formation of deep anthropogenic soils? To explore this it is necessary to move from consideration of the pastoral sector of the infield-outfield system to an examination of the arable.

During the pre-Improvement period, a limited range of crops were grown in the farming townships of Scotland. Almost without exception, grain cultivation was restricted to oats and bear, or *bere*, a kind of barley (Smout 1969: 118; Fenton 1978: 332), and occasionally rye, which although offering a slightly better yield than oats, was known to impoverish the soil (Shaw 1980: 97; 98). Favourable climate and soils allowed some variation in certain areas: south-eastern areas such as Lothian, Fife and Angus cultivated wheat, peas, beans and even flax for linen manufacture (Smout 1969: 119) but in areas such as the Northern Isles, pre-Improvement period writers record that such crops were unknown (Shaw 1980: 94). This was, however, not a universal north-south divide: in Galloway, the entire infield land was habitually given over to bere (Smout 1969: 119).

The cultivation pattern of the central bere and oat crops appears to have been generally the same throughout Scotland, and reflects the individual requirements and returns of each crop. Bere, although more demanding in terms of soil and fertiliser, gave a better return than oats. Unlike bere, oats would grow on poorer soil and without the aid of manure, and still give return enough to make cultivation worthwhile. These considerations meant that bere was invariably grown on the more productive infield land, and was given the vast majority of available manure, whilst the oat crop was grown in both the infield and outfield areas, with little or no manure application save that dropped by livestock that had been folded on the outfield areas (Shaw 1980: 97). The infield was therefore divided into a constant crop rotation of oats and bere, while the rest of the oat crop was rotated with fallow (i.e. pasture) as a part of the outfield system. Rotations varied, but there appears to have been a tendency for the bere crop to take up about one third of the infield area (Fenton 1976: 13; Dodgshon 1980: 77-79). The association of manured infield land with the bere crop was extremely strong: the infield area is even referred to as the ‘Bear Fey’ in eighteenth century records (Webster 1794: 12).

The significance of this for investigating deep anthropogenic topsoil development is clear: intensive manuring, and thus the possibility of deep topsoils, would be confined to the infield area under this system of cropping, as the oats on the outfield are widely documented as receiving only intermittent dung applications. Furthermore, this infield manuring would be confined to the bere crop, which, in the majority of townships, would have taken up not more than a third, certainly less than half of the infield area. Therefore, in a typical farming township, any one crop section of the infield would only receive manure once every three years, just before the raising of the bere crop.

Could this system have led to deep topsoil development? As the resume of the plaggen system in Chapter 2 indicates, this would depend upon whether or not mineral manures - turf, peat, sand or soil – were a *significant part* of the manuring regime in this pre-Improvement period.

3.2.2.3 Pre-Improvement manuring: the factors affecting deep topsoil development

The fine resolution of documentary sources such as the First Statistical Account allow us to conclude with some confidence that manure materials which could contribute to deep topsoil development were frequently in use in Scotland in the pre-Improvement period. Alongside the seaweed, or *ware*, that was used in coastal areas, manure collected by housing cattle overnight in the byre formed the backbone of manure applications within the farming township. Such overnight housing was frequently undertaken the year round (Fenton 1978: 281) – for example, in eighteenth-century Mid-Lothian, ‘winterers’ were cattle deliberately kept through the winter for the purpose of ‘*consuming the straw and making manure*’ (Robertson 1793: 32). Early Improvement period writings urge Scottish farmers to ‘*increase manure by feeding every animal upon the farm within doors, as is the practice of the Netherlands*’ (Fullarton 1794: 19).

Almost invariably, these stabled animals were bedded on material that would have had some mineral component, and this would have therefore formed part of the manure material removed from the byre. Evidence from Improvement period and later ethnographic sources (e.g. Sinclair 1813; Somerville 1796; Fenton 1978) name a huge range of materials that were used for this purpose, from turf and peat to machair turves in the Hebrides, straw, and even ashes from the fire. Several sources report that the byre would not be mucked out until ‘full’; that is, until the heads of the cattle were touching the roof, with up to four or five feet of composted dung and mineral material beneath them (e.g. FSA V: 193; XX: 277; and see Fenton 1978: 281): clearly, bedding additions produced a large and bulky manure. In many areas, the tradition was to muck out the byre and bedding mixture to an adjacent dunghill, where trouble was taken to prepare composts from this byre manure, often containing a wide range of mineral and organic materials (Smout 2002: 72, and see Section 3.3.1) which would have further augmented the manure bulk.

However, despite this evidence for the *existence* of plaggen-creating systems, what emerges more decisively from a detailed consideration of the documentary sources are a series of factors which appear likely to have inhibited the potential for these systems to result in widespread deep topsoil development.

Firstly, there appears to be an important difference of emphasis between accounts of manuring practices in Scotland and those from the plaggen regions. It would seem that in Scotland, mineral additions in particular were neither as extensive nor as well organised as in the Continental system, and there is thus a doubt as to whether such additions were included for the express purpose of *creating* mineral bulk. Where the European system was clearly geared towards producing a huge amount of manure material, deliberately intended to augment the soil, reports from the farming townships of the pre-Improvement period suggest that bulking the manure output was largely undertaken so that there would be enough manure to go around (Shaw 1980: 98). First Statistical Account returns even from the Central Belt, for example, report setbacks in the cultivation of barley and wheat, as there is not enough dung available to support it (FSA XVII: 567; XV: 51). It would seem that the composting of dung with bulk mineral material was a necessary way of maximising the organic manure resource, rather than a strategic decision aimed at physically augmenting the arable soil.

This is further supported by evidence which seems to suggest that dung was typically intermixed with far less mineral material than would be necessary to create a compost analogous to a plaggen manure. As stated in Chapter 2, a typical ratio of turf to dung in the plaggen system could be as high as 5 or 6 to 1 (Stoklund 1999: 210), thus requiring 5-10 ha of heath to be stripped to provide plaggen material for 1 ha of arable land (Blume 1998: 1). What evidence we have for the proportion of mineral material to dung from Scottish sources describing the pre-Improvement system suggests that rather less was used, from half and half (FSA XV: 50) to the more common two or three parts ‘earth’ ‘moss earth’ or ‘sand’ to one of dung (FSA III: 27; Sinclair 1795: 100; Sinclair 1814: 549). The County Agricultural Report for Aberdeenshire, in quoting ‘three *or four parts of earth* (muck fail) *to one of dung*’ is the only recipe which approaches the ratio known from the plaggen regions (Anderson 1794: 107). Interestingly, whilst there is certainly an awareness among Scottish agriculturalists of the intensive manuring regime of the Netherlands, there seems to have been less appreciation of the central role played by turf-based materials in the plaggen system.

This fundamental difference is very likely to be at least partly a result of the way in which the use of turf as a manure material appears to have been perceived, both by the farmers themselves and the authorities above them. Turf was commonly pared, usually from outfield land but also from the common grazings, for use in the byre or the compost midden. However, unlike the organised, officially sanctioned turf cutting operations seen in supporting the plaggen system on the Continent, documentary sources strongly indicate that turf cutting was generally discouraged throughout Scotland during the historic period. It is not difficult to see why: in taking turf from the outfield, farmers inevitably put even more stress on a vital part of their pastoral resource, which was already routinely cropped to exhaustion through the outfield rotation system (Smout 1969: 119; Lythe and Butt 1975: 19). Laws were passed prohibiting the cutting of turf in several areas from as early as 1685 (FSA XV: 456; Fenton 1970: 155) and it is clear that in many areas, grazing lands were ‘scalped’ for turf, not only for use as manure, but for use in the building of houses and dykes (Nicolson 1978: 52). While alternative sources of mineral material, such as the ‘earth’ ‘moss’ and ‘sand’ mentioned above were frequently utilised both in composts and as manures in their own right (Section 3.3.4), there is no doubt that the sensitivity of the Scottish authorities to the removal of turf in both the pre-and post-Improvement periods is likely to have been a significant block to the development of deep anthropogenic topsoils. However, with turf being – along with peat – a common fuel source upon which many areas of the country depended, the picture is more complex. Sources certainly indicate that, as in the plaggen regions, a significant amount of turf ash was utilised as manure, and, interestingly, there is evidence that the re-use of not only fuel residues but also building material from houses and dykes was seen as an effective means of circumventing regulations and obtaining turf-based material for the dunghill. The issue of turf use and the extent to which Scottish farmers were in a position to utilise this essential plaggen resource is key to understanding potential deep topsoil distribution in Scotland, and is discussed further in Section 3.3.3.

However, while it is possible that the farmers of this period did not have access to enough bulk compost to undertake plaggen-type manuring, both documentary and field evidence also suggest that it is equally possible that they did not see deep topsoil creation through bulk manuring as the solution to the problems created by thinner or poorer soils. This is illustrated by the preponderance in many areas of so-called *lazy-bed* cultivation. Lazy-beds are a pre-Improvement cultivation feature of unknown origin which are mainly confined to the north-west areas of Scotland, but are also found in areas of Argyll and Galloway (e.g. FSA IV: 143) and in upland areas of the south-east, such as the Cheviots (Dixon 1994: 41). Lazy-beds are, in effect, the spade-dug equivalent to the ridge-and-furrow cultivation method, and were constructed in areas of the farming township where ploughing was not possible, for example in rocky areas around lochs, against hill slopes (Smith 1994: 27) or, more usually in the Highlands, in wet, peaty areas (Fenton 1976: 5).

Lazy-beds were created by spreading a layer of manure (usually seaweed) on the area to be raised (usually an area of 3-4 feet in width), then digging out turf and earth from either side of the bed setting, and piling this on top of the manure, creating a larger version of the deeper topsoil and drainage channel provided by the ridge-and-furrow (*ibid*.) While generally an outfield phenomenon, in townships where arable land was scarce, lazy-beds would be created to form infield-standard soils, manured and sown with bere. In other areas, lazy-bed cultivation was an effective way of breaking up and reclaiming peat or waste land, disaggregating soil and providing drainage (FSA XIX: 248; Smith 1994: 28). The County Agricultural Reports in particular reflect this: generally disapproving of what was seen as a retrogressive cultivation method, lazy-beds are frequently cited as an effective means of bringing new ground into cultivation (Graham 1812: 175; Robertson 1799: 172; Robertson 1808: 126). When potatoes were introduced as a crop in the immediately pre-Improvement period (the mid 1700s), lazy-beds, with their advantages of soil depth and good drainage, became the preferred method for potato cultivation (Fenton 1978: 285) and are often referred to as 'potato-beds' in eighteenth century records (Webster 1794: 6). The beds were also versatile: there are accounts of two or more beds being raked together to create a larger cultivation area (Smith 1994: 28). Surviving lazy-beds can be seen at numerous locations in the MoLRS landscape, for example at Waternish on the Isle of Skye (Dixon 1994: 45). The proliferation of lazy beds in areas of poor and thin soil indicates that the popular solution to this problem among pre-Improvement Scottish farmers was not to create a deep topsoil in the manner of the plaggen system, but to create a raised cultivation area by redepositing soil.

Along with the evident complexity surrounding the role of turf in the Scottish manuring system, a second, but no less significant factor affecting not only the likelihood of deep topsoil creation but also its distribution throughout Scotland appears to have been the central role of seaweed as a manure in many areas. In coastal areas, the sandy margins immediately adjacent to the sea were often the most fertile, and were commonly cultivated as infield, particularly in areas such as the Hebrides, where light, well-drained *machair* soils are still a feature of the coastline (Smith 1994: 29). Documentary sources strongly indicate that in these areas, seaweed was preferred to animal manures as a fertiliser, partly due to its high potassium content, ideal for often potassium-deficient sandy coastal soils (*ibid*.: 128). This preference has been cited as a factor influencing the location of farm mounds and deep anthropogenic topsoils in Norse Orkney (Davidson *et al*. 1986). Early Improvement period records show that there was a marked preference for spreading seaweed fresh, unmixed with dung or other composted materials, seaweed only being composted itself in order to preserve an excess of material (Somerville 1796: 40; Sinclair 1814: 528). Ethnographic study has also indicated that heavy, bulk manures were also considered unsuitable for sandy machair soils, as these were too friable for the manure to bind and mix, and animal manure too wet for the light soil (Smith 1994: 100). Although it was therefore not unknown for seaweed applications to be composted in some way, either with dung or mixed waste material

(Fenton 1986: 50), it is clear that in areas where using uncomposted seaweed was the preferred manuring method, deep anthropogenic topsoils would not develop. Again, there is an indication that creating a deep topsoil was not seen as a priority: in contrast to the Irish coastal plaggen areas, the use of sea sand as a manure – which would have fulfilled the chemical and physical requirements of the machair soils as well as creating depth – was generally absent (Shaw 1980: 98). Neither is this a purely coastal, or Highland issue. Seaweed was heavily utilised in the southern coastal areas (e.g. FSA XIV: 462) and was valued as a manure highly enough to be transported considerable distances inland (FSA IV: 338; VII: 127; Fenton 1986: 53). This appears to have been largely as a result of the well-documented preference for seaweed as the best manure for the barley crop: barley (or bere) manured with seaweed was known as 'ware bear' which, although it produced a small sized grain, was associated with a much larger yield (FSA VI: 17) and was considered 'of double value' by brewers, as it ripened earlier (FSA XIII: 225). The popularity of seaweed manure and the likely effect of this on the development of deep anthropogenic topsoils is discussed further in Section 3.3.5.

From the above, it would seem that in the Scottish farming township of the pre-Improvement period, the creation of deep anthropogenic topsoils through a plaggen manuring system was seen as neither important nor easily achievable. Cultivation techniques indicate that a sufficient depth of soil seems to have been created through compost manuring coupled with soil redeposition as a result of the creation of ridge-and-furrow and lazy-bed features. Furthermore, documentary sources suggest that the stripping of turf, the essential component of the plaggen manuring system, was widely restricted, and in addition was possibly recognised by farmers themselves as detrimental to their essential resources of outfield and common grazing when practiced to excess. Finally, the preferred mechanics of manuring in coastal areas, by using mainly un-composted seaweed, would not have contributed to deep topsoil development. These factors are discussed further in Section 3.3.

3.2.2.4. Pre-Improvement: a failing system?

Much has been written on the economic and ecological viability of the pre-Improvement farming system, particularly in the Highlands and Islands. Discussion of this is only necessary here as it relates to manuring practice, specifically the use of plaggen-style manuring techniques. Dodgshon, in particular, provides several stimulating critiques which challenge the assumption that the pre-Improvement system was inherently unstable, arguing instead that aspects of the largely communal organisation of the farming township were uniquely suited to the specific climatic and environmental conditions of (especially) the Highlands, and that perceived disadvantages, such as the restricted cultivation pattern and high population density, could be seen as part of a finely-tuned risk aversion strategy (Dodgshon 1988; Dodgshon 1992; Dodgshon 2004). It is also widely recognised that several aspects of the pre-Improvement farming regime that were initially considered retrogressive by the Improvers, such as spade cultivation, were in fact well-suited to the areas in which they were used (Dodgshon 1988: 50; Smith 1994: 40).

Nevertheless, it is certainly the case that key environmental and economic factors created difficulties for the farming township during this period, and perhaps made the creation of deep topsoils an investment beyond their reach. Climatic conditions in the centuries leading up to the Improvement period were generally poor. The Little Ice Age saw a temperature drop of perhaps 2^{o}C between the thirteenth and the seventeenth centuries, the worst period being c. 1580 - 1650, with no clear recovery until after 1850 (Edwards and Smout 2000: 16). The concurrence of this with steady population growth meant that by the late 1700s, cultivable arable land per person was largely insufficient, and crop returns generally poor (Dodgshon 1988: 139). Occurrences of famine are a common theme of the First Statistical Account treatises. Such conditions would not have been generally conducive to deep topsoil creation: it appears that during these periods of poorer climatic conditions, arable cultivation was pushed into ever more physically marginal sites in an attempt to increase overall yields, with even shieling sites being turned into permanently occupied farms by the early eighteenth century (Dodgshon 2004: 3), and possibly earlier (Robertson 1799: 340).

Rather than the consolidation and improvement of existing lands seen in the Continental plaggen regions, the emphasis, in certain areas of pre-Improvement Scotland at least, would appear to be on the opportunistic, often forced expansion of a finite manuring resource.

3.2.3 The Improvement Period

In 1695, the Scottish Parliament authorised the consolidation of arable land held in the runrig system and the division of *commonties* – the uninhabited areas of land that were used within the farming township system as a source of grazing, fuel, and building material (Devine 1994: 1, 51). Although these changes were not effectively undertaken until the latter half of the eighteenth century, the advent of enclosure marks the beginning of the most effective and widespread change seen in Scottish agricultural history – the Improvement. One hundred years after the passing of these land tenure acts, oat yields in Angus and Lanark were triple their seventeenth-century averages (*ibid*.: 56), and 'the Lothians were treading on Norfolk's heels for the reputation of being the most advanced and productive agricultural region in Britain' (Smout 2002: 69).

Although the Improvement period in Scottish agriculture is most noted for the writers by whom the period is so well chronicled, the majority of the changes which revolutionised agriculture from the late seventeenth century on were brought about by events outside their sphere of influence. One such shift was that of the ruling class towards making their estates capable of producing a marketable surplus of both grain and livestock and thus profiting from an increasingly wide-ranging commercial economy, a move bolstered by greater political stability, especially in the Lowlands. There were no fortified dwellings built in the Lowlands after the 1660s, and in this new climate land began to be seen as 'an asset to be exploited rather than simply the basis of personal authority and family power' (Devine 1994: 1). The radical shift in the organisation of farming settlement in the Lowlands, away from the farming township and towards large, planned farms, is seen as early as 1649 in the plans of the West Gagie farmstead in Angus (Dalglish 2003: 141). One of the earliest major changes in the structure of the farming economy is the establishment of longer leases of tenure for farmers and the conversion of the traditional rents in kind (paid in produce) to cash rents. This last was a change of enormous import, for it introduced the tenant farmers themselves to market forces and to the concept of generating enough produce for export (Dodgshon 1983: 47). This, alongside the gradual process of land enclosure taking place throughout the eighteenth century, was to completely reorganise the farming system throughout Scotland. Enclosure itself appears to have taken place in a number of stages: initially in the stock-rearing areas of especially the south-west, with the enclosure of stock into parks and folds. Main farms on the estates were then gradually taken out of the communal farming system, becoming independent units and providing a basis for the trials of new cropping and stock-breeding techniques which, near-impossible to introduce within a joint-tenure system, were a key feature of the Improvement period. Finally, individual tenancies in the farming township itself were subdivided and the lands enclosed (Fenton 1976: 14). Here, perhaps, is the first strong body of evidence for Scottish farmers aspiring to the levels of autonomy and awareness of market forces apparently long facilitated in the Continental plaggen regions by the *beklem-regt* system of leaseholding (Section 2.1.4).

The Improvement period agricultural writers were thus a product of, rather than a catalyst for, this new atmosphere of investment and experimentation (see Dodgshon 2004: 17). This is illustrated in part by their preoccupation with the disadvantages of the traditional cultivation and manuring systems which still held sway in the Highland regions during the period in which the County Agricultural Reports and the First Statistical Account were compiled. Enthused by the evident success of efforts to increase agricultural productivity already underway in the Lowlands by the early seventeenth century, the Improvement writers largely act as advocates for the many significant technological developments that were already gaining a foothold in Scotland. There is thus a strong element of propaganda to these contemporary accounts of cultivation practices in the individual counties and parishes during the period c. 1785-1814 (e.g. FSA I: 255) and, as noted above, it is now generally recognised that many traditional farming techniques criticised by the Improvers represented appropriate solutions to cultivation in many areas, especially the Highlands and Islands (Fenton 1976: 1; Devine 1994: 2; Dalglish 2002: 489).

A detailed discussion of these changes is only relevant here insofar as they relate to changes in manuring practice, particularly the application of bulk manures. However, most of the key changes in farming technology introduced during this period would have had an indirect effect on manuring strategies. For example, the tile drainage systems developed during this period not only made large-scale reclamation of land possible, theoretically increasing the available area of land that would need manuring, but also over a relatively short period did away with need to create an artificial raised soil bed for cultivation in many areas, making ridge-and-furrow cultivation largely obsolete (Fenton 1976: 23). The introduction of new crops and new breeds would have also affected the mechanics of manuring. The advent of cash rents encouraged farmers - especially in the Highland areas where arable returns were significantly less than for their Lowland competitors - to concentrate on breeding cattle for market rather than on arable production from as early as the mid-seventeenth century (Coutts 1986: 64; Dodgshon 1998: 34), a change of emphasis which would certainly have affected the system of manure production and application in these areas. New crops, such as potatoes and turnips, also altered the traditional grain-based rotation which largely determined the allocation of manure resources discussed in the previous section. The most significant change, however, was the gradual development of large-scale commercial sheep farming and a complementary shift into improving the long-ignored pasturelands through the introduction of sown grasses. This was to largely eclipse arable production in areas such as the southern uplands through the eighteenth century (Dodgshon 1983: 54 ff) and begin the gradual process of pushing small tenant farmers out of the agricultural economy that culminated in the Clearances of the nineteenth century (Devine 1994: 3). The spatial distribution, as well as the nature of arable production, was changing.

However, the effect of these developments on the traditional system of manuring through bulk organic and mineral materials is largely masked by the final significant change in agricultural technology of this time: the advent of artificial manures. The burning of lime for use as a manure was practised increasingly from the early seventeenth century in areas where both lime and the coal to burn it could be accessed (Fenton 1976: 14), a manuring method which improved soil quality to such an extent that large areas of previously outfield land could be brought into cultivation (Devine 1994: 3). The arrival of lime, coupled with the improved transport links of the eighteenth century, paved the way for a vast array of ‘exotic’, off-farm manure materials to come into use which, usually boosted to efficiency through being composted with lime, pushed traditional bulk manuring methods further into the background. Many of these were by-products of the expanding industrial sector, such as coal ashes, soap ley, woollen rags, and leather parings (Smout 2002: 72). The huge variety of manures of this type is discussed in Section 3.3.7.

The use of lime as a manure undoubtedly drastically changed the system of fertiliser application throughout Scotland, effectively ending any dependency Scottish farmers may have had upon the bulk manures that contribute to deep topsoil development. However, documentary sources indicate that not only did lime use not in any way replace organic manures during the Improvement period, it even appears to have acted as a catalyst for a greater awareness of the importance of mixing different manure types to maximise soil fertility which, paradoxically, focused greater attention on the use of bulk manures to balance the powerful effects of lime (Marshall 1794: 36). The role of lime in the history of plaggen-type manuring in Scotland is discussed further in Section 3.3.6.

Despite the rise in productivity associated with the Improvement period, many of the changes which took place during this time proved a mixed blessing for the ordinary farmer and township. Resistance to the process of enclosure and subsequent loss of land access among farming communities is well documented (e.g. Nicolson 1972: 118 ff), although there is evidence that many townships were divided through choice long before the eighteenth century (Dodgshon 1977: 63). In the Lowlands and the north-east region, the consolidation of land into larger, often specialised farms gradually displaced the traditional system of steady, year-on-year work for families of sub-tenanting 'cottage labourers' in favour of the use of short-term, more specialised workers such as ploughmen, often young, unmarried men who were housed in 'bothies', or bunkhouses (Gray 1984: 14). The Improvement period writers noted this trend, and pointed out that this created a less stable, and therefore less reliable, agricultural workforce (Donaldson 1794a: 133). The subtenant population, consisting of families who, as the poorest economic group in the farming township, often relied on small-scale *kailyard* cultivation to survive, were pushed into increasingly marginal areas of land. No longer a part of a communal farming system, this sector of the population were left largely to fend for themselves in the small 'crofts' that they cultivated (*ibid*.: 19). As large-scale farming became ever more specialised, this ghettoisation of the sub-tenant class is seen throughout many Lowland areas (Robson 1984: 88; Devine 1994: 136), and is likely to have displaced many small-scale, traditionally manured arable land patches.

In other areas, Improvement period pressure upon the peasant farmer came in another form. In the second half of the eighteenth century, the processing of seaweed to produce kelp, a source of potassium and iodine salts that was used in the glass and soap industries, became an important source of income for the estates (Fenton 1978: 58). Kelp processing was based around areas where large quantities of seaweed were thrown up by storms, mainly western Scotland, the Northern Isles and western Ireland (Bell 1981: 117). Concerns that this industry used seaweed that was needed for manure are voiced by the Improvement writers (Heron 1794: 92) - although a closer looks at the specifics of seaweed manuring systems as presented in the documentary sources indicates that this may not have been the case (see Section 3.3.5). Although kelp production was a short-lived industry, it, along with the continuing expansion of commercial sheep-farming, led to drastic changes in the distribution of farming communities in these areas, and ultimately to the creation of the crofting system of farming still pursued in areas of the Northern and Western Isles today.

The crofting system was a radical and often harshly imposed change in the pattern of land tenure implemented by estate owners seeking both to clear large areas of arable and pasture for large-scale sheep farming, and to maintain a tenant population based around the coast in order to utilise labour, mainly for processing kelp (Smith 1994: 57). The runrig system in these areas was finally dismantled as individual holdings were created for this purpose, and although longer leases were presented as an incentive to small farmers to move to this new system, in reality, the kelp industry placed increased pressure upon these tenants by absorbing labour needed for farming as well as removing certainly a part of their seaweed resource, while the profits created by the industry went of course to the proprietors (Fenton 1978: 59). In other areas of the Highlands, however, the situation was worse: this late-eighteenth century period is notorious as that of the Clearances, where in many areas whole townships were forcibly dispossessed by estate owners in order to use the land for sheep-farming, often without realistic alternative settlement and land provision (Smout 1969: 331).

Individual crofting tenancies were deliberately small, and rents were increased, so that farmers would be obliged to take work in the kelp or other associated industries (Dalglish 2003: 229). When kelp and cattle prices dropped following the Napoleonic Wars, conditions for the crofting population became dire, worsened by the potato blight of the mid-nineteenth century (Grantham 1996: 226). Public concern for the standard of living endured by crofting farmers led to the establishment of the Napier Commission in 1884 and the eventual creation of the Crofter’s Commission, which ensured fair rents and security of tenure for crofters, an organisation which continues to this day (Nicolson 1972: 116; Grantham 1996: 226, and see Willis, 1991).

To summarise, while the Improvement period may not have sounded the death knell for the use of traditional manure materials in Scotland, in terms of security and organisation, it is difficult to imagine the conditions which fostered those elements of the plaggen manuring system seen in the historical record still in evidence throughout the Improvement period in the communities within which we might expect traditional regimes to continue. Meanwhile, the intensively-farmed and highly productive arable centres, mainly concentrated in post-Improvement southern Scotland, are likely to have owed this productivity not to the use of bulk manures, but to the introduction of lime and other ‘artificial’ manures.

3.3 Manure materials and methods documented in Scotland in the post-medieval period

During the different historic periods discussed above, a huge number of materials were in use as manure material throughout Scotland. The preceding sections have mentioned the most significant of these, mainly the animal dung, seaweed and mineral manure combinations that, prior to the Improvement period, were relied upon by the vast majority of farmers, and the use or disuse of which would have determined the formation of deep anthropogenic topsoils. The following section looks at each of these core manure types in greater detail, and uses evidence from documentary sources to examine more closely the factors identified in Section 3.2.2.3 which may have affected the development of deep anthropogenic topsoils in Scotland.

3.3.1 Animal manures

Along with seaweed, animal manures were the backbone of the manuring system throughout all areas of Scotland prior to the Improvement, with farming leases often specifying that the farmer was '*to lay the whole dung he makes upon the farm*' (FSA XIX: 521) and even some ministerial stipends including dung provision (FSA X: 613).

While cattle dung was the most plentiful and therefore the most widely used of these, it was popularly ranked below other dungs, such as poultry, pig and sheep, as being poorest in nutrients and also a 'cold' manure, slow to ferment, at least partly due to its high water content (Fenton 1981: 211). Only one Improvement period report ranks cattle dung highly (Anderson 1794: 108). For this reason, cattle dung was almost always preferred as a compost. Typically, this would comprise materials used in the byre as bedding, and this mixture would sometimes be removed to an outdoor midden and composted with additional materials prior to spreading on the fields, or occasionally spread straight from the byre, the dung having been composted by long periods during which cattle would be stalled at night and fresh bedding added at intervals until the byre was full (Nicolson 1978: 56; Fenton 1976: 11; Dodgshon 1998: 204). Bedding materials, though usually mainly made up of some turf-based component (see Section 3.3.3), were many and varied, and documentary and ethnographic evidence clearly shows that great care was taken to use, and often prepare, specific materials as byre bedding with the intention of creating a good quality compost (e.g. FSA XVI: 186-7; XIV: 240). Ethnographic evidence from Shetland lists a variety of basic bedding materials which were stored for use as winter byre-bedding, such as turf, or *truck*, pared from the common grazings and piled in heaps known as *moldie-kooses*, light mossy earth which would be kept in storehouses near to the byre, 'mould', or the dry upper surface of bare peatland, and quantities of grass and short heath which would be cut in the summer, carried to the farm when dry and stacked like hay until needed for the byre. Ash from household peat and turf fires would also be saved for this purpose. These materials would be applied to the byre in such a way as to create a well-mixed compost. Grass, hay and turf would be bedded below the cattle and a layer or *sloo* of dry peat mould, and then household ash, would be spread at intervals to create a sandwiched mixture of ash, turf, mould, dung and grasses which would be raked and levelled, but kept within the byre until the heads of the cattle were almost touching the roof (Fenton 1978: 281; Heron 1794: 28). In this way, the high water content of the dung would be absorbed, and the entire nutrient waste from the cattle utilised, as not only the dung but the urine would be retained for fertiliser. Such arrangements were quite deliberately made: the construction of byres through the pre-Improvement period, and definitely later, highlights the evident priority given to conserving and maximising the animal manure resource. In Lewis, for example, a hole was deliberately constructed in the byre floor to collect run-off urine for the midden (Smith 1994: 99), and up until the nineteenth century, the byre-end of some Hebridean blackhouses were built of loose stone or even turf, so that they could easily be opened up to remove the manure (Fenton 1981: 214). In eighteenth-century Perthshire, clods of moss would be laid in the '*straw-yard, to form a compost with the dung, by the treading of cattle*' (Robertson 1794: 31) in a manner not dissimilar to that described in Denmark using *traek* (Section 2.1.2).

A second composting procedure would often be undertaken once the material was removed to the outdoor midden, especially in areas where seaweed was used. In Shetland, *slooin a midden* involved creating a compost consisting of layers of this byre manure with earth and seaweed. The variations on this are endless: rotten seaweed instead of fresh, cattle dung alone with ashes, *feal* (thick-cut earthy turf sods) alternating with moss-turf (Fenton 1978: 281), or sandy peat mould (Fenton 1981: 215). In short, almost any waste material is recorded as being added to the compost midden, such as grain chaff, household sweepings, the remnants of turf dykes and roofing thatch, and even food remnants such as fish and bones (e.g. Fenton 1987: 18; Dodgshon 1988: 146; Smith 1994: 99; and see also below).

The central importance of conserving dung and making dung-based composts is a theme of the Improvement period agricultural literature. Rather than this being a period in which traditional methods were eclipsed by the introduction of artificial fertilisers, the Improvement period writers stress the value of '*putrefying manure*' and bemoan the apparent lack of interest shown by the farming population in the proper conservation and composting of dung (e.g. Anderson 1794: 107; Ure 1794b: 31; Buchan-Hepburn 1794: 85; Somerville 1796: 20). Improvement treatises on composting invariably stress the importance of the fermentation process to the quality of manure created, advising on compost recipes for different purposes, the shape of the dunghill, its position on level ground, and its protection from the elements and treading by animals (e.g. Somerville 1796: 24-33). Documentary sources from the Improvement period repeatedly cite similar byre composting systems, almost all of which list a mixture of turf, moss earth (or peat) and often ash or vegetable material, as the foundation materials for a dung and mineral compost (e.g. Johnston 1794: 23; Sinclair 1795: 21; Robertson 1808: 239).

However, it would appear that this does not equate to an Improvement-period push towards the creation of plaggen-style manuring composts. The recommended proportions of dung to mineral are, as seen in the pre-Improvement period, more equally balanced than those of the plaggen regions, with binding materials containing ‘more animals and vegetable matter’ than ‘salts and earths’ (Somerville 1796: 11). Some Improvement writers criticise the housing of cattle as likely to make the animals less hardy (Aiton 1814: 48), and some go so far as to dismiss the entire process of including mineral bulk in composts, preferring more easily handled compost materials (Fordyce 1796: 31).

Most of all, evidence for dung management from both the pre-and post-Improvement periods strongly suggests that composting dung through the addition of large quantities of turf, in the manner of the plaggen system, was simply not undertaken. The handling of such a quantity of turf would represent a huge expenditure of time and energy, most likely requiring a well-organised and communal effort that would certainly be a feature of contemporary sources discussing the dung-based manuring system. The reasons for this are discussed further in Section 3.3.3, but it is clear that the widespread and well-documented procedure of creating dung and mineral based compost middens in post-medieval Scotland does not provide a strong indicator for the creation of areas of deep anthropogenic topsoil.

Other animal dungs, though less plentiful, were also used in Scotland, and were often earmarked for particular crops. Horse dung was especially highly rated, and considered the most valuable animal manure after that of poultry and sheep, a ‘hot’ manure, suited to damp, acid land (Fenton 1981: 211). This is in contrast to the classical authors, who rated horse dung poorly (*ibid.*: 210). In the Hebrides, horse dung was reserved for the demanding (and valuable) potato crop

(Smith 1994: 107), and considered to be superior because it was free of straw (*ibid.*: 99). Given that sheep manure was also rated highly, it is perhaps curious that little effort seems to have been made in many places to collect their manure. Apart from the folding of sheep on (usually) outfield land, the only system frequently mentioned for the collection of sheep manure was the lamb-house, which would be bedded to create a compost from the dung in much the same way as in the cattle byre (Donaldson 1794b: 14). This may, however, be a quirk of the data: in Aberdeen, it is recorded that sheep '*are universally housed for the greatest part of the year during the night, and the dung thus produced is accounted a very valuable manure*' (Anderson 1794: 108). Reports of pig manure are rarer, but poultry and especially pigeon manure seems to have been highly rated, and is frequently mentioned in Improvement period and earlier reports (FSA XIX: 497; Woodward 1990: 262, Dickson 1770: 378, Sinclair 1814: 545). Rabbit droppings are described as even more effective (Somerville 1796: 34). The Improvement period writers advocate mixing a range of dungs of different properties in composts to aid fermentation (Sinclair 1814: 515).

Dung, of course, was also used as a fuel source in areas ranging from Orkney to as far south as Galloway (Fenton 1985: 96). Where this practice is documented, it appears that seaweed was commonly used as a source of manure, and it must be concluded that in areas where this was commonly practised, deep topsoil development would have been limited.

3.3.2 Human manure

Human waste, often referred to as town-dung or night-soil, is considered by Improvement period writers as '*perhaps the richest of all manures*' (Somerville 1796: 34). Given that there seems to be little prejudice against the use of human waste, we can assume that in many places this rich fertiliser source would have been eligible for inclusion in the dunghill along with every other recyclable material. However, human waste tends only to be mentioned in the records in the vicinity of larger towns, where considerations of carriage and disposal come into play (e.g. Dow 1791: 341; Robertson 1799: 33; Sinclair 1814: 525-6), though in all these reports, the material is highly rated. Human manure seems to have increased in value with the Improvement period in Scotland, with several reports of town authorities charging high prices for the waste which they had previously paid the farmers to remove (FSA XVIII: 362). Despite this, there are relatively few references to its use. Neither can the terms ‘town-dung’ or ‘night-soil’ be confidently identified with purely human manure: the terms include ashes and street sweepings, and also horse and cattle manure from town-based inns (Sinclair 1814: 525).

It is possible, however, that the use of large amounts of human waste may have encouraged the development of deep anthropogenic topsoils in localised areas around larger towns and cities. Due to its richness, human manure is recorded as being composted with proportionally larger amounts of composting material in comparison to animal dungs, for example ‘*two cart-loads of ordure mixed with ten loads of earth, and one of lime*’ (Somerville 1796: 35). Improvement period reports note that town-dung areas are ‘*gradually enriched, to the distance of six or eight miles, (beyond which distance town-dung can rarely be profitably conveyed)*’ (Sinclair 1814: 525), a fact also noted by the First Statistical Account authors (FSA XII: 510). It seems likely that in areas where this favoured dung was available it was probably heavily utilised – certainly several parishes near to large urban centres describe themselves as being reliant on this manure source (e.g. FSA XIX: 585; XIV: 452). In such areas, as long as mineral manures were freely available, a manuring system with a mineral input more comparable to that of the plaggen regions may have been in operation, with an emphasis on the importing of urban waste similar to that seen operating as part of the Continental plaggen system (Section 2.1.3).

3.3.3 Turf and peat based manures

Turf, the other main component of the plaggen system alongside dung, appears with regularity in the documentary sources as a manure material in both the pre-and post-Improvement periods. However, its use was often a point of contention. It is very likely that the prejudice against using turf as a manure, seen in both the pre-Improvement historical records and in the writings of the Improvers themselves, would have been one of the key factors limiting the development of anthropogenic deep topsoils in Scotland. Whereas the careful construction of composts is encouraged as vital to good manuring practice, the cutting of turf specifically for use in these composts – the backbone of the plaggen system – is universally discouraged as a ‘*miserable and* *destructive*' practice (Somerville 1796: 45) for the damage it undoubtedly did to the pasture lands:

> '*the manure principally used… is feal, or the sward of the commons; the cutting of which is a practice disgraceful to the husbandry of the country, and attended with infinite loss to the proprietors. On some farms, occupiers have destroyed as much ground in this manner, as the surface of the fields they lay it on…The ground, when the surface is thus taken away, will yield no grass…*' (Sinclair 1795: 202).

And, on a lighter note:

> '*The quantity of pasture grounds has been considerably reduced or destroyed…by the general practice of cutting* feal *and* divot, *or turf…This drew a pleasant sally from an English gentleman, some years ago. Observing a herd of meagre cattle here, gleaning a scanty subsistence on a naked spot, while every cottage was built of feal, and thatched with divot, he sarcastically remarked, that ''though Sutherland was not destitute of stones or grass, ''the people chose to build their houses of the latter, and leave their cattle to feed on the former!''*' (FSA VIII: 6-7).

Restrictions on turf cutting in the pre-Improvement period are closely linked to the practice of 'paring and burning' as well as to cutting turf for the byre. Paring and burning was a fertilising technique in which the top growth of an area of grass or other waste land – or even lazy-beds (FSA XV: 500) - was cut and burned, and the ashes spread over the burned area as a fertiliser (FSA XVI: 120). The issue of paring and burning runs through the County Agricultural Reports of both Scotland and England, and earlier agricultural treatises (e.g. Dickson 1770: 423-4) with authors divided as to whether the technique caused more harm than good (see Woodward 1990: 261). Generally, there is agreement that while waste land '*with a tough sward of grass upon it*' (*ibid*.), or covered with '*useless grasses, or small shrubs*' (Rennie, in Sinclair 1814: 403) or '*where there is a rough and barren surface, over a fertile loam or clay*' (Sinclair 1814: 9) can be improved by paring and burning, '*the supposed benefits resulting from the practice of paring and burning are too often counterbalanced by the evils which it occasions…a temporary stimulus…those articles which are* *carried off during the process of combustion, an irreparable loss is sustained*' (Somerville 1796: 82).

Such opinions voiced a prejudice that, by the time of these writings, already had legal backing. Although the practice of paring and burning appears to have been widespread in pre-enclosure Scotland, laws against cutting turf for both this purpose and that of making manure were established as early as 1685 (FSA XV: 456; Anderson 1794: 57, and see Fenton 1986: 107) and were implemented country-wide. By the eighteenth century, paring and burning seems to have been only rarely used (Fenton 1970: 169) and Improvement period writers were advocating cheaper marl and lime provision, '*so as to render the use of* feal *or turf perfectly unnecessary*' (Sinclair 1795: 218).

How greatly would this situation have affected the amount of turf material going into the byre? Sources indicate that there were other, and legal, ways of channelling mineral bulk into the dunghill. An important turf manure source seems to have been that commonly used as building material for both houses (mainly as roof thatch, but also often in wall construction) and field dykes (Dodgshon 1994: 89). Turves cut for field dykes, in particular, were characteristically thick and earthy, cut with a specially shaped *flauchter* spade (Fenton 1970: 57) and known as *feal*. When *feal-dykes* were replaced, this bulk was added to the midden compost, or deliberately ploughed into the fields (FSA X: 180), as '*it was observed that the crop was always strongest on those parts of the field, on which the earth that had composted the fold dyke was spread.*' (FSA X: 486). Likewise:

> ''*…(from) the swarded surface of the ground, cut into the form of large bricks, they make houses and offices for themselves, covering them with the same swarded turfs, cut thinner and resembling slates in their form. Once in three years, all the earthy part of these houses is thrown on the dunghill, and new houses built again of the same materials*'' (FSA VIII: 375).

Roofing thatches would have been replaced on a regular basis, even annually (Dodgshon 1993a: 423; Smith 1994: 124) and this material would also have found its way into the midden (see

Sinclair 1795: 141). There is evidence that turf utilised for these purposes was officially exempt from the restrictions governing turf cutting. The Coupar Angus Rental of 1464 reminds tenants of the Abbey lands that they were not permitted to '*upturn the meadows or pasture lands for their divots* (turves), *except only for repairing of houses*' (RCAHMS 1994d: 117). (Note the early date of this turf cutting restriction). It would seem that despite a long history of restriction on turf cutting for manure, this valuable source of bulk manure could still be accessed through the recycling of 'legal' turf materials, and that farmers were aware of the advantages of this. Despite having an abundance of stone for building, it has been noted that eighteenth-century Highlands and Islands farmers deliberately chose to build perishable, turf-based houses - possibly explained by the fact that these houses were designed partly with the needs of the midden in mind (Dodgshon 1993a: 423). The relationship between these practices and the dearth of surviving rural settlement remains from, especially, the Medieval period in Scotland has recently been considered with reference to the use of soil chemical analysis as a means of identifying such settlements (Banks and Atkinson 2000: 70-72).

However, even the most diligent recycling of these materials would not have resulted in anything like enough turf-based material going into the midden as would be needed to create a deep topsoil. In addition to this, the Improvement period records show a growing prejudice against turf-based construction methods, comparable to that against turf manuring, and probably also prompted by concerns at the effect of turf removal on pasture land. Turf-roofed houses are '*the worst possible*' (Bell 1814: 262) and '*ought to be prohibited*' and the turf replaced with thatch or straw (Sinclair 1795: 264). Feal dykes are also condemned as inefficient and liable to spread weeds (Ure 1794b: 22) and farmers urged to replace them with stone (Johnston 1794: 48; Skene Keith, in Sinclair 1814: 307). By the time of the First Statistical Account, restrictions on cutting turf for building purposes saw smaller farmers resort to clay and straw for thatching (FSA III: 272).

Another means of turning turf into manure was through fuel residues, and ash was an important source of manure in both urban and rural areas. In some areas of Shetland, turf with a mixture of gritty clay was deliberately burned in the house fires to increase the quantity of ashes for the byre (Fenton 1978: 281). In the Highlands and the Northern Isles, a hearth would often have a hollow in the floor beside it, created by the repeated scraping out of peat ashes pushed aside from the fire. In Orkney, the hot ashes were pushed into a circle of wet, sandy peats, which the hot ash would gradually burn to powder, before the whole mixture was taken to the byre (Fenton 1981: 211). Later versions of these ash-holes, or *leepies*, could be up to three feet deep and six feet wide, and similar structures have been found in farms in Aberdeenshire and Dunbartonshire (*ibid.*). Documentary sources indicate that ash was a preferred manure in certain circumstances, for example in the plantiecrues which housed the young kail plants, which would be dressed with 'a mixture of clay and ashes' (Fenton 1978: 103).

Although perceived as a second-class fuel source, used by those who could not afford peats or, increasingly, coals (e.g. FSA XVII: 387; III: 229; IV: 122) turf was widely used for fuel in pre-Improvement Scotland and, in areas where peat was scarce, was often the main fuel. However, documentary sources suggest that turf was also burnt through choice, with even a parish as near to coal supplies as Lanark apparently still faithful to this '*absurd custom*' (FSA XVIII: 177). Manure provision is clearly recognised as one of the advantages of using turf in this way:

> '*The turf is procured by setting fire to the grass and heath…This practice greatly injures the moors by depriving them of their verdure…The loss, however, is in some measure repaid by the great quantity of ashes for manure, procured from this kind of fuel*.' (FSA XVI: 120).

Here there may be parallels with aspects of the plaggen system: in Denmark, a key part of the heathland-to-infield turf cycle operated by way of the domestic hearth, with turf ashes recycled to a household ash midden before being incorporated into the plaggen dunghill and spread on the fields (Gormsen 1991: 110). Far from being an inferior fuel, heather turves were here preferred to peat as they burned slowly, keeping the fire going throughout the night (Lerche 1970: 151). Interestingly, Scottish sources show an awareness of turf fuel use on the Continent:

> '*As soon as the Dutch have sown their spring corn, they begin to prepare the turf for winter fuel. They…squeeze the mud, while soft, into round forms, resembling*

loaves,…and then let them dry the fields…' (FSA XI: 463).

Nevertheless, by the time of the First Statistical Account, not only were turf fuel supplies running short in certain areas (FSA IX: 46), but prohibitions upon cutting turf even for fuel were beginning to take effect in Scotland, sometimes causing great hardship:

> '*…great distance from coal, and a total want of every other species of fuel. This is a real calamity to the poor; and most heavily felt by them since they were, some years ago, all prohibited from casting turf on the moors. Every cottager used to have liberty from his master to cast a* darg *or two of turf*.' (FSA XIX: 129).

Aside from the economic considerations affecting turf use, is interesting that the disapproval of the Improvement period writers was not only related to the removal of the turf, but also to the *addition* of bulk material as a manuring strategy in itself:

> '*to pare the Moorish and uncultivated parts of the farm, and make the turf into composts. This is certainly a pernicious practice, as it robs those parts of soil where it is scanty, to accumulate it in others; where perhaps this species abounds too much*'. (Headrick 1796: 34).

Improvement period records, whilst encouraging the formation of bulk manure composts, in many instances specifically discourage the incorporation of turf and peat within these. There is a perception that 'moory' (or peaty) earth '*proves a poison to any soil on which it can be applied*' (Anderson 1794: 107), and that this is largely due to its *mineral* content:

> '*moorish or mossy ground, which is very often of a very poor quality, and sometimes impregnated with mineral particle, and consequently injurious to vegetation; yet the common farmers will carry this beggarly, and sometimes noxious stuff, for miles, on the backs of their little horses*' (Sinclair 1795: 130).

Turf is similarly vetoed for composting: '*feal…impregnated with mineral substances* (is)…

noxious to vegetation' (*ibid*.: 202). While a certain measure of bulk is acceptable, Improvement writings go on to urge caution in applying too much earth material to a compost, as excessive weight is apt to compress the dunghill, impeding the circulation of air and thus the fermentation process (Headrick 1796: 5; Somerville 1796: 12). By contrast, studies from the plaggen regions report that dunghill content was generally 5-6 times more turf and earth than animal dung (Stoklund 1999: 210).

It must be concluded that for a plaggen-type manure to be created, more turf than could be produced either through recycled farm building materials or fuel residues must have been composted, especially given the restrictions eventually imposed on both of these practices. This returns us to the situation of cutting turf straight from the hills for use in the byre. The historical records surrounding turf cutting in Scotland, coupled with evidence from the plaggen regions, would suggest that deep anthropogenic topsoils may possibly be restricted to areas within which restrictions on cutting turf from pasture grounds were either not implemented or were ignored. This is supported by evidence from the recorded plaggen soil area of Papa Stour, Shetland, where peaty turves were taken from the available grazing until the whole area was scalped (Fenton 1978: 223). The association between *high-intensity* turf removal and the location of deep anthropogenic topsoils is strong, and therefore the restrictions on turf removal seen throughout many areas of Scotland is likely to have been a serious bar to the creation of plaggen-type deep topsoils.

The only recorded Improvement-period innovation which may have *encouraged* bulk mineral compost additions is seen in the early nineteenth-century interest in the conversion of peat ('moss earth') into a bulk manure source (Aiton 1805; Sinclair 1814: 191). Various composting recipes neutralising the negative effects of the insoluble mineral portion of the moss in order to convert it into a manure source are given in several reports (e.g. Somerville 1796: 47; Headrick 1796: 34). Possibly an attempt to wean farmers from the use of the more precious turf resource, this is more likely to be a result of the desire to remove peat areas as a part of the improvement of waste grounds for pasture. It is unlikely that these recommendations would have led to a great increase in the large-scale composting of peat, especially give the fact that areas with a large peat resource tended to rely on this as fuel. In some areas, peat sources had already been exhausted and the inhabitants had turned back to turf cutting to supply fuel, and we can assume that in such areas neither substance would have been readily available for the dunghill (Fenton 1986: 106).

3.3.4 Soil and parent material manures

Soil, sands and gravel as manures in their own right, or added to composts, were popular in both pre-and post-Improvement Scotland. Although there is a certain confusion of terminology in the documentary sources – there are, for example, many references to 'earth' when it is clear that turf or feal is being discussed (e.g. Headrick 1796: 5), it is evident that these materials were used on a large scale, and often as part of a well-organised system:

> '*This earth is sometimes brought from a distance, where it can be spared from a deep soil: at other times it is taken from a ridge in the same field where it is to be spread…the ridge from which the earth was taken, is afterwards very well limed and dunged, to make up the loss of the earth'* (Ure 1794a: 33).

Despite this, the large-scale use of earth generally attracted the same disapproval associated with turf cutting: '*Digging pits into the ground…retards the improvement of the country. This cold sterile mixture enlarges the quantity* (of manure) *indeed, but debases the quality of the dung, by its deleterious qualities, and throws up a variety of weeds…*' (Robertson 1808: 342-3). The digging of pits, which left large areas unusable as pasture, was especially disliked (e.g. Sinclair 1795: 58; 123; Robertson 1808: 112). However, although the use of such materials would seem to indicate a system that would lead to deep topsoil development, a closer reading of the documentary sources indicate that in many cases, applications of soil were taken from areas of the same, or adjacent, fields that were to be manured, creating an overall system of soil redeposition (not unlike that seen in lazy-bed creation) rather than large-scale topsoil augmentation (Sinclair 1795: 100). This method was preferred as it did away with the necessity of carting in the earth (Ure 1794a: 61) and early Improvement period reports urge farmers to site their dunghills in the fields that they were to manure so that 'the earth is at hand, and can easily be thrown on the dunghills' (Dickson

1770: 450). This indicates the very localised nature of this kind of manuring system – presumably, the concern was to provide earthen manure for individual ridges rather than to increase the topsoil depth throughout the entire area.

Despite the criticism that *removing* earth attracted, the Improvement period writers were generally positive about the concept of fertilising land through the use of certain soils and parent materials. In particular, the notion of using one soil type to counteract the properties of another was popular, for example, to manure clay soils with sand, and mossy areas with gravel (Somerville 1796: 12) and was certainly in use in the Improvement period (FSA XIX: 544). '*Virgin earth*' was also recognised as a useful addition to an exhausted soil '*at least for one season*' (Somerville 1796: 44). There is even a report from the parish of Forgandenny in Perth that it uses no manure, as the colluvium from the hillsides serves this purpose well enough (FSA III: 302). Many of the Improvement period reports draw special attention to the properties of mud, or 'sleech' from the sea (FSA I: 194; Somerville 1796: 43; Sinclair 1814: 530). In more recent periods, this has been associated with land reclamation, especially in peaty areas (Smith 1994: 38). 'Sea-sand' is also occasionally mentioned as an alternative to lime in coastal areas (FSA VI: 24; and see Section 3.3.6) and the use of this as a manure in Cornwall is mentioned, though not with reference to deep topsoil creation (FSA 20: 543).

Though it is possible that the application of this class of manures in Scotland could have led to the development of deep topsoils, it is more likely that the addition of soil, clay, mud, sand and gravel are more closely associated with the localised redeposition of land in order to create deeper individual cultivation features. It must be remembered, however, that there is a sliding scale between a redeposited soil of this nature and a deep anthropogenic topsoil: a lazy-bed, or an enhanced ridge, continually manured and the manure ploughed or spade-dug in and mixed, will have many of the characteristics of a deep anthropogenic topsoil with regards to the retention of cultural information.

3.3.5. Seaweed manures

Along with dung, seaweed appears to have been the key manure resource available to pre-

Improvement Scottish farmers, and one that the documentary sources record an extensive, and sometimes dramatically strong preference for:

> '*Even the dung of their cattle, which is at their hand, and which is generally considered as an excellent manure, rather than be at the pains to carry to their fields, they in some places throw into the sea, by way of a peace offering to Neptune, in order to render him propitious in casting ashore for them plenty of sea-weed, which is the only substance they consider as a valuable manure*.' (FSA XVII: 229).

Although the actions of these farmers – in the parish of Shapinshay, Orkney – appear incredible, this account illustrates not only the preference for seaweed as a manure, but the widespread opinion that other manures – especially the 'heavier' manures such as dung and bulk mineral material – were actively unsuitable for sandy coastal soils, and there are other reports of dung being left, in piles, unused on the beach (Fenton 1978: 281). Certainly there is some validity in this: seaweed is a hugely valuable manure, equivalent to animal dung in nitrogen content, and twice as rich in potassium (Fenton 1986: 48). As sandy coastal soils – such as the machair areas of the Western Isles (Smith 1994: 109) - are often potassium-deficient, seaweed was an appropriate and successful manure for such areas (e.g. FSA XVII: 285; X: 462; XIX: 627). By contrast, especially in the machair areas of the Western Isles, dung was considered too wet and heavy to 'bind' correctly with these light, friable soils (Smith 1994: 99). Another advantage of seaweed was that, unlike dung, it did not spread weeds into the arable areas (Dickson 1770: 429; Fenton 1986: 50). However, while seaweed is often cited as giving greater returns than dung, this is difficult to quantify: the only historical account to directly compare the two is the First Statistical Account report from North Uist, which concludes that seaweed, although 'better', does not enrich the ground as much as dung (FSA XIII: 305). The preference for seaweed was also not confined to sandy soil areas: seaweed also praised for its success on '*wet clay land*' (FSA II: 52) and its '*salts and juices which promote vegetation*' (FSA XVII: 211) were valued for treating poorly drained ground:

> '*Every kind of sea-ware is used for manure, and is found to answer the soil best, probably from the great quantity of salt, sea-ware contains, and the cold nature of the soil.*

Sea-ware is the only manure that answers mossy ground.' (FSA Vol. XIV: 181).

Seaweed was also preferred for the attributes it gave to the crop. Seaweed was used as animal feed in many areas (e.g. FSA VIII: 367), even being taken to the shieling sites as feed for the summer (Bell 1982: 118), and the preference of cattle and sheep for seaweed manured grass is noted – that it 'acts as a condiment' (Sinclair 1814: 528). Unlike midden material, seaweed is also associated with manuring of the oat crop (Fenton 1978: 275). But most importantly, seaweed was preferred to dung and composts for its perceived effect on the precious *bere* or barley crop. Bere manured with seaweed was known as '*ware bear*' which, although it produced a small sized grain, was associated with a larger yield (FSA VI: 17) and was considered '*of double value*' by brewers, as it ripened earlier (FSA XIII: 225), and crucially, though seaweed was valued throughout the year, there was a perception that:

> '*at the time of sowing barley, it is considered at least of double value; partly owing to its being, as they say, ripe at the season, having the strongest manuring quality, and partly to its efficacy in producing fine crops of barley, both in quantity and quality…*' (FSA XIII: 224).

The seaweed resource was so important that in some coastal areas, extra horses were maintained specifically to cart seaweed when storms threw large quantities of it ashore (FSA VI: 318; Fenton 1978: 275), and, with some reports from larger parishes stating that '*most parts of the parish'* (FSA VIII: 147) were fertile as a result of seaweed manuring, there is some indication that such transportation may have gone considerable distances inland (FSA VIII: 147). Coastal gathering rights to seaweed were jealously guarded (FSA 6: 281), and seaweed-manured land attracted higher rents (FSA Vol. 16: 515).

Although there was certainly a popular perception that seaweed was best spread fresh from the sea, used alone, rather than left in midden heaps or in dunghills – '*better unled than unspread*' (Sinclair 1814: 528), a closer look at the documentary sources reveals that the picture is more complex, and that seaweed was often in fact both composted before application and used in conjunction with other manures. Much of the reason for this appears to have been practical: in areas where seaweed was applied fresh, directly to the crop, the manuring strategy was necessarily dictated by the weather and the amount of seaweed that was washed ashore at individual times. Although many areas appear to have taken some control over the seaweed resource by placing it in heaps to rot before spreading (FSA XIV: 173), this situation may not have been ideal. The Improvement period writers generally agreed with the preference for using fresh, uncomposted seaweed, stating that it lost its efficacy if left in heaps (Sinclair 1814: 528).

Furthermore, as a huge amount of seaweed was required for manuring – one arable acre required as much as two hundred creel loads (Dodgshon 1992: 178) - seaweed often *had* to be used with other materials: in Shetland, seaweed was applied in winter, spring and again through the midden when this was spread (Fenton 1978: 275). Composting is thus seen to be an effective means of *preserving* excess seaweed for later use (Somerville 1796: 41) and it is this need to maximise manure resources that may provide a link between seaweed use and the potential development of deep anthropogenic topsoils in these areas. The County Agricultural Reports, in particular, record that seaweed was generally one of a suite of manures (e.g. Ure 1794b: 37; Graham 1814: 316), and certainly by the time of the County Agricultural Reports, there are frequent mentions of seaweed composts (e.g. Donaldson 1795: 32; Robertson 1808: 112). Despite the prejudices of the farmers, it is likely that bulk manure and seaweed composts were in fact successful as, due to its lack of lime and phosphates, the long-continued use of seaweed alone would certainly have been as detrimental to the soil as heavy manure applications were imagined to be (Fenton 1986: 49). Final comment should be made, however, on the fact that different *types* of seaweed are reported as requiring different treatments – 'tangle', for example, is described as having a '*hot, scalding nature*' which requires mixing with milder materials before use (FSA VIII: 93). The different types of seaweed, and their use as manure, are discussed further below.

Of all the traditional manure materials used in Scotland, it is popularly supposed that seaweed was the one affected most by the changes seen in the Improvement period – not only by the introduction of lime, but the emergence of the kelp trade – the processing of seaweed to produce potassium and iodine salts for the glass and soap industries (Fenton 1978: 58). Kelp processing was a lucrative business for those fortunate enough to be based in seaweed-rich areas, and in western Scotland, there is certainly evidence that estates involved in the industry appropriated the seaweed manure resource, with reports of proprietors placing restrictions upon farmers cutting seaweed for manure (FSA XIII: 330) and likewise, reports of more publicly-minded owners refusing to enter the trade for the hardship it would place upon the farmers (FSA XVI: 197). The effect of this supposed seaweed drought could theoretically have affected the development of deep anthropogenic topsoils in two ways: either negatively, by removing a key manure source, or positively, by forcing farmers in kelp-producing areas to turn to other manures, such as bulk composts. This appears to be the more likely scenario: in reports from coastal areas with poor seaweed resources, farmers are described as resorting to dung and bulk composts as a 'substitute' (FSA XX: 249; XV: 404).

However, while some reports bemoan the effect of the kelp trade, more common are those accounts which explain that generally, as the best manures for seaweed were not those preferred for kelp, the two industries coexisted relatively comfortably. The First Statistical Account for St. Andrews makes reference to kelp being made from '*…the common weed…This weed the farmers never cut for manure*' (FSA XIII: 200), in Kirkwall, '*The kelp…is formed of the ashes of the different species of sea-weed…*' (FSA VII: 548), and in Portree, Inverness-shire, manure is made from '*a certain kind called* leathagan, *or tangle, which is very rarely made into kelp…*' (FSA XVI: 153). The distinction appears to have been partly economic:

'*Every kind of sea-ware is used for manure…Button wrack and lady wrack, are best for kelp, and the only kinds used, unless the price be very high. Except these two kinds, every other is very expensive in manufacturing, and produces but little kelp.*' (FSA XIV: 181).

In Berwick, there is a distinction drawn between different *parts* of the seaweed, with '*the coarser part…applied as manure to the land near the shore. The finer parts are manufactured into kelp…*' (FSA XII: 46). However, other reports maintain that certain seaweed types provide a particularly rich manure, and one that is not targeted for kelp:

'*The sea weeds, commonly used as manure, are the tang and kelp ware, which are got in* *abundance. But besides these, there is another kind of ware, resembling kelp ware, of an unctuous appearance, and so very rich, that it must be cut into small pieces, otherwise the crop would be too luxurious. It is called, in Gaelic,* 'semman nam portan*' (crab ware) from the number of crabs that are found among it. Notwithstanding the great quantity of ware, there is little kelp made in this parish*.' (FSA III: 531).

With documentary sources therefore indicating that kelp production may not have had a particularly drastic effect on the availability of seaweed manure in coastal areas, it must be concluded that this industry would have had a similarly minimal effect on deep anthropogenic topsoil development.

Overall, there is strong evidence that in many of the more marginal Scottish areas in which intensive manuring systems may have been expected to flourish, seaweed manuring, rather than bulk composting, was by far the preferred method and, while the incorporation of seaweed in a compost certainly allowed this material to become a *component* of a deep anthropogenic topsoil – pictorial records show a midden composed of a byre-manure and seaweed compost located in Papa Stour, Shetland, as late as 1967 (Fenton 1976: 15) - seaweed and its use as a manure is likely to be more strongly associated with a dearth of deep anthropogenic topsoil. Furthermore, documentary sources would seem to indicate that the advent of the kelp processing industry would have had little effect on this bias, with the preferred seaweed resource remaining generally available. The separation of these two quite different modes of fertiliser application – seaweed and bulk composts - is one that is visible in the soil record: the deep anthropogenic topsoils recorded at Marwick, Orkney, are located in areas with poor seaweed resources (Simpson 1997: 366).

3.3.6 Lime and other calcareous manures

Calcareous manures were in use in Scotland prior to the Improvement period, in the form of shells, shell-sand, and, most popularly, marl – a shelly or clayey soil containing carbonate of lime. While sand and marl could have contributed to deep topsoil development, they do not appear to have been used to any great extent in the pre-Improvement period, and were certainly exploited for their mineral properties rather than the bulk manure they provided. Shell sand was known as an especially valuable alkaline manure for acid soils, but its use is only recorded from a few Scottish counties, with Improvement period writers reporting that it was not considered worth the effort of digging it up (Robertson 1808: 239). More recent ethnographic study indicates that in the Hebrides, however, sand was applied to middens in areas of acidic soil (Smith 1994: 122). Marl, also recognised as a valuable manure source in the pre-Improvement period, does not seem to have been widely utilised either – although this seems to be due to the difficulty of finding and extracting it (e.g. Donaldson 1794b: 24). However, in Ross, although '*rich marl*' was to be had, '*none of the tenants can be prevailed upon to make any use of it*' (Sinclair 1795: 100), perhaps for the same reasons that the manure is so disliked at the other end of the country, in Berwick – '*lumpy and hard…a return too tardy to be waited for.*' (FSA IV: 12).

The introduction of lime as a manure, from the middle of the eighteenth century (Naismith 1814: 71) is an interesting point in the history of manuring practice in Scotland. Early reports describe the miraculous power of the manure (e.g. Donaldson 1794a: 12), but are quickly followed by reports of widespread soil 'exhaustion' due to repeated and excessive doses (e.g. Dickson 1770: 367; Robertson 1794: 134; Johnston 1794: 39). By the latter part of the eighteenth century, the effects of lime were better understood. Farmers were advised to either treat it as a 'stimulus' for the ground by using one large application, or, if using lime as a manure, to add only a little at a time, in order not to exhaust the ground (Dickson 1770: 391-408) and, most importantly, to use lime in conjunction with other manures (Marshall 1794: 36). The result of this is that by the time of the Improvement period agricultural literature, lime was generally recommended to be applied in a compost with other materials such as earth and dung. Far from supplanting this traditional procedure, lime became a part of it (e.g. Naismith 1794: 61; Somerville 1796: 57; Sinclair 1814: 534) – '*the proper stimulus for bringing the powers of the heap into action…a kind of yeast*' (Sinclair 1814: 548). Experiments with lime composts may have even encouraged a greater use of bulk mineral material in some areas, seen for example in this recipe from East Lothian: '*mix moss and quick lime together in the ratio of five or six cartloads of moss to one of lime...dung is then* *added, in the ratio of about a fourth of the original compound…*' (Buchan-Hepburn 1794: 87). In a final irony for those who opposed the practice of turf cutting associated with the more traditional manuring system, sods also began to be cut to be used to build makeshift lime-kilns in several areas (Marshall 1794: 36). Farmers are also warned against turning their backs on traditional manures: '*…none of these (other manures) are to supersede the use of dung, which can be employed to so great advantage*' (Dickson 1770: 375).

The introduction of lime, then, did not discourage the use of traditional or bulk manures. However, evidence from the Improvement period seems to suggest that despite the recommendations above, with the advent of lime many farmers *did* move away from composts with a mineral element, mainly moving to successive applications of dung and lime, or dung and lime mixed (e.g. Martin 1794: 10; Graham 1814a: 295). It would seem that this mixture satisfied the requirement to add lime within a 'putrefying mixture', and avoided the expense and trouble of creating a lime-based compost cited by many farmers (Sinclair 1814: 188). It is therefore likely that lime did lead to an overall reduction, or at least a change in the way bulk manures were used which is likely to have discouraged the formation of deep anthropogenic topsoils. This would have been particularly true of manuring strategies relating to land reclamation: lime is universally recommended as a part of the 'suite' of new methods for bringing waste lands into cultivation: draining, watering, ploughing, liming and trenching (Robertson 1808: 216). However, given that in many Scottish areas, land reclamation appears to have been associated with soil redeposition methods such as lazy-bed creation (Section 3.2.2.3) rather than plaggen style manuring as seen on the Continent, it is debatable whether this shift would have affected the creation of deep anthropogenic topsoils.

The shift to lime was not universally welcomed, although there are very few dissenting voices. Some parish reports offer practical reasons for rejecting lime use: for example, Corstorphine in Edinburgh, where lands which '*have received dung mixed with so much ashes, would be injured by liming; the ashes having performed that which the lime is intended to produce, viz. to loosen the soil, and act as a stimulus.*' (FSA XIV: 455). The only real complaint at the new system seems to be that '*the culture of barley is not so much attended to as under the old* *system….not so good in quality as formerly, when grown on the best of the infield land that was richly dunged, now it is …sown on outfield land, manured with lime or marl*' (Ure 1794b: 32).

3.3.7 'Exotic' manures

These are not only a feature of the Improvement period. Contemporary sources list a number of unusual farm-produced manures which indicate that, despite the limitations to importing off-farm manure sources in the pre-Improvement period (Woodward 1990: 267) farmers were resourceful in their recycling of fertilising materials. Bones were considered very valuable, especially when rendered down using quick lime (Somerville 1976: 36). Vegetable matter, often burnt, was extremely popular for composts, such as '*breckins'* (bracken) (Ure 1794a: 56) and ferns (Somerville 1796: 78) and the remains of green crops were often either ploughed back into the soil or added to the dunghill (Robertson 1799: 281). Building wastes were also used, not only turf-based materials, but also the clay and mortar from stone-built houses (Skene Keith 1811: 436). General rubbish was also collected: '*the rakings of roads, scourings of old ditches, roots of couch grass, lime rubbish, coal ashes, and every species of refuse that can be procured…*' (Kerr 1809: 377). Not all of these were additions to the dunghill: in Perth, potatoes were manured in their lazy beds '*by wrapping each seedling in a rag of woollen cloth and laying it in the earth without any other manure*' (Robertson 1799: 175).

After the Improvement period, these manures increased in both variety and availability. A huge range of materials are mentioned, both in the Improvement period reports and from ethnographic sources, as being used by farmers as manure throughout Scotland. There were animal and food wastes, such as cockles, mussels, fish, whale blubber, and horn shavings (Smout 2002: 72). Skin and hide from a huge variety of animals was used, from seal hair to '*fell-monger's poake*', which was a mixture of lime, hair, and the scrapings of sheep pelts and, in certain areas, the numerous by-products of industrial processes: woollen rags, parings of leather, soap lees, soot, tanner's bark, malt dust, oil, coal-ash, the refuse of potteries, salt and many other materials (e.g. FSA XV: 328; XVIII: 362; Somerville 1796: 45-46; Headrick 1796: 11-30; Naismith 1798: 63).

In large amounts, or where composted with bulk manures, it is possible that mineral-based additional manures such as this could contribute to the development of deep anthropogenic topsoils. For the main part, however, these domestic and industrial manures are not associated with plaggen-style manuring systems.

3.4 Summary

It can be seen that while there is a great deal of historical information available on manuring practices for Scotland for the historic period, the source data is largely generalised. Likewise, although survey and some excavation work on immediately pre-Improvement period farming structures and field systems exists, soil depth as a factor in exploring the nature of cultivation techniques and the use of manure resources has so far not been a part of research methodology in this area. Later cultivation also makes it difficult to isolate specific episodes within the MoLRS resource, thus making manuring practice an area of research upon which current MoLRS and other rural settlement archaeological work is largely unable to comment, with not even infield from outfield being sufficiently recognisable on the ground (Dixon 1994: 32).

Despite this, the source data available on cultivation techniques and manuring practices can and does provide an indication of the circumstances in which deep anthropogenic topsoils may have formed during the post-medieval period in Scotland. Well-documented manuring strategies indicate that any deep topsoil formation will reasonably be confined to the infield area of a township. However, it has also been established that in many areas, sufficient topsoil depth would very likely have been created through the twin cultivation techniques of ridge-and-furrow and lazy-bedding, techniques of *redeposition* rather than plaggen manuring. Cultivation practices in Scotland, therefore, seem to indicate that the creation of deep anthropogenic topsoils would not have been widespread.

This conclusion is further supported by an analysis of the manure resource exploited which, for the most part, although generally utilising the same materials seen in the plaggen system, shows a very different emphasis. The mineral component of these manuring systems arises from a pattern of *recycling* of a variety of settlement resources, especially fuel residues and building refuse, and the composting of these with animal dung, rather than with the system of large-scale turf processing known to be the backbone of the plaggen manuring system. This approach appears to have been at least partly a result of the numerous legal and economic restrictions governing large-scale turf removal in many Scottish regions, and this would seem to suggest that areas most likely to have developed deep anthropogenic topsoils are those where such restrictions were either absent or ignored – a conclusion supported by the presence of deep anthropogenic topsoils on Papa Stour, Shetland.

A further, and very interesting, point is also raised when the role of seaweed as a manure resource in Scotland is considered. Due to a popular preference for using seaweed in place of both dung and bulk materials, and the perceived unsuitability of coastal sandy soils for heavy bulk manures, it appears likely that deep anthropogenic topsoils are less likely to be found in coastal areas of Scotland. This provides an interesting comment on the relationship between the choice of manuring system and the surrounding environment. The Continental plaggen soils are almost universally located on sandy soils, but do not generally have resources of seaweed within reach. It is possible, then, that it is the plaggen manuring system which should be regarded as the more constrained of the two: lacking the more suitable and easily-applied seaweed resource for their sandy soils, was the development of the plaggen system an effective, but a time-consuming and costly way of dealing with this problem by using the only available alternative manure source – the heathland? Put this way, a general lack of deep anthropogenic topsoils in Scotland seems a very likely proposition. With the free-draining sandy soils more suitable for plaggen-style manuring tending to be located near the Scottish coast, and the usually poorer-draining clayey soils of the interior districts generally unsuitable for this method of manuring, the historic evidence would seem to point to deep anthropogenic topsoils being a comparative rarity in Scotland.

It is clear that an overview of this kind, whilst technically correct in its interpretation of the evidence for deep topsoil formation, does not paint a complete picture of manuring practice. Given this, it would seem that the methodology employed by this thesis – to combine a detailed analysis of the most finely-resolved data on agriculture and manuring practices for this period with soil-based survey work – is both an appropriate and original method of investigating the possible distribution of deep anthropogenic topsoils in Scotland. One of the most significant observations to emerge from the review undertaken in this chapter is that it is impossible to assess the true potential of this period in agricultural history for creating deep anthropogenic topsoils without adopting a methodology that allows individual examination of the manuring strategies employed at as near to individual township level as possible. The database created for this project, presented in the next chapter, manipulates the most detailed of these sources in order to investigate the likely extent of deep anthropogenic topsoils in Scotland, both in order to locate sample sites for this project and to answer some of the questions regarding deep topsoil development in Scotland which have been posed in this chapter.

4. The manuring database

In this chapter, the first aim of this thesis – to research the geographical distribution and cultural context of anthropogenic deep topsoils in Scotland – is undertaken. This chapter discusses the construction and evaluation of a geo-referenced database within which historical, geographical and archaeological source data which may inform upon deep anthropogenic topsoil development are linked to form a research tool, presented in ArcView GIS, through which the location and context of these topsoils can be investigated.

In so doing, this chapter represents a continuation, and in one sense a conclusion, to the discussion of Scottish manuring practices of Chapter 3. In its analysis of historic period source data relating to manuring practice, Chapter 3 highlighted several issues in Scottish agricultural history upon which it seems likely that the presence or absence of deep anthropogenic topsoils in Scotland may depend. In this chapter, these issues are explored in greater depth with the aid of this database which, in collating the most extensive and finely-resolved historic period data available on agricultural practices in Scotland, is likely to represent the best possible means of exploring the questions so far posed in this thesis. Taken together, Chapters 3 and 4 therefore represent the effort of this project to analyse the distribution and frequency of deep anthropogenic topsoils in Scotland, an understanding of which is essential in order for this thesis to make meaningful comment on the nature and seriousness of the threat theoretically posed to these soils, and to the cultural information they retain, by modern land cover and land management practices.

Overall, this database provides a tool through which the diverse fields of research in this thesis – textual, field-based and analytical - can be combined, providing a more holistic insight into the historical and environmental context of deep anthropogenic topsoils in Scotland, and therefore what effect their loss or damage may have upon our understanding of the cultural landscape.

This chapter begins by introducing the three categories of source data used in the database: historical, geographical and archaeological. The manipulation and analysis of the historical source data – the backbone of the database – is then discussed. A methodological section describes the interrogation of this dataset to isolate information on manuring practices and the conversion of this information into a GIS format. The potential of this creation as a research tool for historical analysis is then demonstrated, through a reappraisal of the factors identified in Chapter 3 as possibly affecting the development of deep anthropogenic topsoils in Scotland.

The chapter then moves on to introducing the use of this database as an investigative tool for locating deep anthropogenic topsoils, through the integration of geographical and archaeological data with this historic period dataset. The manipulation of these secondary datasets is described in a second methodological section and their potential for indicating deep anthropogenic topsoils explained. A final consideration of the potential for integration of these three datasets - historical, geographical and archaeological – concludes with the formulation of a classification system, the use of which facilitates the program of auger survey and eventual sample site location presented in Chapter 5.

4.1 Database creation: source data

4.1.1 The digital resource

Digital data used in the creation of this database was supplied by Historic Scotland. This consisted of a set of GIS data files detailing the Scottish coastline along with Scottish county and parish boundaries. All GIS data was referenced to the British National Grid projection system (datum OSGB 1936). Coastline, county and civil parish boundary data was obtained from the Ordnance Survey ‘Boundary Line’ dataset, originally digitised from the Ordnance Survey 1:10,000 map, and compiled as an Historic Scotland dataset in 2000. Additional parish data was obtained from the General Registers of Scotland. The original date of capture of this information is not known (R. Strachan pers. comm.).

4.1.2 The historical resource

As discussed in the preceding chapter, the earliest significant body of historical source data relating to Scottish agriculture dates to the Improvement period of the eighteenth century.

Therefore, despite the fact that the Improvement period literature relates to a time during which traditional manuring (and other) agricultural practices were being superseded by more modern farming technologies, Improvement period texts are nevertheless the most contemporary accounts available describing the traditional modes of cultivation in Scotland discussed in Chapter 3. The historic component of this database is therefore based on analyses of the two key documentary sources containing agricultural data from this period: the first editions of the County Agricultural Reports (1793-1814) and the First Statistical Account of Scotland (1791-1799), material from which has already been introduced in the preceding chapter.

The comparatively late dates of these historical sources are compensated for by the large amount of very finely resolved data that they provide. The County Agricultural Reports, published for counties throughout the British Isles, are a series of in-depth surveys of the methods of cultivation, land management and improvement commonly in use during this late eighteenth century period, and, being specifically agricultural texts, provide a large amount of detail on manuring practices. The First Statistical Account, unique to Scotland, is an immense collection of almost 900 parochial reports responding to a formal statistical enquiry canvassed during the same period. The twenty-one volumes of the First Statistical Account are an unrivalled source of information on Scottish social history and, although not focused solely on agricultural topics, provide the most extensive body of data available on agricultural activity in Scotland in, and immediately prior to, the eighteenth century.

Both of these sources owe their existence largely to one public figure, Sir John Sinclair. The First Statistical Account arose from a largely unsuccessful attempt by Sinclair to compile a report on the 'political circumstances' of the country, during which he found that statistical data on, especially, the state of the agricultural economy was unavailable:

'*I then saw the necessity of forming the plan of some institution, for the express purpose of collecting useful political information, the public at large having felt the most serious inconveniences and losses, from information of that nature, not being anywhere to be obtained…*' (Sinclair 1796: 5).

As a lay member of the General Assembly of the Clergy in Scotland, Sinclair proposed that the Church could help address this problem, through individual ministers providing returns upon a set list of 'Queries' on economic and social topics, sent out to each parish. Initially intending to condense these into an overall report, the response was so enthusiastic that, rather than '*depriving the Clergy, of the credit which they were entitled to derive, from such laborious exertions*' (Sinclair 1798: iv) he printed the responses in full.

The scheme was not, however, universally popular, with some parishes suspecting taxation to be the real purpose of the report, and some tenants reluctant to offer information on their circumstances of which their landlords might take advantage (e.g. FSA IX: 537-8; XX: 150). It took several years of encouragement, by way of both financial incentives and repeated requests to more reluctant ministers from Sinclair and other public figures, such as the Duke of Argyll, before this nominally voluntary exercise was completed. Some parishes eventually required a visit from a 'Statistical Missionary' to complete a report for them (Sinclair 1798: viii), such as Torbolton in Ayrshire, possessed of an aged minister and his 'bibulous' assistant (Withrington and Grant 1975: xvii). As a result, the quality of individual parish reports varies hugely, with some running to over a hundred pages, for example that of Kilsyth (FSA XVII: 214-316), but many others ignoring the vast majority of Sinclair's list of questions and giving no more than a cursory two-page summary. It is also fair to say that in many instances, the content of a parish report undoubtedly reflects the personal interest of the minister compiling it, and this often counts against particular topics. While few ministers fail to record the size of the parish or details of poor relief, of a total of 876 parishes, 278 give no information on manuring practices (although agricultural concerns are included in all but the most basic accounts).

The content of the early Statistical Account returns, highlighting in particular pressing agricultural concerns, convinced Sinclair that for the '*spirit of improvement*' to succeed, a national 'Board of Agriculture' was required (Sinclair 1826: 303). Political lobbying eventually paid off and the Board of Agriculture was established in 1793 (Sinclair 1796: 9). Initially, an agricultural census project similar to the Statistical Account, conducted at parish level and including the rest of the British Isles, was planned (Sinclair 1826: 68) but financial and logistical considerations eventually saw the new Board settle for a series of county-level Agricultural Reports (Sinclair 1796: 11). The

County Agricultural Reports were followed by a series of 'Communications to the Board of Agriculture' (Sinclair 1814: 2), several of which focus on manures (e.g. Somerville 1796).

Lacking the resolution of the First Statistical Account, as agricultural records the County Agricultural Reports have the advantage of being compiled by experts in the field, with the Board appointing suitable surveyors for each district, one report compiled by John Sinclair himself (*ibid*.: 11; 48). Scottish counties were at the forefront of the survey programme, largely because '*great assistance was to be derived, from a work completed there…entitled, the Statistical Account of Scotland*' (Sinclair 1814: 4). On completion of the first series of Reports from each county, a second set of surveys was quickly commissioned, reorganising several Reports so that their contents followed a common pattern.

While many of the County Agricultural Reports do include large tracts of information taken from parish reports of the First Statistical Account, the two surveys are entirely separate, and in many instances, even provide conflicting information on manuring. Much of this appears to indicate that, despite the specialist nature of the County Agricultural Reports, their relative brevity in comparison to the First Statistical Account may make them a less useful data source for manuring practices. For example, the County Agricultural Report for Midlothian states that '*Lime (is) but little known as a manure in the low part of the county, yet it is much used for that purpose in the upland districts…*' (Robertson 1795: 142). However, the parish-level data from the Statistical Account shows that the use of lime was fairly evenly distributed throughout the county at this time.

A further concern relating to the County Agricultural Reports is that, as might be expected from data resolved to only county level, the information given on manuring practices is not only fairly generalised – and often, quite brief - but also fairly uniform between counties in similar regions. What is perhaps more surprising is that this uniformity persists between Reports of counties for which we would assume fairly different environmental and economic circumstances – for example, Berwick and Sutherland (see Lowe 1794; Sinclair 1795).

The differences between the two data sources illustrate the difficulties inherent in using historical, text-based records to compile a database of this kind. In attempting to manipulate these sources into a resource that provides meaningful quantitative data, the idiosyncrasies of both the county Agricultural Reports and the First Statistical Account must be taken into consideration, as demonstrated in the analyses presented in Section 4.2.2. It is clear that the level of data provided by the County Agricultural Reports is difficult to utilise effectively in a detailed analysis, although it provides an invaluable overview of the state of agriculture throughout Scotland during this period. Therefore, use of the data from the County Agricultural Reports is limited to the general analyses presented in Section 4.2.2. The more finely resolved First Statistical Account data is used to provide the historical component to the investigation of deep anthropogenic soil location presented in Section 4.3.2. The methodology used to interrogate these documentary sources and translate this information into a GIS format is described in Section 4.2.1.

4.1.3 The geographical resource

The earliest geographical survey data relating to soil distribution also dates to the eighteenth century Improvement period in Scotland, with the inclusion within some of the County Agricultural Reports of 'soil maps' showing the suitability of local soils for cultivation, e.g. Clackmannanshire (Graham 1814). Throughout the nineteenth century, advances in geological understanding saw soil classification emerge as a scientific branch in its own right (Avery 1980: 38), but it was not until the early twentieth century that systems classifying soils on the basis of their own characteristics, rather than those of their underlying geology, became widespread (*ibid*.: 39). Systematic soil survey and soil mapping for agriculture began in earnest in 1946 in England, Wales and Scotland, with the inauguration of the Soil Survey programme.

The Soil Survey of Scotland completed detailed soil surveys for a significant proportion of the Scottish mainland and some of the islands, until being discontinued in the 1980s. The classification system used by the Survey groups soils developed on similar parent material and within the same climatic zone into 'Associations' which are then subdivided into 'Series', largely according to their natural drainage properties (Avery 1980: 56). The position and extent of a soil Series therefore largely reflects the topography of the landscape and makes this an appropriate classification system for agricultural use.

With coverage concentrated on the eastern areas of the country, the Soil Survey data was used to produce the Soil Maps and Land Capability for Agriculture Maps provided today by the Macaulay Land Use Research Institute, Aberdeen. By the time the Soil Survey programme was terminated, about half of Scotland, including most of the arable land, had been surveyed and published in thirty-six main maps and several smaller individual area surveys (Avery 1980: 59).

The Soil Survey records represent the most extensive geographical direct and indirect indicator for the location of deep anthropogenic topsoils available in Scotland, indicators which take three forms. Firstly, although the survey aimed only to map natural soil types, several of the soil surveyors noted the presence of ‘deep phases’ of topsoil within certain soil series, distinctions which were included upon several of the final Soil Maps – those for Orkney Hoy and Orkney Mainland (Soil Survey for Scotland 1981), Nairn and Cromarty (Soil Survey for Scotland 1974), Auchentoul and Reay (Soil Survey for Scotland 1985), and Latheron and Wick (Soil Survey for Scotland 1970). Although these are not explicitly identified as being of anthropogenic origin, previous investigation of the deep phase areas shown on the Orkney map series successfully identified these deep phases as plaggen-type deep anthropogenic topsoils (Simpson 1997).

Secondly, the original field notes of the surveyors record the details of the vertical profile of each auger point taken for the survey. This includes the *topsoil* depth for each point taken for each survey, and therefore even those surveys which map only natural soil types hold information on deep topsoil profiles as a part of their original dataset (J. Gauld 2001 pers. comm.).

Finally, each of the Soil Maps is accompanied by a volume giving descriptions of each soil series and its Associate-level variations. These discuss the suitability of each soil series for agricultural development. This provides a potentially useful body of secondary information on factors relating to deep anthropogenic topsoil development. Drainage class, for example, is indicated by the Continental plaggen soils to be an important likely factor in deep anthropogenic topsoil development. Values for soil chemical properties, such as phosphorus levels, can also be useful indicators highlighting anthropogenic influence upon the soil. In some cases, the surveyors also note the propensity of certain Soil Associations to develop anthropogenic topsoils, for example, the Tarves Association, found in Aberdeenshire (Glentworth 1963: 172).

Information from both the published Soil Maps and the original field surveyor’s notes on individual auger points are used in this database to provide a source of geographical information on the possible location of deep anthropogenic topsoils. The methodology used to integrate these sources with the manuring database is described in Section 4.3.1.

4.1.4 The archaeological resource

The third and final set of source data included in the database created for this project is archaeological in nature. In recent years, both Historic Scotland and the Royal Commission on the Ancient and Historical Monuments of Scotland (RCAHMS) have undertaken extensive projects to bring together large bodies of extant archaeo-historical surveyed data into a GIS format, intended to facilitate mapping and interpretation of historic landscapes both for archaeological and cultural heritage management projects: the First Edition Survey Project (FESP) (RCAHMS/Historic Scotland 2002) and the Historic Landuse Assessment (HLA) (Bruce *et al*. 1999). Digital data from both of these resources has been supplied for use within this project.

Both of these datasets relate to the rural economy of the pre-improvement period, and therefore complement the historical datasets which form the backbone of the database. The Historic Landuse Assessment (HLA) was devised in 1996 as a joint project between Historic Scotland and RCAHMS in order to create a method of assessing historic landuse patterns and their effect on the survival of archaeological sites within them by integrating Ordnance Survey, National Monuments Record, land cover and aerial photograph data into a GIS (Macinnes 2003: 4). The resulting database has now been made available as HLMAP, a web-based research tool allowing users to view landscapes by type, category or period (http://jura/rcahms.gov.uk/HLA/start.jsp). The First Edition Survey Project, conceived among other projects as a response to growing concern at the lack of attention given to Scotland's medieval or later rural settlement, is a survey of the unroofed buildings recorded on the first edition of the Ordnance Survey 6-inch map series. Spanning the period 1843-1878, this therefore provides spatial information on the pattern of rural settlement and abandonment for the pre-Improvement period (RCAHMS/Historic Scotland 2002).

In the database analyses presented in this chapter, these datasets are used to provide only supplementary information, with the integration of the historical and geographical sources providing the main tool through which the location of deep anthropogenic topsoils is investigated. The archaeological datasets described above are primarily included in this database as an illustration of the theoretical capability of this database to interact with other spatial archaeological databases, and therefore the potential of this database as a tool for individual archaeological research projects. As discussed in Section 2.5, information on the location and distribution of early anthropogenic deep topsoils is so far limited to reports of individual archaeological excavations and small scale surveys, usually concentrated upon the immediate settlement area. In order for archaeological research on the distribution of deep anthropogenic topsoils to progress beyond this point, the use of datasets which allow comparison to be made between larger landscape areas, on a more detailed scale than that generally possible from intra-site study, must be considered. The inclusion of these datasets therefore illustrates the potential for other areas of MoLRS research to inform upon the wider landscape context of deep anthropogenic topsoils.

However, the inclusion of archaeo-historical survey data is also seen to provide a useful addition to the historical and geographical datasets at a more local level. For example, First Edition Survey data applied to a parish showing strong historical evidence supporting deep topsoil manuring can potentially indicate the pattern of settlement *within* this parish relating to the period during which these manuring methods would have proliferated. The relative inability of standard archaeological survey techniques to investigate individual episodes of cultivation, and therefore manuring practices, has already been discussed in Chapter 3. The inclusion of these survey datasets within this database represents a first attempt at using these substantial archaeological resources to investigate the effects of different manuring strategies within the landscape. As a result, the archaeological databases play a greater role in the individual survey programmes described in the following chapter, than in the analyses undertaken below. The integration of these datasets with the manuring database is described in Section 4.3.1.

4.2 The database as a tool for historical research

The following sections describe the construction of the primary component of the database:

the historical information on manuring practices taken from the County Agricultural Reports and the First Statistical Account, and illustrate the way in which this part of the database stands alone as a tool for researching specific questions relating to deep anthropogenic topsoil development.

4.2.1 Methodology: the historical dataset

4.2.1.1 The County Agricultural Reports

A complete set of the County Agricultural Reports for Scotland was accessed. In order to obtain the earliest possible data on manuring practices, wherever possible, the first edition for each county was used. Counties for which first editions could not be located were Clackmannanshire, Kinross, Inverness and Stirlingshire.

A spreadsheet recording all references to manuring practices was compiled. An edited version of this, indicating the presence or absence of a manure or manuring method in each county, is seen at Appendix 1.

This information was then imported into ArcView and linked to the digital county map with the county name acting as a common field. This required the reorganisation of several areas whose county boundary or name has changed since the compilation of the County Agricultural Reports. These changes are described in Appendix 2.

The linking of this manuring database with the digital county map allows the manuring database to be viewed as a graphic, and spatial analysis to be conducted on the manuring information given for each county. Examples of this are given in Section 4.2.2.

4.2.1.2 The First Statistical Account

The text of the First Statistical Account of Scotland was made available online in 2000, through EDINA, the JISC-funded national data centre based at Edinburgh University Data Library (www.edina.ac.uk). All 873 parish records were read and all references to manuring methods, materials and related data were entered into an Excel spreadsheet, provided as Appendix 3. The full text relating to each of these database entries was collated as a .pdf file for each parish, with the intention of allowing the user to access and query the primary data source for any manuring reference used in the database. This was considered appropriate, providing not only the means for the user to negotiate the complex and often ambiguous nature of the historical sources, but also as a means of mitigating the necessarily reductive nature of the spreadsheet data. This information is provided as Appendix 4 through the medium of a web browser, with each parish catalogued by the five-figure code used as a primary key for the spatial database (see below).

The manuring spreadsheet was then linked to the digital parish map provided by Historic Scotland. In order for this link to be possible, it was necessary to correlate the names and locations of current-day Scottish parishes with their First Statistical Account counterparts. This was a fairly complex process, and is therefore described in full in Appendix 2. Appendix 2 forms an important part of the archive to the manuring database, allowing the user to query how the database has handled information from those parishes whose name or position has changed since the compilation of the First Statistical Account.

The spreadsheet of manuring information (Appendix 3) was then imported into ArcView and linked to the parish map by the creation of a five-figure code for each parish to act as a common field. The linking of this manuring database with the digital parish map allows the manuring database to be viewed as a graphic, and spatial analysis to be conducted on the manuring information given for each parish. The relationship between the information provided at county and parish level can also be analysed. Examples of this are seen in Section 4.2.2.

4.2.2 Interrogating the historical dataset

The review of historical evidence for manuring practices in Chapter 3, although confirming that the manuring materials necessary for the creation of deep anthropogenic topsoils were in use in Scotland throughout the historic period, also highlighted several issues that would appear to indicate that the pattern and intensity of their use may have discouraged the formation of a plaggen-type manuring system. In the following section, these factors are explored with the aid of the manuring database, in an attempt to examine and quantify their possible effect on the development of deep anthropogenic topsoils in Scotland. This section therefore investigates the potential of this database as an analytical tool for historical data.

4.2.2.1 The use of turf as a manure

One of the most interesting issues to arise from the review and discussion presented in Chapter 3, and certainly that likely to have had the most effect on plaggen-type manuring strategies, is that surrounding the cutting of turf from common or waste lands, for use as either manure, fuel or construction material. Documentary sources repeatedly indicate that all of these practices were discouraged as detrimental to pasture lands, particularly that of taking the thicker, earthier turves used for making compost manure, which was even prohibited by law in some areas during the seventeenth century (Section 3.3.3). However, as late as 1825, Improvement period writers comment that '*there are still many places, where this law* (prohibiting turf cutting for manure) *should be enforced*' (Sinclair 1826: 306). How widespread, then, was the practice of using turf as a manure material at the time of the County Agricultural Reports and the First Statistical Account?

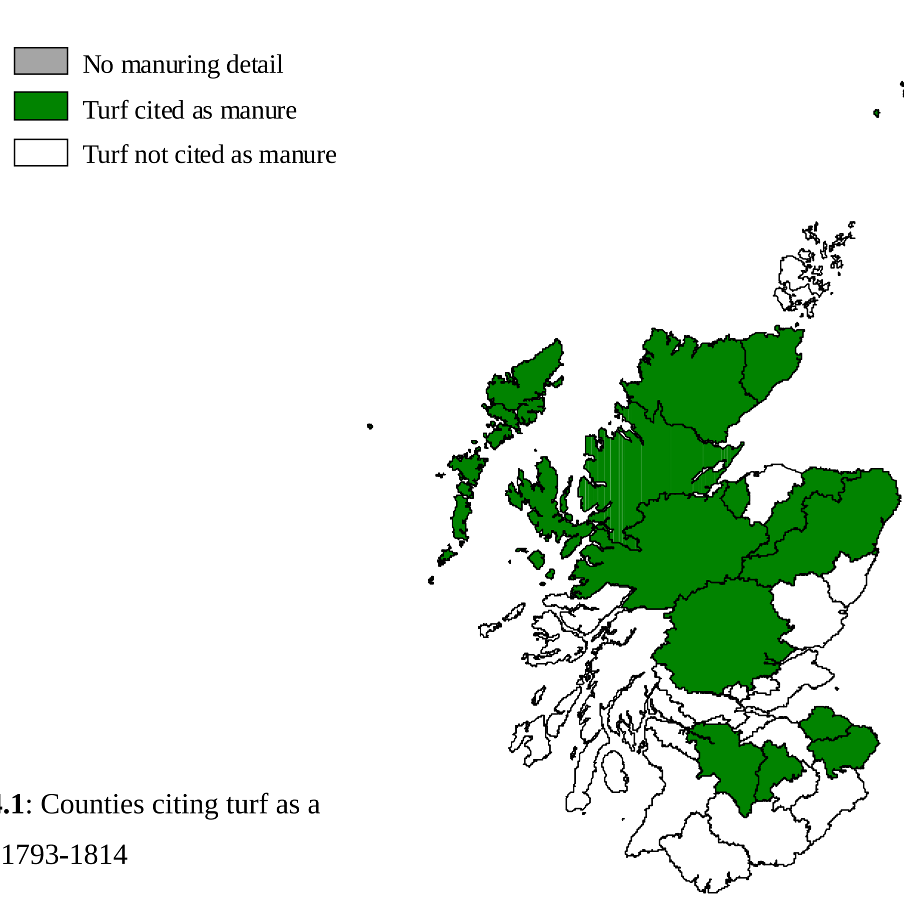


Figure 4.1: Counties citing turf as a manure, 1793-1814

Figure 4.1 shows the distribution of counties which cite the use of turf as a manure, and Figure 4.2 the distribution of parishes citing the same. While Figure 4.1 shows that the majority of counties list turf as one of the manures used, with a bias toward the more northerly counties, Figure 4.2 shows that very few parishes clearly cite the use of turf as a manure material: only 18 parishes in all, with no discernable geographical bias.

How accurate is this parish-level record of manuring practices, so different from that presented in the County Agricultural Reports, likely to be?

Firstly, as Figure 4.2 clearly shows, this small number of citations is partly attributable to the large number of parishes that give no details on manuring at all. This is a significant drawback to the manuring database: while the First Statistical Account provides a more finely resolved dataset than that of the County Agricultural Reports, the records are generally poorer in

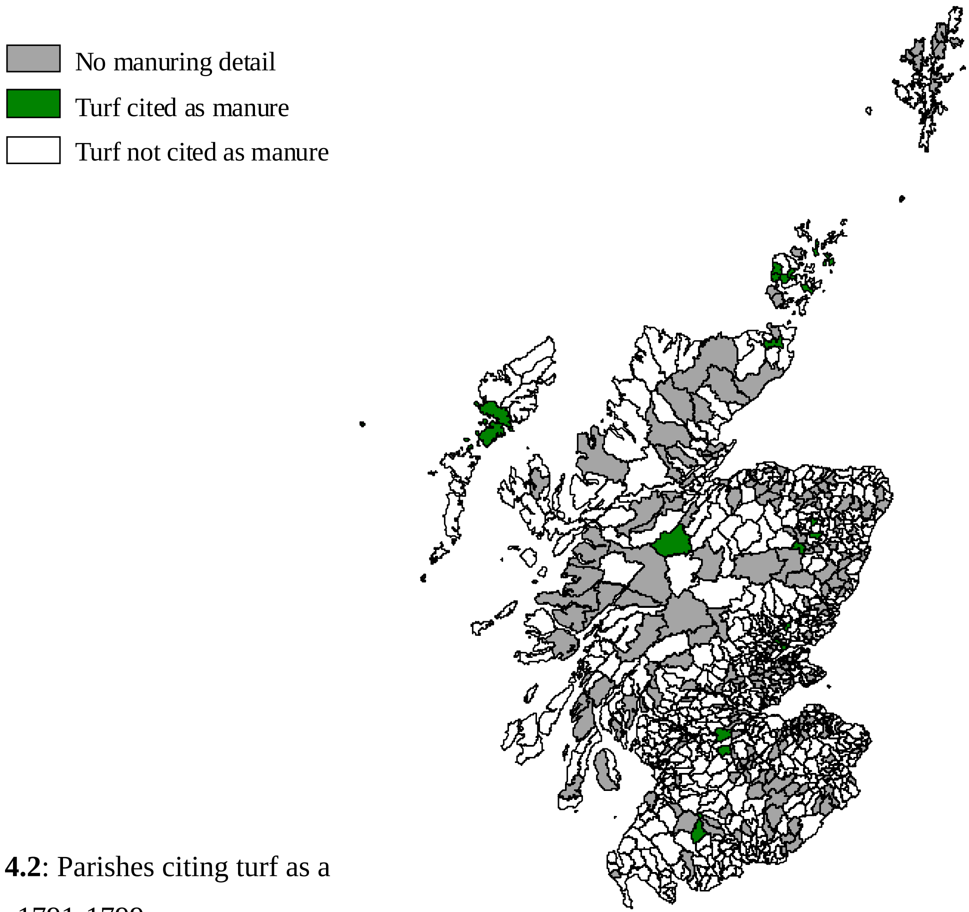


Figure 4.2: Parishes citing turf as a manure, 1791-1799

information quality, whereas the County Reports give comparatively detailed information on manuring which covers every Scottish region, albeit at a far cruder scale.

Secondly, the textual ambiguity often present in the First Statistical Account has to be taken into consideration. The distribution shown at Figure 4.2 highlights those parishes in which 'turf' is clearly cited as a manure resource. But the text presents many more observations which imply that this material is likely to have been part of a parish manuring system without clearly stating the fact. For example, there is a tendency in reports of this period to use the word 'earth' to describe earthy turf sods (e.g. FSA VII: 585). Other ambiguities include references to 'byre-dung' (likely to consist of turf on which cattle were bedded) or 'moss' (likely to refer to peat, but possibly also to turf taken from waste lands such as heath). Most prevalent in the less detailed accounts of manuring practice common in the parish records are references to 'composts' – an ambiguous term which implies the mixing of dung with bulk manures, possibly turf, but could also refer to the

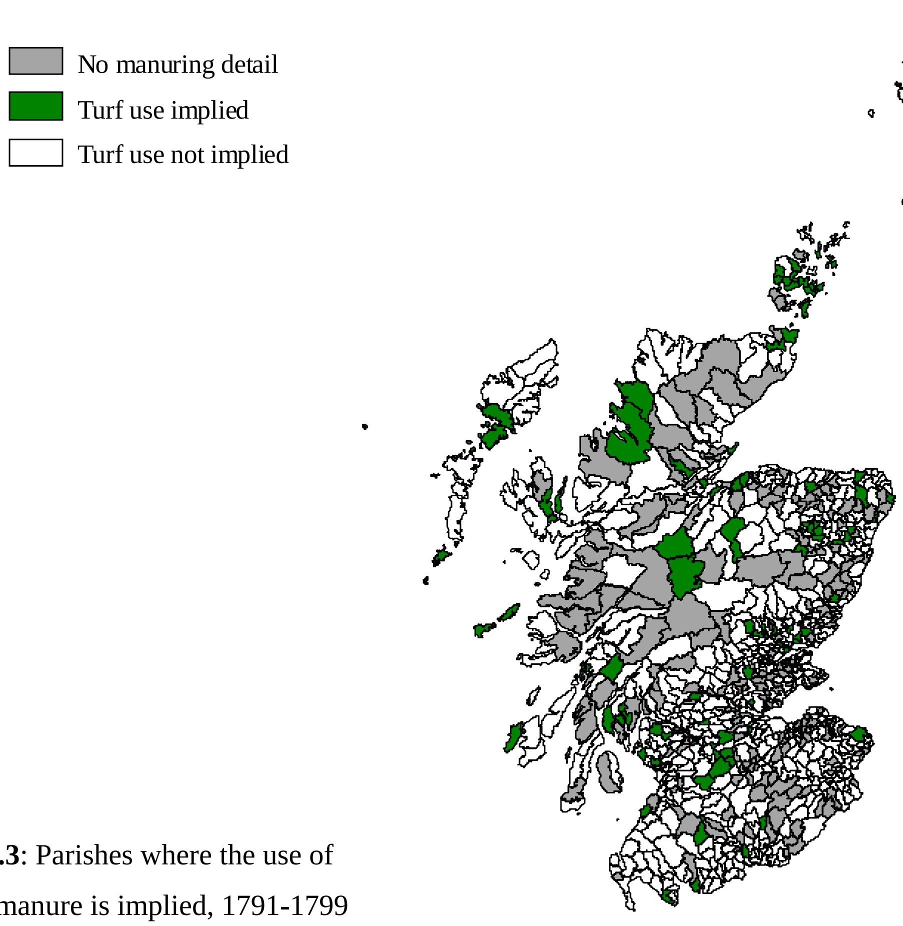


Figure 4.3: Parishes where the use of turf as a manure is implied, 1791-1799

addition of domestic waste (such as ash) or other, non-bulk, manures (such as lime, seaweed or vegetable waste) to the dunghill.

Figure 4.3 combines these more ambiguous references to show the possible maximum distribution of turf use according to the First Statistical Account data: 88, from a total of 598 parishes which provide information on manure materials and practices. It is clear that in order to use the information provided by the parish dataset effectively, the specific interpretation of the text must be considered - and also clearly stated within the analysis.

Regardless of the way in which the data is interpreted, however, it is clear that of the parishes which do give information on manuring, comparatively few record the use of turf compared to the County Agricultural Reports. Is it possible that the discrepancy between these two sources could be a reflection of the public disapproval known to exist toward the use of turf as a manure? Were the County Agricultural Report compilers, as ‘outside agencies’, less hesitant to record the use of this material than the ministers required to present an account of the activities within their own parishes?

Figure 4.4 shows the distribution of those parishes whose reports give a clear opinion as to the acceptability of removing turf, either in the form of cutting turf for manure or in the form of paring and burning. The widespread discouragement of the practice of paring and burning is cited in Chapter 3 as an indicator of the negative attitude of the Scottish agricultural system towards the large-scale removal of turfed areas that would have to underlie a plaggen-style manuring system. Parishes which cite the removal of turf for manure, or the use of paring and burning as a manuring method are plotted against those which remark on the negative effects of either of these activities. Twenty-two parishes are happy to record their use of these practices (some parishes utilising both methods), with only sixteen speaking out against. It would seem that despite the date of the parish accounts, the ‘spirit of improvement’ does not seem to have manifested itself within the First Statistical Account as a desire to portray the agricultural state of individual parishes in a way calculated to impress the Improvement period writers. While the absence of information from so many parishes must weaken this interpretation, it does indicate that a lack of citations for the use of turf is more likely to be a genuine reflection of the manuring situation as perceived by the ministers than an attempt at propaganda.

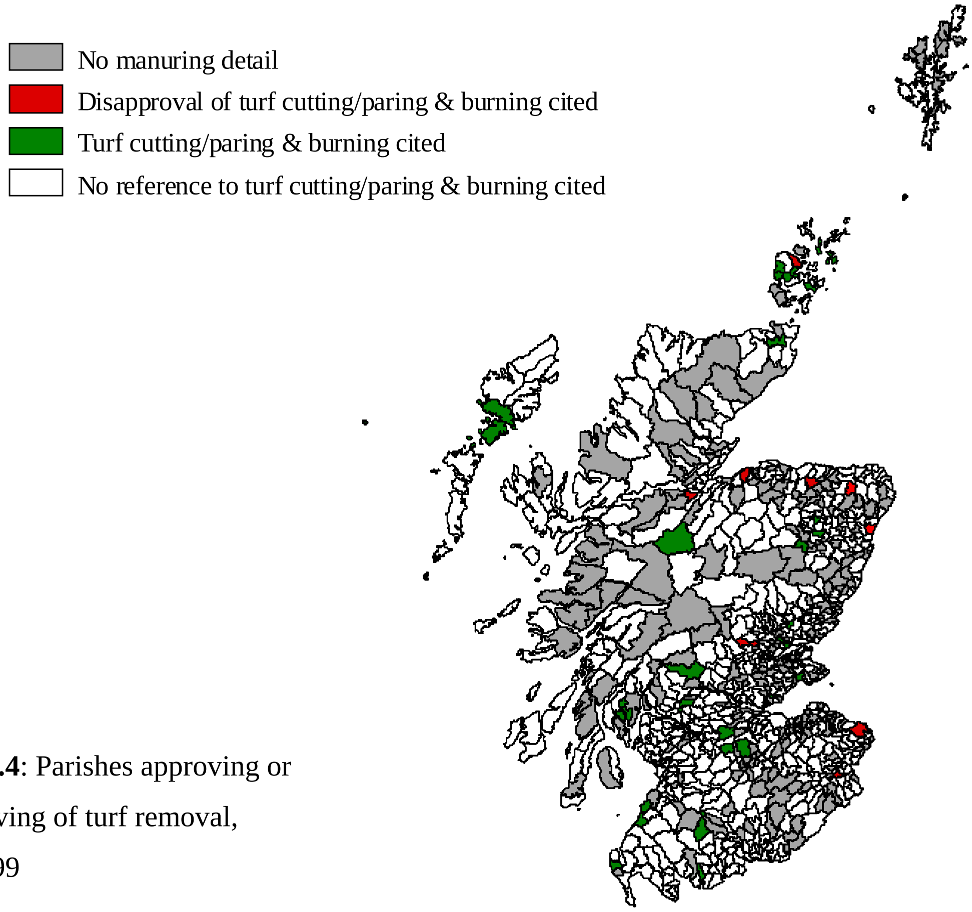


Figure 4.4: Parishes approving or disapproving of turf removal, 1791-1799

It would seem that the evidence for the use of turf in the manuring system from both the County Agricultural Reports and First Statistical Account broadly supports the conclusion reached in Chapter 3: that while turf certainly was a part of the manuring system in both pre- and post-Improvement Scotland, its use was neither as intensive nor as well organised as to indicate a plaggen-type manuring system. Recognised as a manure material in the majority of reports written by agriculturalists, turf appears to have been a small enough part of the system either to go unnoticed by the great majority of 'lay' commentators, or to be genuinely absent from many manuring systems at the village, or farming township, scale. If the possibility that the role of turf is deliberately underplayed is ruled out, these data sources support the interpretation that turf was included as a manure material largely as a result of patterns of settlement resource recycling, rather than through well-organised, large-scale systems of turf processing that would be unlikely to pass unnoticed by even the Statistical Account writers.

4.2.2.2 The use of seaweed composts

A second issue highlighted in Chapter 3 is the possible effect that the use of seaweed as a manure material may have had on the development of deep anthropogenic topsoils in Scotland, especially (though not exclusively) in the coastal regions. Historical sources point to a marked preference for seaweed over dung both for certain crops and certain soils (Section 3.3.5) but, more crucially, also to a preference for seaweed *alone* – specifically, not composted using bulk manures- in areas of light, friable sandy coastal soils which were perceived to be unsuitable for wet, heavy bulk manures.

Despite this preference, sources also note that long-continued use of seaweed alone was detrimental to the chemical balance of the soil (Fenton 1986: 49). However, although many of the early Improvement period writers discuss the composting of seaweed, this is mostly with reference to preserving seaweed manure resources for later use, rather than as a manuring strategy in itself (e.g. Donaldson 1795: 32; Robertson 1808: 112). Historical evidence, then, suggests that the use of the bulk manure materials necessary to create a deep anthropogenic topsoil might have seen restricted use in many coastal areas, and possibly also in those inland areas which chose to import seaweed resources.

How real, and how widespread, might this prejudice have been? Figure 4.5 shows the distribution of those counties, according to the County Agricultural Reports, which cite seaweed as a manure resource, against those which specify that seaweed was used as part of a compost containing bulk manures. Figure 4.6 shows the First Statistical Account records for the same.

It can be seen that Figure 4.5 indicates that although a slightly larger number of counties record that seaweed is used alone, a significant number also record the use of seaweed composts: eight in all, against a total of seventeen citing seaweed alone. These eight are noticeably distributed towards the northern part of the country.

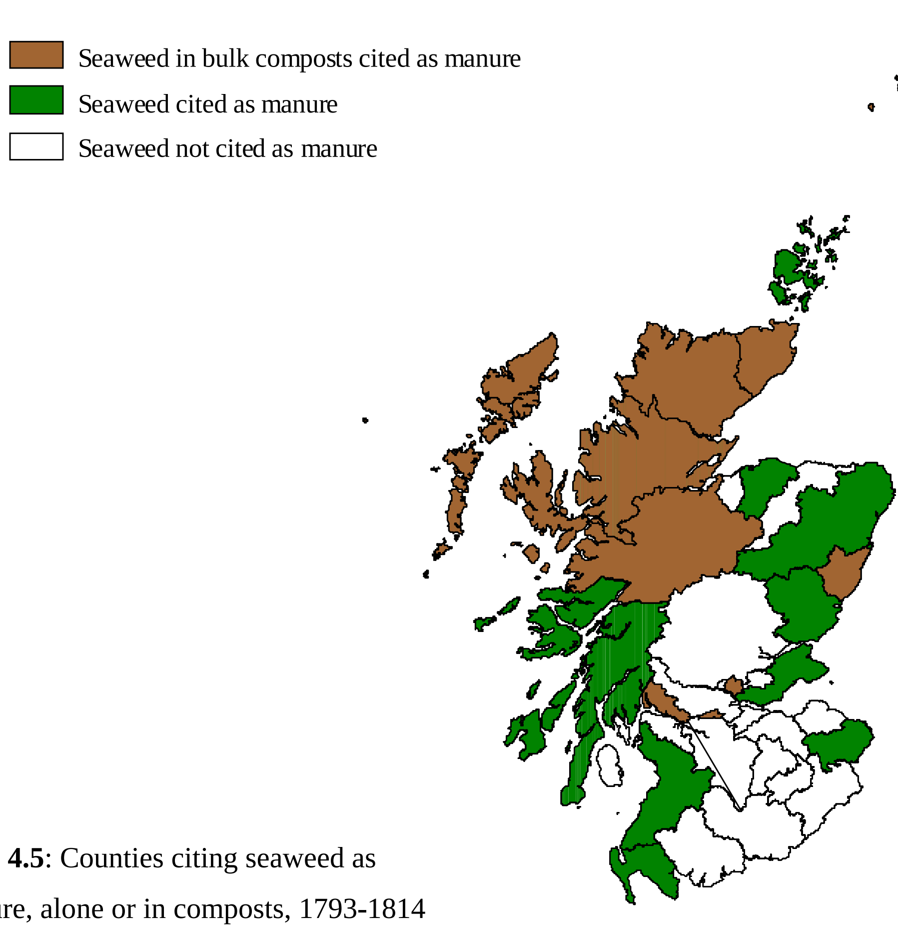


Figure 4.5: Counties citing seaweed as a manure, alone or in composts, 1793-1814

However, this distribution appears to highlight several inconsistencies which should be explored as part of the analysis. It can be seen that Bute does not record the use of seaweed at all – which seems unlikely, given its geographical position within a coastal area known from other county and parish reports to have extensive seaweed resources. Appendix 2, however, cites that the Bute GIS record is taken not from an individual Report for that county, but from the Agricultural Report for the Hebrides, which represents the earliest county record for that area. It would appear that, although it is extremely likely that seaweed would have been part of the manure resource on Bute, there is no specific mention of this within the Bute section of the Report. Seaweed cannot therefore be added to the Bute list of manures. A similar situation is seen for the counties of Nairn and Banff, both of which have large stretches of coastline, and even parish records within their county boundaries which cite the use of seaweed, but from whose County Agricultural Reports seaweed manures are omitted. This distribution illustrates the fact that despite the expert authorship that results in their generally more detailed manure listings, the County Agricultural Reports, like the First Statistical Account, must certainly contain some factual omissions.

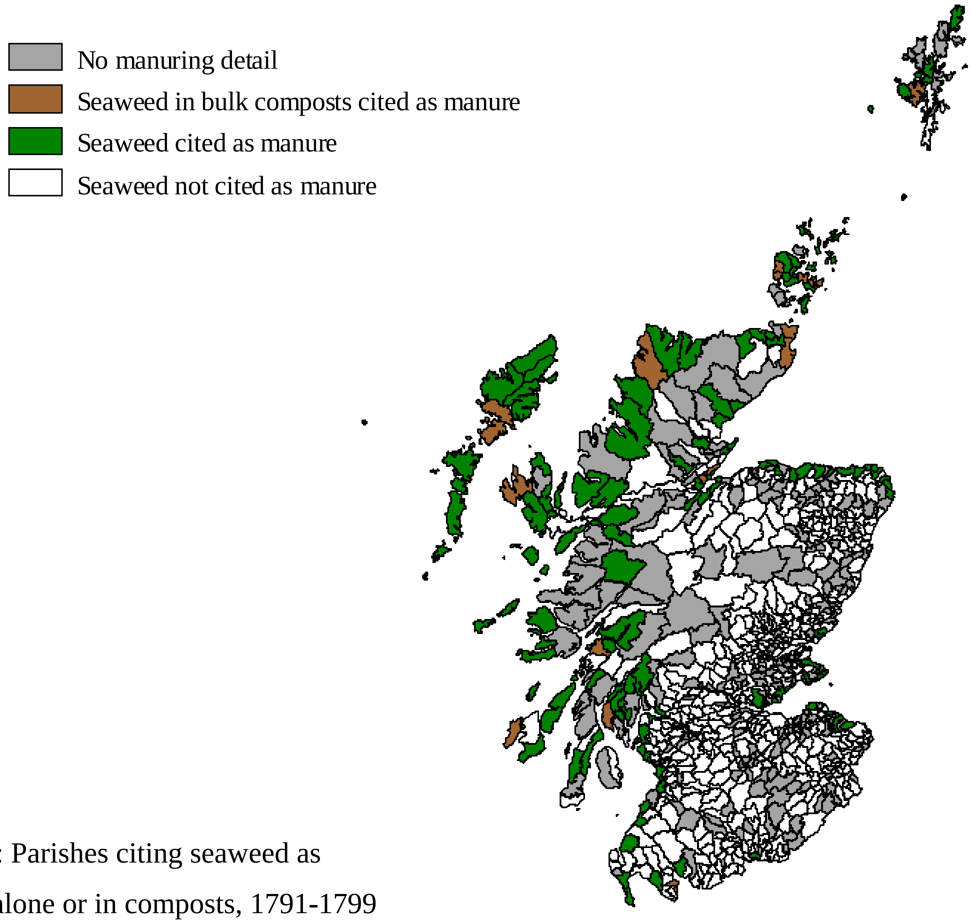


Figure 4.6: Parishes citing seaweed as a manure, alone or in composts, 1791-1799

In a situation similar to that seen in the analysis of the distribution of turf manuring, Figure 4.6 gives a far less comprehensive record of seaweed manuring, especially in composts, with 138 parishes listing seaweed use but only seventeen recording its inclusion in a bulk compost. Again, it is likely that the text itself may mask the true number of instances in which bulk manures may have been used in coastal areas. Many parish reports give a brief summary of the manures used with little detail as to their mode of application or whether they are mixed together, for example the parish of Ardchattan in Argyle, which states that '*the manures used here are lime, shell-sand, sea-weeds, and dung*' (FSA VI: 176) but does not state whether, for example, this sand and dung were mixed with the seaweed, or whether different manures were reserved for particular crops or types of soil.

Despite these possible omissions, the evidence from both the county and parish reports indicate that while seaweed appears to have been more commonly used without a bulk compost, the use of seaweed in a compost with other bulk manure material is sufficiently common throughout the coastal areas where seaweed was used to be cited by both experts and lay writers alike. While there is a definite preference for seaweed as a manure resource in these areas, this does not appear to preclude the use of bulk manures, and therefore the development of deep anthropogenic topsoils, in the coastal regions.

4.2.2.3 The use of lime

A factor commonly cited as central to the decline in the use of the traditional bulk manures which facilitate deep anthropogenic topsoil development is the introduction of modern manure applications, such as lime. Section 3.3.6, in discussing the evidence for this from historical sources, concludes that frequent references to the inclusion of lime *within* bulk-manure composts indicates that the introduction of lime did not necessarily have a strongly detrimental effect upon the tradition of making compost manures. However, equally frequent references to the use of 'lime and dung' systems, satisfying the need to dilute lime with a 'putrefying mixture', may mean that for many farmers, the shift to lime meant an end to the need to maximise manure collection through using bulk mineral material, which would presumably have been a time consuming and perhaps arduous task they would happily have avoided (Sinclair 1814: 188). The ultimate effect, therefore, would be a likely overall reduction in the amount of bulk composts used in Scotland.

A look at the distribution of counties (Figure 4.7) and parishes (Figure 4.8) citing lime and lime mixtures among their manures indicates that, according to the parish records at least, this interpretation appears to be a reasonable one. While the more detailed County Reports list lime composts as known in the majority of areas, it would appear that at parish level, lime composts are in a distinct minority, mentioned in only twelve accounts, despite lime being the most popularly cited manure of all the parishes which provide detail on manure methods, with 464 citations.

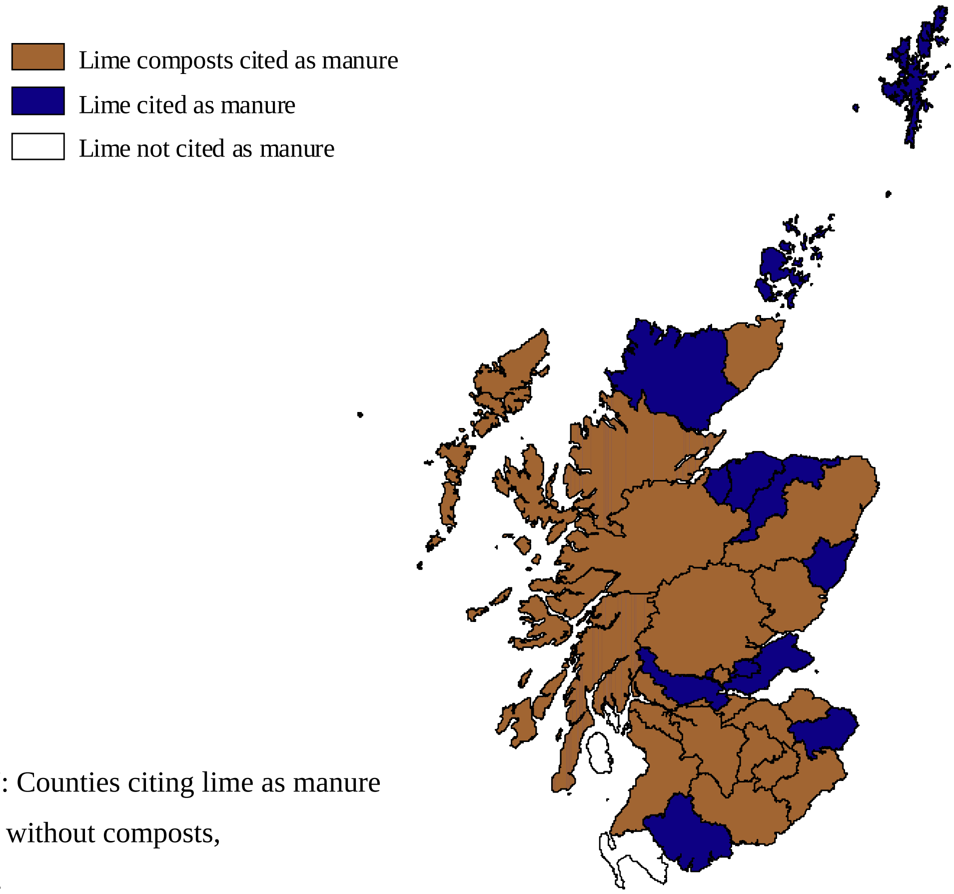


Figure 4.7: Counties citing lime as manure within and without composts, 1793-1814

Of these 464 parishes, Figure 4.8 shows the distribution of those who cite the use of lime, but do *not* mention the use of composts, therefore giving as clear a picture as possible of the distribution of parishes applying lime *instead of* making bulk manure composts. 252 of 363 parishes fall into this category. The total number of parishes citing the use of lime with dung is 176.

Once again, these figures should be approached with an understanding of the way in which these manures are commonly cited, especially in the parish reports. As is the case with seaweed composts, many parishes may cite 'lime', 'dung' and 'composts' in their list of manures without specifying whether or not these coincide. The real number of parishes using lime in their composts is therefore likely to be higher. There is also a strong tendency for parishes with little detail on agriculture and manuring in general to favour statements such as '*Lime is used as a manure on all the farms*' (FSA XI: 431) or state that the land is '*much improved by lime*' (FSA III: 110), without giving further details on other manures. It would appear, then, that the less agriculturally informed

Statistical Account authors may have a tendency to remark on that manure which signifies improvement and change, or perhaps the most widespread manure, at the expense of others.

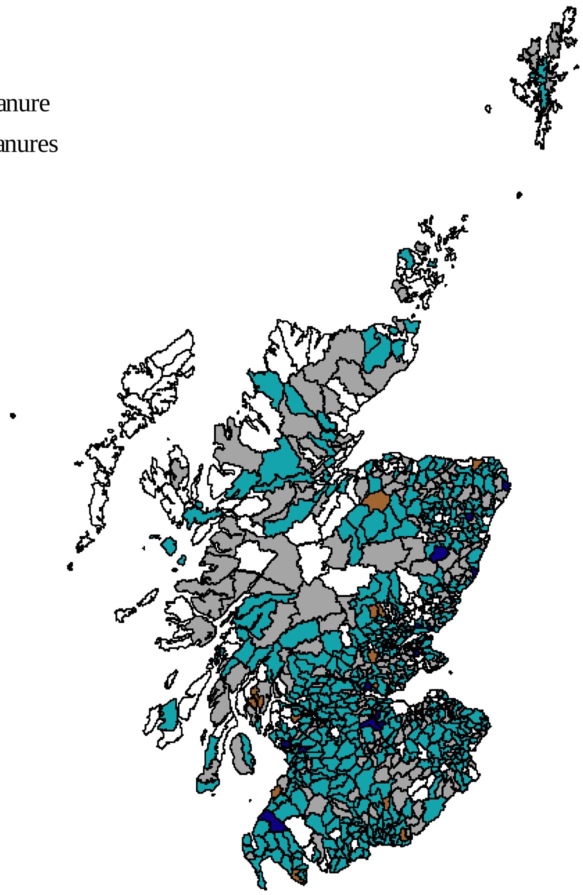


Figure 4.8: Parishes citing lime as a manure in composts, with dung, or alone, 1791-1799

Despite these caveats, the parish records in particular would appear to indicate that the use of lime is indeed likely to be linked with a decline in the making of bulk manure composts, but that this is not necessarily strongly linked with the adoption of a pattern of dunging and liming. Overall, it would appear that the introduction of lime as a manure in Scotland would have resulted in a reduction in the number of areas using compost manures, and therefore developing deep anthropogenic topsoils.

4.2.2.4 Analysis using the historical database: conclusions

It can be seen from all three analyses discussed above that one of the most important factors affecting the conclusions presented by the database is the way in which these historical datasets are interpreted. The examples cited above demonstrate that both the county and parish accounts do not necessarily provide a complete record of manuring practices in the areas they describe. Furthermore, the parish records in particular are susceptible to misinterpretation due to the language used by their authors who were, often, only partially informed of the intricacies of manuring systems in their districts, and who also often provide only an abridged account of agricultural and manuring practices in their reports.

In spite of this, the analyses presented above have also demonstrated that these records, representing the most extensive accounts relating to manuring practice available for Scotland in the historic period, are also an extremely powerful resource capable of displaying trends in manuring systems across the country. The creation of a database from these records has made it possible to see to what extent conclusions on the likely distribution of deep anthropogenic topsoils in Scotland taken from more general contemporary sources are supported by individual records which can be related to small-scale land parcels. As such, the historic component of this database the makes the first aim of this project – to research the geographical distribution and cultural context of anthropogenic deep topsoils throughout Scotland – achievable. The following sections describe how additions to this key resource allow this powerful dataset to be used in completing the project's second aim - finding deep anthropogenic topsoil areas with which to investigate the impact of land cover and modern-day agricultural activity upon the cultural information that these deep topsoils retain.

4.3 The database as a tool for locating deep anthropogenic topsoils

The following sections describe the addition of the secondary components of the database: geographical information taken from the Soil Survey for Scotland and archaeological information taken from the First Edition Survey Project and the Historic Landuse Assessment, and illustrates how the combination of these datasets with the historical data resource can produce a research tool to identify areas of deep anthropogenic topsoil.

4.3.1 Methodology: the geographical dataset

4.3.1.1 Manipulating the Soil Survey data

Section 4.1.3 described three features of the Soil Survey for Scotland dataset which have the potential to indicate the location of areas of deep anthropogenic topsoil: one, 'deep phases' of topsoil illustrated on several of the final Soil Maps, two, original soil surveyor field notes recording topsoil depth for each auger point taken for the survey, and three, written data on soil properties which may highlight areas of anthropogenic influence on the soil. The first two of these datasets, containing mapped survey information relating to topsoil depth, were added to this database.

In order to do this, this information had first to be transformed into a digital format. With the permission of the Macaulay Institute for Soil Research, the outlines of the deep topsoil phases shown on the final Soil Maps for Orkney Mainland and Orkney Hoy (Soil Survey for Scotland 1981: Sheets 6 and 7), Nairn and Cromarty (Soil Survey for Scotland 1974), Auchentoul and Reay (Soil Survey for Scotland 1985), and Latheron and Wick (Soil Survey for Scotland 1970) were digitised using AutoCAD and added to the database containing the county and parish records as polygon features. An illustration of this can be seen at Figure 5.2.

Permission to access the original survey data containing auger point records for topsoil depth was given by the Macaulay Institute, Aberdeen, where the original Soil Survey records are held. With the assistance of the Macaulay Institute, the auger point data remaining in the Institute's archive was located and the complete auger point record hand-traced from the original maps (a necessary step, as much of these original records were in a comparatively fragile condition).

Unfortunately, complete records for the areas covered by the Soil Survey were not available. The areas for which auger point data were available were portions of the counties of Ross and Cromarty, Nairn, Inverness, Caithness (already covered as deep phases on the final 'Nairn and Inverness' and 'Latheron and Wick' Soil Maps), Perth, Kinross and the majority of Aberdeenshire and Angus. Approximately 115 maps, each covering an area of approximately

1000m^2 were traced, with the number of topsoil points varying from one or two to over 500 per map. This point data was digitised in AutoCAD, separated into layers according to topsoil depth recorded, and added to the database, thus making it possible to filter topsoil points according to depth within the database. An illustration of the topsoil point dataset can be seen at Figure 4.9.

4.3.1.2 Disadvantages of the Soil Survey data

The major disadvantage to the Soil Survey dataset is that both the polygons and points of deep topsoil do not necessarily indicate anthropogenic soils, but may represent natural deposits of alluvium or colluvium, or features such as raised beach deposits. For example, alignment of the Soil Map for Latheron and Wick (Soil Survey for Scotland 1970) with topographical maps for the area shows that many of the areas of deep topsoil marked within the Camster and Bilbster Soil Series upon this map echo watercourses and are therefore likely to be alluvial deposits. Several other deep topsoil areas are marked as areas of peat on the original survey field maps, although no such distinction is seen on the final Soil Map, which simply records the entire area as deep topsoil.

These factors did not pose a significant problem for the dataset, however. The generally clustered nature of the deep topsoil phases shown made it feasible for surveys focused on these features to investigate those polygons suspected of representing natural deposits along with those more likely to be of anthropogenic origin without compromising the efficiency of the surveys (for example, the survey at Nairn presented in Section 5.2).

A second concern for the Soil Survey data is the locational accuracy of the topsoil points traced from the original field surveyor’s maps. The condition of this original dataset was fairly poor, which made geo-referencing the topsoil points difficult for some areas. The Aberdeenshire topsoil point dataset is particularly problematic. As the oldest set of surveyor’s maps that could be located, the field maps for Aberdeenshire were not aligned to the Ordnance Survey grid, and could only be located using topographic features noted on some of the maps. Many of the maps were also damaged and therefore also difficult to locate. Some distortion, especially in the Aberdeenshire topsoil point dataset, would seem to be inevitable.

A trial auger survey was undertaken to explore the extent of this possible distortion through the parishes of Keig and Alford in Aberdeenshire, which show a large number of topsoil points of up to 30 inches deep, heavily clustered at various points within these two parishes. The survey failed to locate topsoils any deeper than c. 10 inches. It was decided as a result of this survey not to use the deep topsoil points taken from the Aberdeenshire maps.

4.3.2 Methodology: the archaeological dataset

Both the First Edition Survey Project (FESP) (RCAHMS/ Historic Scotland 2002) and the Historic Landuse Assessment (HLA) (Bruce *et al.* 1999) digital datasets were supplied on CD ROM by RCAHMS. These datasets were provided in a GIS format and referenced to the British National Grid projection system (datum OSGB 1936), and could therefore be added immediately to the ArcView database with no data manipulation necessary. An example of this is seen in Figure 4.9, which shows a snapshot of the First Edition Survey Project data and the deep topsoil points from the Soil Survey field data displayed together for an area of Kinross, delimited by parish boundaries. Extant MoLRS remains are seen to coincide with topsoil points over 15 inches deep in several areas.

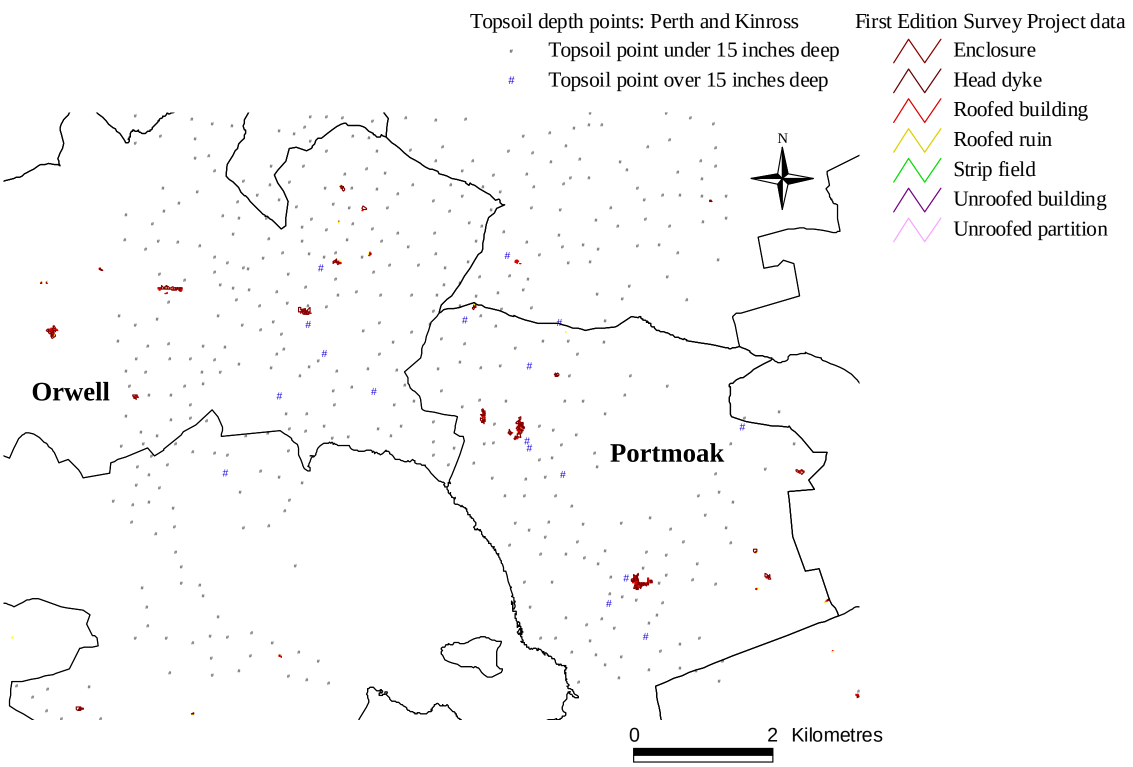


Figure 4.9: Orwell and Portmoak parishes, Kinross: interaction of FESP and Soil Survey point data

4.3.3 The historical dataset as a tool for locating deep anthropogenic topsoils

With the Soil Survey and archaeological data in place in the database, the potential role of the historical dataset as a tool for locating deep anthropogenic topsoils was considered. How could this powerful dataset be manipulated to provide the most accurate indication of likely areas of deep topsoil development whilst taking into account the particular limitations of a historical resource?

The analyses presented in Section 4.2.2 clearly illustrate that individual pieces of information from the historical datasets cannot be simply 'fed' into the GIS database and used as a predictive tool. However, what these analyses do indicate is that, especially in the case of the First Statistical Account, the large amount of data available on manuring coupled with the sheer number of data records means that information from an *entire* parish record read *in context* can provide a valid and detailed dataset which can display trends in manuring practice across the country.

A classification system for the First Statistical Account was therefore established which attempted to translate the sum total of evidence for different manuring materials or practices given in each parish record into a series of categories, grading each parish on its potential as a location for deep anthropogenic topsoils. Table 4.1 describes this classification system.

Table 4.1: Classification of First Statistical Account manuring data

Class	Description
0	No reference to manure materials or manuring practice
1	Reference to the use of lime **only**
2	Reference to the use of a variety of materials, but **excluding** dung or bulk manures such as earth or turf
3	Reference to the use of dung **only**
4	Reference to the use of dung and other materials such as lime, but **excluding** bulk manures such as earth or turf
5	Reference to the use of a mixture of dung and bulk manures (providing the potential for deep anthropogenic topsoil development) but including other materials such as lime, indicating a **modification of traditional manuring practices**
6	Direct reference to plaggen-type manuring practices, citing the use of dung and bulk manures such as earth or turf, indicating a **continuation of traditional manuring practices**

It can be seen that this classification serves a variety of purposes. At its simplest, this system provides a means of isolating those parishes which give direct evidence for the use of manure materials and practices which have the potential to lead to deep anthropogenic topsoils: Classes 5 and 6. However, this classification system also separates out other features of this complex dataset in a way that takes into account many of the idiosyncrasies of the historical record highlighted in Section 4.2.2. For example, the abridged style of many of the First Statistical Accounts strongly suggest that many of the Account authors, by mentioning the use of lime only, are perhaps reflecting their interest in a material signifying improvement and change, or are perhaps either ignorant of or uninterested in manuring, citing only the most widespread manure (this last is also possible with citations of dung alone). Therefore, while the overall classification attempts to reflect the shift from 'traditional' to 'modern' methods, in separating those parishes citing lime only into a unique subset, the classification takes this possible bias into account.

More importantly, however, this classification system also takes into account the fact that the shift from the use of bulk manures to modern fertilising materials was not a linear process, a fact clearly reflected in the huge variety of manuring practices described in the First Statistical Account. The presence or absence of a particular manure does not necessarily reflect the likelihood of deep anthropogenic topsoils having developed in a parish. For example, as discussed in Section 4.2.2.3, individual responses to manuring strategies plus the varying distribution of manure resources make it incorrect to cite the presence of lime as an indicator for 'modernisation' and therefore the absence of manuring practices with the potential to create a deep anthropogenic topsoil. The classification system attempts to address this by highlighting those parishes which directly cite plaggen-type manuring systems along with those which may use more 'modern' manures such as lime, but whose parish accounts also indicate that sufficient elements of a plaggen-type manuring system were in place for deep anthropogenic topsoils to develop.

Most of all, however, the strength of this classification lies in the fact that the process through which it is created – a careful reading of the entire record in context – is the most appropriate means of extracting usable information from this particular dataset. To reduce the information given in First Statistical Account to its most accurate quantified format, a certain degree of *interpretation* of the record has to be admitted into the process. While this does not sit easily with the concept of creating a quantified database, the nature of the source data is such that without this treatment, the historical dataset remains effectively unprocessed.

This classification system was applied to the entire First Statistical Account record and the six Classes added to the GIS database. From this, Classes 5 and 6 (those indicating a potential for deep anthropogenic topsoil development) could be isolated to show a distribution of potential according to the historical dataset. Figure 4.10 shows the distribution of this, isolating Classes 5 and 6 (described at Table 1) as the set showing the highest potential to develop deep topsoils.

In addition to this, a second set of lower, but still present potential is indicated. This consists of those parishes classed as 4 according to the description at Table 1: areas where dung and a mixture of other manures are cited, but bulk manures such as earth and turf are not

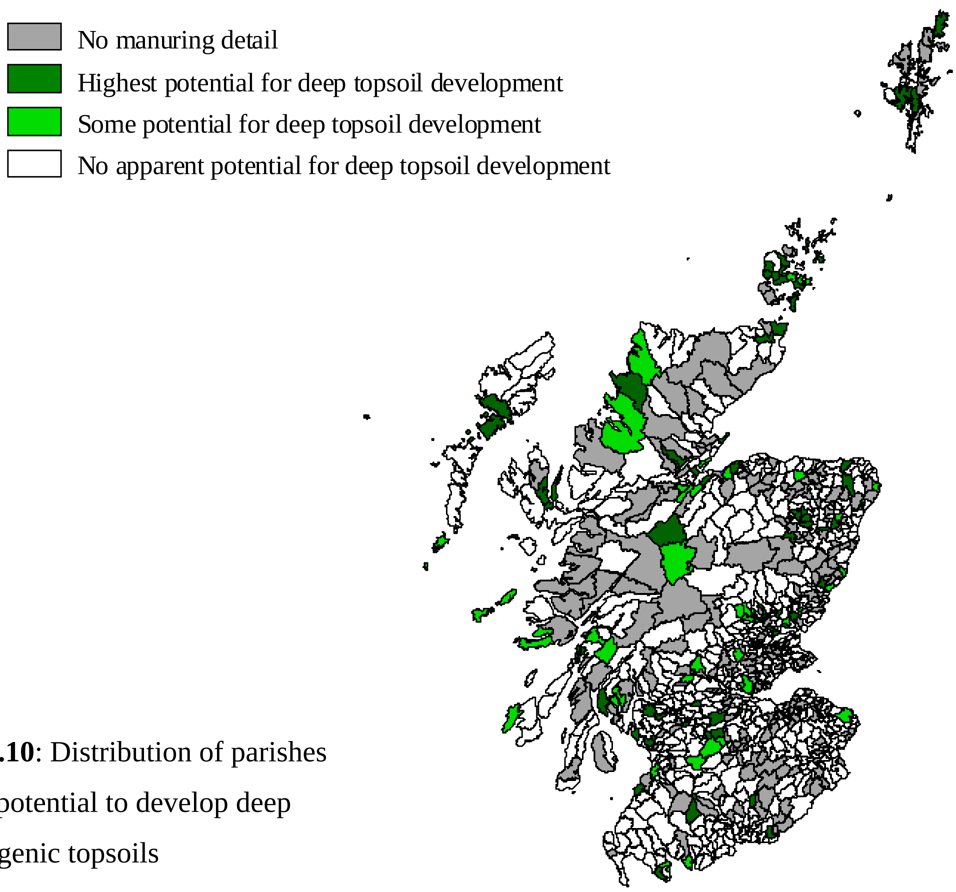


Figure 4.10: Distribution of parishes with the potential to develop deep anthropogenic topsoils

specifically mentioned. This illustrates the way in which this classification can be used to explore a variety of possibilities within the historical dataset: historical evidence indicates that it is likely that much of the domestic waste added to compost dunghills would have comprised some mineral element, through ashes or the remains of turf or earth housing or dyke fragments, although this is rarely specified in the Statistical Account texts. This combination of materials would, by default, fall into the Class 4 set in Table 1. The manuring classification can therefore also be used to examine the distribution of more general categories of evidence than those listed within Appendix 4, highlighting areas within which some potential for deep topsoil development may exist.

4.3.4 Summary

Through the spatial analyses presented in this chapter, several of the factors identified in Chapter 3 as potentially having an effect upon the distribution and frequency of deep anthropogenic topsoils in Scotland have been explored further. The first of these supports the suggestion made in Section 3.3.3: that although turf was an important part of the manure resource, there is little evidence for a well-organised plaggen-type manuring system of the kind recorded on the Continent. Rather, Section 4.2.2.1 indicates that turf and turf-derived materials appear more likely to have been utilised through general processes of recycling which would cause little comment among, especially, the First Statistical Account authors - for example through ash going into the dunghill.

A graphic presentation of the distribution of seaweed versus seaweed composts in Section 4.2.2.2 also supports the observation made in Section 3.3.5: that although seaweed does appear to have been preferred as an uncomposted manure, the record of seaweed composts maintains that the reliance of a parish or area on seaweed for manure need not preclude the development of bulk manuring techniques, and therefore the development of deep topsoils. Finally, the analysis of the distribution of lime manuring and its relationship to more traditional manure systems seen in Section 4.2.2.3 appears to indicate – as suggested in Section 3.3.6 – that the spread of lime would indeed have had a negative effect upon patterns of intensive manuring across Scotland.

Alongside these observations, this initial analysis has acted as an evaluation of the manuring database itself, highlighting several potential drawbacks to using these historical sources from within a database format. However, this chapter demonstrates that the notable inconsistencies, omissions and most particularly, textual ambiguities present in the data need not present insuperable problems. The manuring classification presented in Table 4.1 provides a framework through which these issues can be addressed to provide the maximum possible insight into likely deep topsoil distribution as indicated by the historical records. The use of this manuring classification, in conjunction with the geographical and archaeological datasets presented in Sections 4.1.3 and 4.1.4, therefore provides a powerful and intelligent database tool for use in the investigation of the distribution and frequency of deep anthropogenic topsoils, a tool which facilitates the survey program presented in the following chapter.

5. Site survey and sampling

This chapter discusses the programme of auger survey undertaken for this project within five Scottish regions, and the sampling parameters chosen for the deep topsoil profiles successfully identified at sites within three of these areas. The purpose of the survey programme was threefold. Firstly, to identify a suitable group of sites to provide sample locations for the second aim of this project: investigating the impact of land cover and modern agriculture on the cultural information retained in Scottish deep topsoils. Secondly, to construct a methodology for the survey programme as a means of investigating the practical capabilities of the manuring database, described in detail in Chapter 4. Finally, the survey programme also allowed scope for several of the propositions concerning the distribution of deep anthropogenic topsoils in Scotland suggested in Chapters 2 and 3 to be explored further. By incorporating a series of desktop studies into the historical and archaeological likelihood of deep topsoil development in each study area, undertaken prior to fieldwork investigation, a more focused exploration of several of these themes became possible.

Two of these are familiar from both the database assessment in Chapter 4 and the review and discussion in Chapter 3: namely, the position of turf and bulk manures in the Scottish system, and the possible role of seaweed fertiliser in discouraging deep anthropogenic topsoil formation in coastal areas. The first of these is a feature of each of the surveys but especially Survey 3 (Unst), and the latter the focus of Survey 4 (Tiree). However, the design of the survey program and the areas targeted as a result (Section 5.1.3) also provided an opportunity for two additional propositions to be explored. Already introduced in the review and discussion presented in Chapter 2, these are the possible influence of imported agricultural techniques, particularly those linked with the spread of monasticism, upon Scottish manuring practice (Survey 4, Solway), and, especially, the likely significance of urban settlement patterns on the distribution of deep anthropogenic topsoils (Survey 1, Nairn, and Survey 2, Angus). This last is shown in this chapter to be a potentially significant influence on the distribution of deep anthropogenic topsoils in Scotland.

In addition to this, however, the five studies that comprise this chapter also illustrate the dangers inherent in adopting only these generalised hypotheses to explain the distribution and frequency of deep anthropogenic topsoils in Scotland. As discussed in Chapter 4, these cultural soils are the result of a complex relationship between society and its environment which, unlike that seen on the Continent, appears to have operated in Scotland on a small and individualistic scale. To be credible, research into these soils must therefore be conducted at the same scale, and cognisant of the great variety of both environmental and cultural factors which combine to characterise *individual* anthropogenic deep topsoils. The structure of this chapter therefore follows the suggestion offered at the beginning of Chapter 2 – the placing of the manure input system within its *specific* cultural context in order to create a meaningful archaeological framework. Such an approach is central if one is to understand the various manuring strategies leading to the creation of these soils and therefore their specific cultural significance. The structuring of the survey methodology to allow exploration of these general hypotheses alongside factors particular to individual survey areas is discussed in the following section.

Chapter 5 is therefore at the centre of this thesis. The survey programme described below links the two aims of this project: exploring the practical potential of integrating the archaeo-historical research themes discussed in the preceding chapters with the analytical programme undertaken in those to come.

5.1 Survey programme methodology

5.1.1 Assessing the manuring database

As described above, a key aim of the survey programme was to investigate the potential for the different components of the manuring database to be used as a tool for locating deep topsoils.

The design of this maintained the primacy of the historical component of the manuring database, mainly represented by the First Statistical Account research. Therefore, each area selected for survey is one either wholly or partly indicated as having a high potential for deep anthropogenic topsoil development according to this historical component (Section 4.3.3). From within these groups, individual areas were then selected which provided an opportunity to integrate the secondary database resources – the geographical and archaeo-historical datasets described in

Sections 4.3.1 and 4.3.2 – into the fieldwork investigation. Examples of such areas include locations where historical and geographical information combine to create an area of particularly high potential for deep topsoil development, a location where the existence of secondary archaeological or historical survey data exists to refine an area of potential highlighted by the manuring classification described in Section 4.3.3, or survey over a range of areas with a range of both high and low potential in the database.

5.1.2 Thematic approaches

The five survey areas were also selected to represent a range of geographical areas and a variety of both urban and rural contexts. This contributes to the value of the survey programme as an evaluation of a database which has been shown to provide varying levels of information across different areas of Scotland, as discussed throughout Chapter 4. However, of greater value to this project is the insight that a range of surveys within the varied farming regimes associated with different parts of the country may offer. As discussed in Chapter 3, the range of manure materials used by farmers throughout Scotland during the pre-Improvement period appears to have been influenced by a variety of economic, geographic and social factors which are likely to have either encouraged or inhibited the development of deep anthropogenic topsoils in different farming regions. Several of these input-related factors are highlighted further in the analysis of the historical element of the manuring database seen in Section 4.2.2, such as the complex role of seaweed in the manuring system, and the varied attitudes seen to exist towards the use of turf manure. The theoretical importance of understanding the crucial role played by *localised* farming traditions throughout Scotland in creating deep anthropogenic topsoils is outlined above; however, from a methodological point of view, an additional consideration is how even a database resolved to parish level can adequately investigate and identify such patterns. The survey methodology, in undertaking not only localised survey, but also localised desktop archaeo-historical study takes this research programme to a level beyond that possible through analysis of the manuring database alone. Therefore, the survey programme can be viewed as an end in itself – a series of field investigations into a range of areas with differing farming strategies, and an exploration of whether their individual circumstances could result in the area supporting a plaggen manuring system.

Overall, this survey programme acts as a representative series of evaluations, both of the reliability of this database and its potential to interact with other sources of information, and of the potential for pre-Improvement Scottish farming regimes to develop deep anthropogenic topsoils.

5.1.3 Conditions of the survey methodology

A variety of conditions were applied to the survey programme in order to investigate, and ultimately to obtain sample sites, from a range of geographical and agricultural contexts. These were as follows:

- To select at least one survey site within each of the following: the Highlands, the Central Belt area, the Lowlands or Border region, the Northern Isles, and the Western Isles;
- To select survey sites within a mixture of rural and urban-influenced contexts of the Improvement Period. An 'urban-influenced' context in manuring terms would refer to areas where urban manures such as human waste, or industrial manures, would have been available;
- To select at least one survey site within each of the following pre- or immediately post-Improvement period landscapes: a predominately arable area, a predominately pastoral area, and a 'crofting' area supporting a mixed farming regime.

Within these parameters, a series of locations were selected for survey which also provided an opportunity to explore the following:

- Integration of the historical dataset with the Soil Survey 'deep phase' polygon dataset (Section 4.1.3; Figure 4.9);
- Integration of the historical dataset with the Soil Survey 'topsoil point' dataset (Section 4.1.3; Figure 4.10);
- Exploration of the possible role of other digital archaeological datasets in assisting identification of sample areas for deep anthropogenic topsoils (Section 4.1.4; Figure 4.11);
- Survey in an area where no secondary dataset is available to further resolve the parish dataset.

Five survey areas were chosen using this methodology. These were:

- Selected areas surrounding Nairn, located to the west of Inverness in the Highlands;
- A group of parishes in Angus, to the north of Dundee, in the east of the Central Belt;
- Selected areas on Unst, the northernmost inhabited island of the Shetlands archipelago;
- Selected areas on the island of Tiree, in the Inner Hebrides;
- A group of parishes on the Solway coastline, in the south-west Dumfries and Galloway region.

Figure 5.1 shows the location of these survey areas. The following sections describe the selection of each area, the results of desktop archaeo-historical investigation into the manuring tradition of each area, the results of each auger survey programme and, where a suitable range of deep anthropogenic topsoils were identified, the sampling programme for each site.

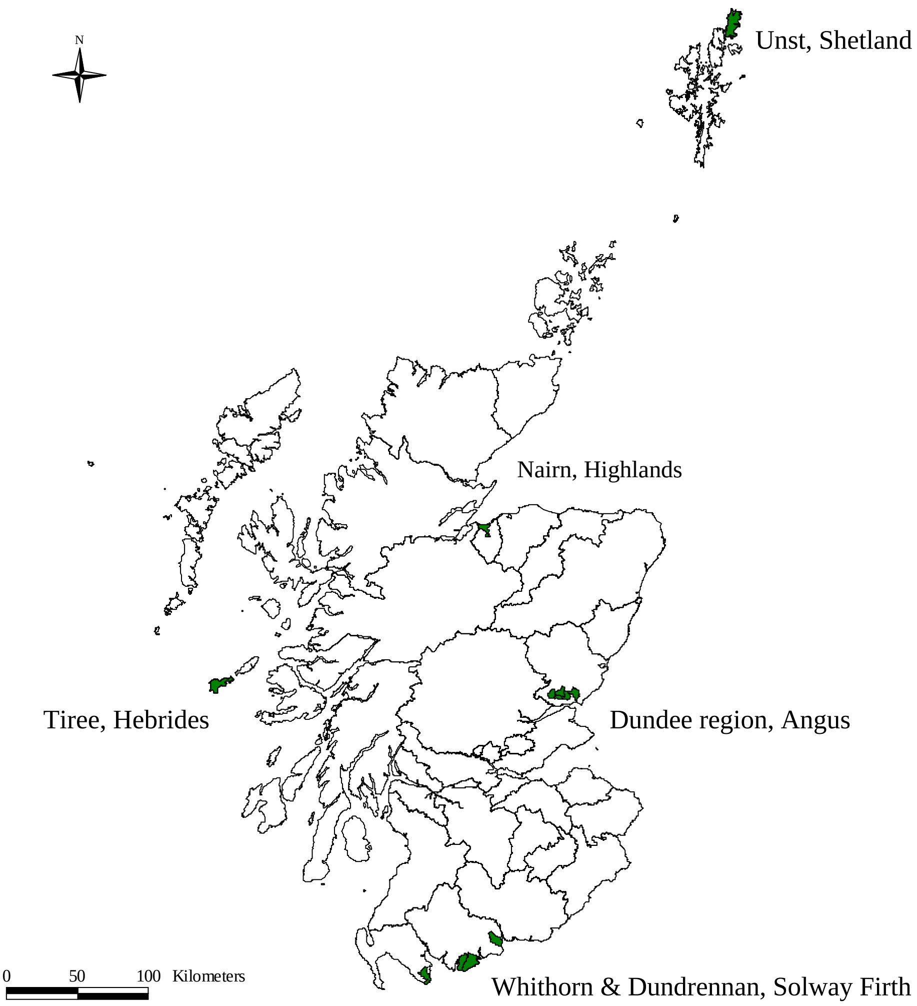


Figure 5.1: Location of parishes selected for the auger survey programme

5.2 The auger survey and site sampling programme

5.2.1 Survey 1: Nairn, Highlands

5.2.1.1 Site selection

The first survey area to be selected centred on the town of Nairn, located on the Moray Firth approximately 15 miles north-east of Inverness. This area fulfilled several of the requirements of the survey methodology. Firstly, this area provided an opportunity to explore the potential of data integration between the historical and geographic components of the manuring database, with the Nairn and Cromarty Soil Map (Soil Survey for Scotland 1974) as one of the five Soil Maps indicating deep phase topsoil polygons. From these five maps, the topsoil polygons recorded by the Soil Survey at Nairn were selected as the most suitable for analysis, for two reasons. As previous work (e.g. Simpson 1997) had already taken place using the Orkney Soil Maps, these were ruled out, and of the remaining three maps (Section 4.3.1.1), that of the Nairn area showed the least likelihood of indicating alluvial or peat areas rather than anthropogenic topsoils, as discussed in Section 4.3.1.2.

In addition to this, the series of deep topsoil polygons mapped on the Nairn and Cromarty Soil Map cover several parishes which fall into each category defined by the historical dataset, from those giving no data on manuring practices to those with the highest potential for developing deep anthropogenic topsoil. This provided an ideal opportunity to assess a possible relationship between deep topsoil indicators provided by the historical and geographical datasets (Figure 5.2).

Nairn fulfilled the requirement to undertake a survey in a Highland area, and with several of the polygons relatively close to Nairn - a medieval Scottish burgh, now a thriving seaside town - this survey also provided a possible opportunity to investigate an urban-influenced context.

5.2.1.2 Auger survey

Auger survey was undertaken through each deep topsoil polygon indicated on the Nairn and Cromarty Soil Map, through the parishes of Inverness and Bona, Petty, Ardersier, Nairn, and Forres further to the east. Approximately 100 auger points were taken, on a generally random basis dictated by access to the polygon areas.

Most of the polygons within the high rated parishes located along the Moray Firth coast proved to be raised beach deposits. The survey also failed to locate the deep phase polygon at Forres, also a high-rated parish (Figure 5.2).

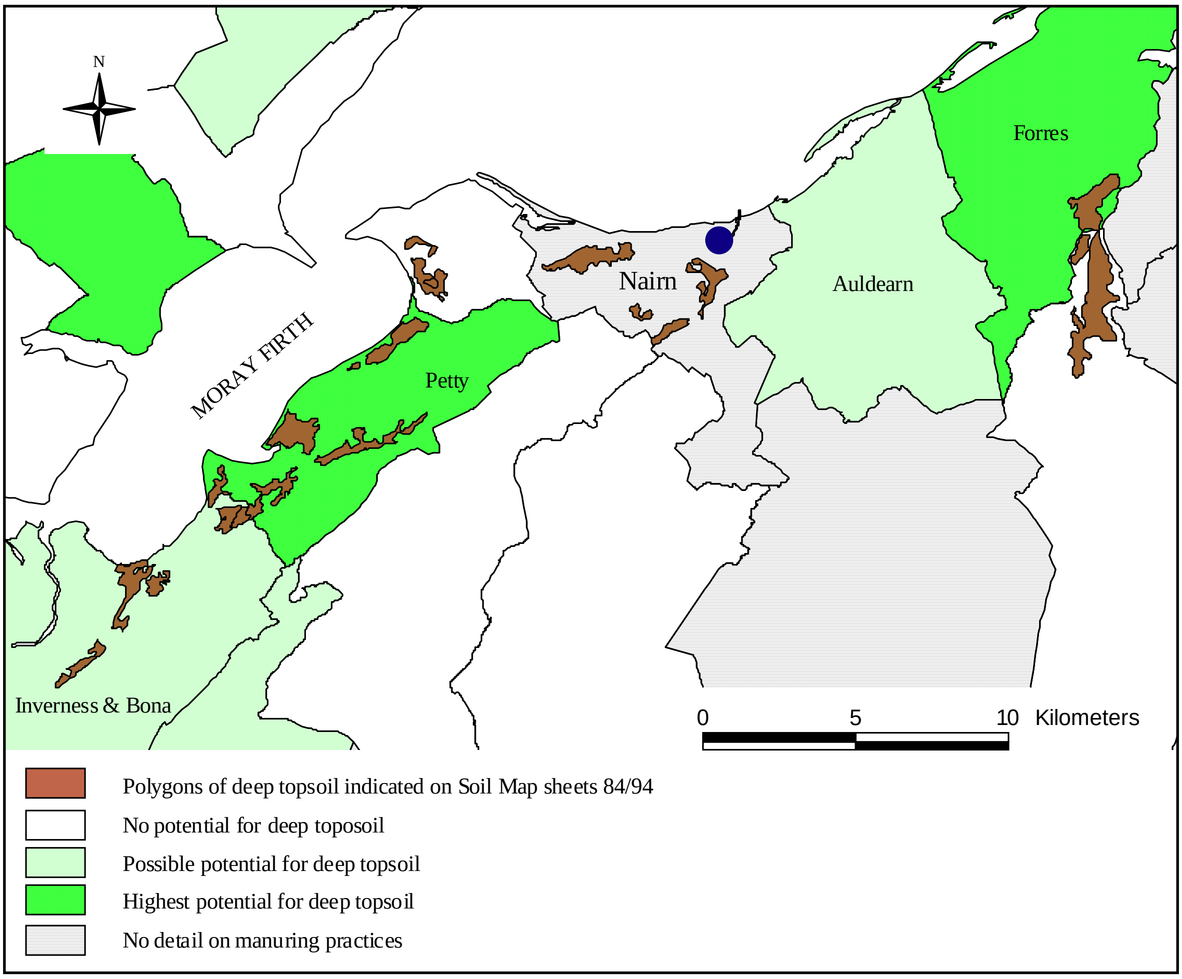


Figure 5.2: Integration of parish and Soil Survey data around Nairn, Highlands

However, survey within the polygon immediately to the south of Nairn itself identified a very deep (up to 1.15 m), dark topsoil, which appeared to be of anthropogenic origin. The deep anthropogenic topsoil identified from the survey was therefore located within a parish providing 'no detail' on manuring practice according to the historical component of the database – a feature already identified as a major drawback to the Statistical Account-based dataset.

Located on the immediate edge of the current extent of the south Nairn suburbs, the deep topsoil polygon was located mainly within arable farmland, extending into small areas of grassland and woodland associated with residential buildings. The polygon was bisected from north to south by a road of medieval origin (Figure 5.3).

More detailed auger survey was undertaken throughout the deep topsoil polygon, conducted at 10 to 30 m intervals, through approximately 50 auger points. This confirmed that the deep topsoil area consisted of one soil unit, deepest in the northern part of the polygon (to a maximum depth of 1.15 m) and gradually declining south to an average depth of 30-50 cm. The eastern part of the polygon, adjacent to the river, contained some areas of lighter alluvial deposits.

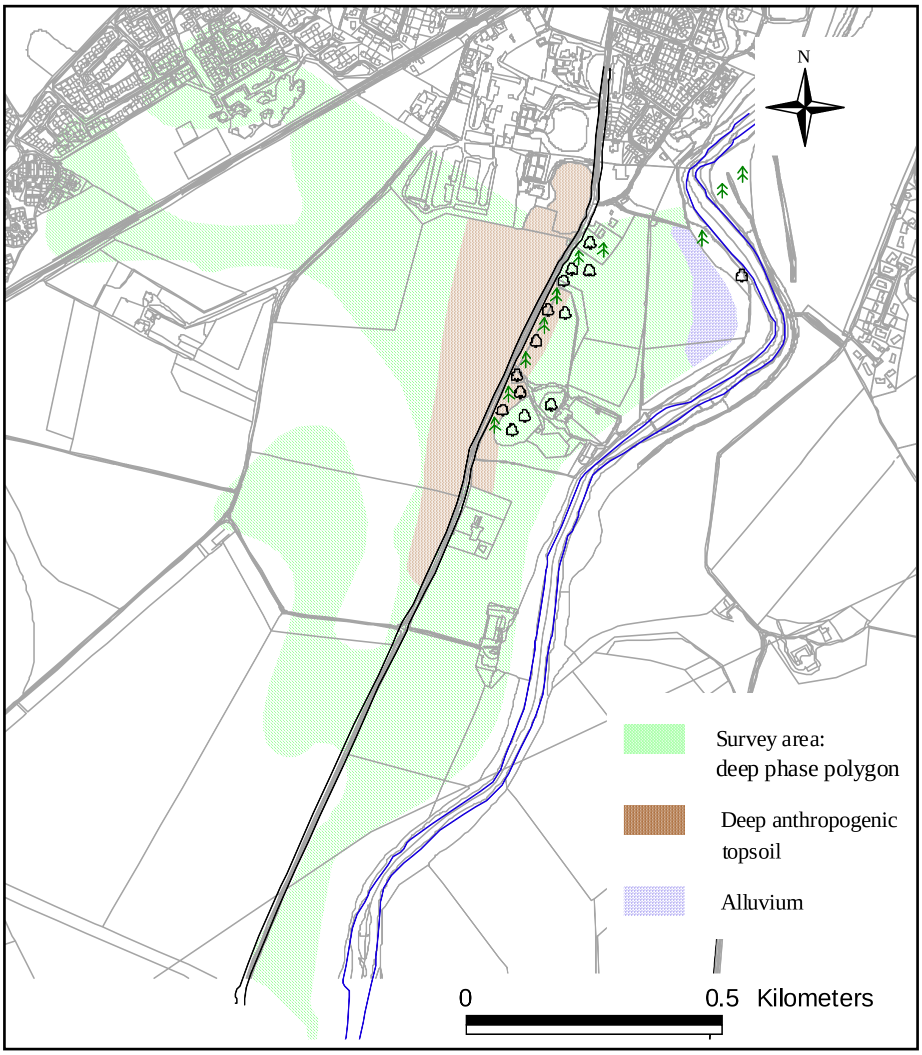


Figure 5.3: Detailed auger survey through Nairn deep topsoil polygon

Slightly deeper topsoil was recorded immediately adjacent to the fence and road in the areas under current arable cultivation. This was interpreted as most likely to be the result of ploughing technique (J. Forbes pers. comm.) and is unlikely to indicate topsoil disturbance through road construction/ modification.

5.2.1.3 Historical and archaeological context

a. Nairn and surrounding area

As the parish of Nairn is one of those which give no detail on manuring practices, direct information for manuring tradition in Nairn appears to be limited to the County Agricultural Report of 1794 (J. Rose-Miller, Nairn Museum pers. comm.). No historical farm diaries survive for the local area, the closest being the records for Balintraid (near Fortrose, to the north-west), which also give no detail of manuring traditions (Inverness Regional Archive pers. comm.).

The County Agricultural Report for Nairnshire mentions the use of dung, marl, turf and sand as manures, applied via compost dunghills or, in the case of pure dung, by 'teathing' animals on the land (Donaldson 1794b: 14). In addition to these popular methods, however, is described the following:

> *'Sheep… are shut up in the house every night, the floor of which is from time to time thickly covered with a bed of turf or sand, so as to form a kind of compost dung-hill…from two to about four feet in depth. Beside this, the dung afforded by the black cattle and horses is also formed into a compost dung-hill, of which about three-fourths is generally pure sand, the least earthy and largest particles being universally preferred. Of these two there must be amassed in the course of a year such a quantity as is sufficient to spread over one-fourth of the farm…'* (Donaldson 1794b: 14).

The parallel with known descriptions of the traditional method of plaggen manuring (Section 2.1.2) is clear. From the account above, manuring inputs appear to be limited within the sheep 'house' to turf, sand and dung: if this is the case, we can assume that the resultant manure, with its high mineral content, would have resulted in augmentation of the soil, and perhaps over time the formation of a topsoil comparable to the plaggen deposits of the Continent. Moreover, the reference to the 'least earthy' portion of sand being used seems to suggest that this sand, rather than being taken from the beach, was subsoil, dug out in a way similar to the plaggen system. However, this is somewhat conjectural.

The above quotation represents the only evidence for bulk manure usage in the Nairn area. Turf houses, common throughout Scotland in the pre-improvement period, are recorded in Nairn (Rampini 1897: 306), but there is no record of their components being used as manure material. Although farmers in the Nairn area held peat cutting rights for extensive nearby mosses, these were exhausted by the late eighteenth century, and there is no evidence to suggest that what must have been a valuable fuel resource were used as a component of byre bedding rather than for burning (Simpson 1956).

The First Statistical Accounts for the neighbouring parishes of Dyke & Moy and Auldearn list lime, marl, seaweed, ashes and even mortar as being used for manuring, indicating an inclusive rather than exclusive tradition of inputs. It is unlikely that the manuring traditions of the people of the area in and around Nairn would have differed greatly, and we should assume that they would have at least been familiar with this variety of manures. Therefore, although there is a strong suggestion that aspects of the Nairn system would result in an augmented, plaggen type topsoil, it is also possible that a greater variety of inputs were used than was typical of the traditional plaggen system.

This is especially true considering the location of the polygon itself, on a main road out of what was a fairly extensive medieval burgh, through which the wastes from the town would have been conveyed. We know that these wastes were extensive: the Nairn Burgh Council Minutes for 23 December 1756 state that: '*the streets had been brought to ruine and become a publick nuisance by laying dung and dunghills upon and near them*'. From this year, a fine was levied on anyone placing rubbish or dung on or within ten feet of the street and leaving it for longer than a week. What was a nuisance within the town was, however, recognised as an asset outside it: anyone willing to remove such waste was permitted to sell it, as long as this was at a reasonable price and, significantly, only to '*occupiers and for the use of lands holding of the town*', since the '*town lands (had) a preferable title to dung made and gathered about the town*' (Dennison and Coleman 1999: 30). It is thus highly likely that components of this town waste, including human manure, would have contributed to the formation of the deep topsoil polygon in this location (Section 3.3.2).

It is therefore likely that the deep topsoils formed at Nairn represent a complex manuring input system, into which both urban and agricultural manure materials were fed.

b. The deep topsoil polygon area

Historical map records for the area covered by the deep topsoil polygon, though providing no direct evidence for manuring practices, contribute significantly to our understanding of possible manuring activity in this particular area. One map of 1770 covers this area in detail. Titled '*A Plan Of The Contraverted Grounds Between John Campbell Of Calder Esq. And The Toun Of Nairn*', this was drawn up as a record of a land dispute, and therefore shows in detail the division of fields for this area, plus descriptions of their use and agricultural value. A group of fields roughly in the shape of the deep topsoil polygon are highlighted on the map as areas of prime 'tillage', bounded by marshland to the west and the River Nairn to the east (Plate 5.1). This strongly indicates that this area had already undergone intensive manuring prior to the eighteenth century, and that the present-day deep topsoil polygon might even reflect the agricultural divisions of this pre-Improvement landscape.

Plate 5.1: Detail from John Calder's 1770 map, with Soil Survey deep topsoil polygon overlain onto 'prime tillage' land parcels

Where might the bulk manure materials responsible for the depth of topsoil in the polygon come from? As is the case today, the 1770 map clearly shows the line of the main road south from Nairn running through the polygon, pointing to a possible waste input from the town itself. Closer than this, however, is an area immediately to the east of the polygon, across the river, marked '*Alcherach*' – sheep haugh (Simpson 1956). It is tempting to think that the deep topsoil polygon might indeed be partly the result of the sheep husbandry strategies described in the County Agricultural Report, carried out adjacent to an area of prime arable land which would receive the manure produced by the 'sheep-housing' method. However, this is conjectural.

More definite are the associations known to exist between the deep topsoil polygon area and the Church. The lands of Broadley, to the immediate south of the deep topsoil polygon, were owned by the church for long periods (Highland Council Archive pers. comm.). As church lands were typically well-managed, by those with money and resources to care for their arable resource, they would be more likely to be intensively manured. This would appear to be the case for the area containing the deep topsoil polygon: the area is marked '*Grishop*', a name derived from '*grieveship*' – that is, the area managed by the *grieve*, or overseer of Church lands (Simpson 1956). Evidence taken from other historical maps of the area seem to indicate that this area was a prosperous one: the houses of Balblair, Broadley and Firhall are all noted on Thomson's 1830 map of Nairn and Elgin, with the next notation to the south being that of Cawdor Castle (Thomson 1830).

5.2.1.4. Assessment of the manuring database

The survey at Nairn represents a significant positive result for the data provided by the Soil Survey final map series. Although the suspicion that many of the 'deep phase' polygons recorded on the final Soil Maps represent non-anthropogenic features was confirmed, the successful identification of a deep anthropogenic topsoil established that this portion of the Soil Survey dataset is a significant resource for the project.

However, the Nairn survey also highlighted the main drawback to the historical dataset taken from the First Statistical Account, namely the lack of data from a significant number of parishes. Were a more complete manuring record available from the parish of Nairn, the development of the deep topsoil polygon could have been investigated more thoroughly. This is discussed further in the assessment of the manuring database in Chapter 8.

5.2.1.5 Site survey and sampling programme

The deep topsoil polygon at Nairn provided an excellent sample site for the project. Within the one deep topsoil area, three land cover types were identified – arable, woodland and long-term pasture. The parent material is fluvoglacial sand (Boyndie Association), and the polygon located on river terrace material (Figure 5.4; Plate 5.2). Within the surveyed area, three sample points were chosen:

1. Long - term pasture. Ruallan Field, at the extreme north of the deep topsoil polygon, is a pasture of approximately 80 x150m, in the care of Mr. Allen, who confirmed that the field has had no agricultural treatment (e.g. ploughing, fertiliser application) for at least 20 years. The field has been intermittently used for grazing horses. Ramage's map of Nairn shows Ruallan Field as established pasture in 1910 (Ramage 1910). The sample profile was taken from the southern part of the field (Figure 5.4; Plates 5.2 & 5.3). See Appendix 5, Profile NA1.

2. Ploughed arable. The land directly to the south of Ruallan Field is part of Loch Ddu Farm, owned by Mr. J. Forbes. It was decided to locate the arable profile in the field immediately to the south of Ruallan Field (Figure 5.4; Plates 5.2 & 5.4). The field is in a ten-year cereal/ grassland rotation, and was planted with barley over the period of the survey. This profile was therefore not dug until after reaping in September. The field is currently manured with lime, potash and straw produced on the farm, fed back through the livestock as dung. However, up until the late 1940s, seaweed was carted into the area for manure, and, more recently, a local gasworks was a source for ash manure until demolition in the 1970s. The soil within the polygon is considered 'lighter and easier', giving higher yields for less effort (J. Forbes pers. comm.). See Appendix 5, Profile NA3.

3. Woodland. Firhall, located east/south-east of the arable sample area, is a stately home which dates to the 1870s, around which is planted approximately half an acre of woodland (Plates 5.2 & 5.4). The layout of the woodland suggests that it is contemporary with the house, planted as part of the layout of the grounds. The house and surrounding lands are currently under development. A sample profile was taken form within the densest part of the woodland, between the house and the road (Figure 5.4). See Appendix 5, Profile NA2.

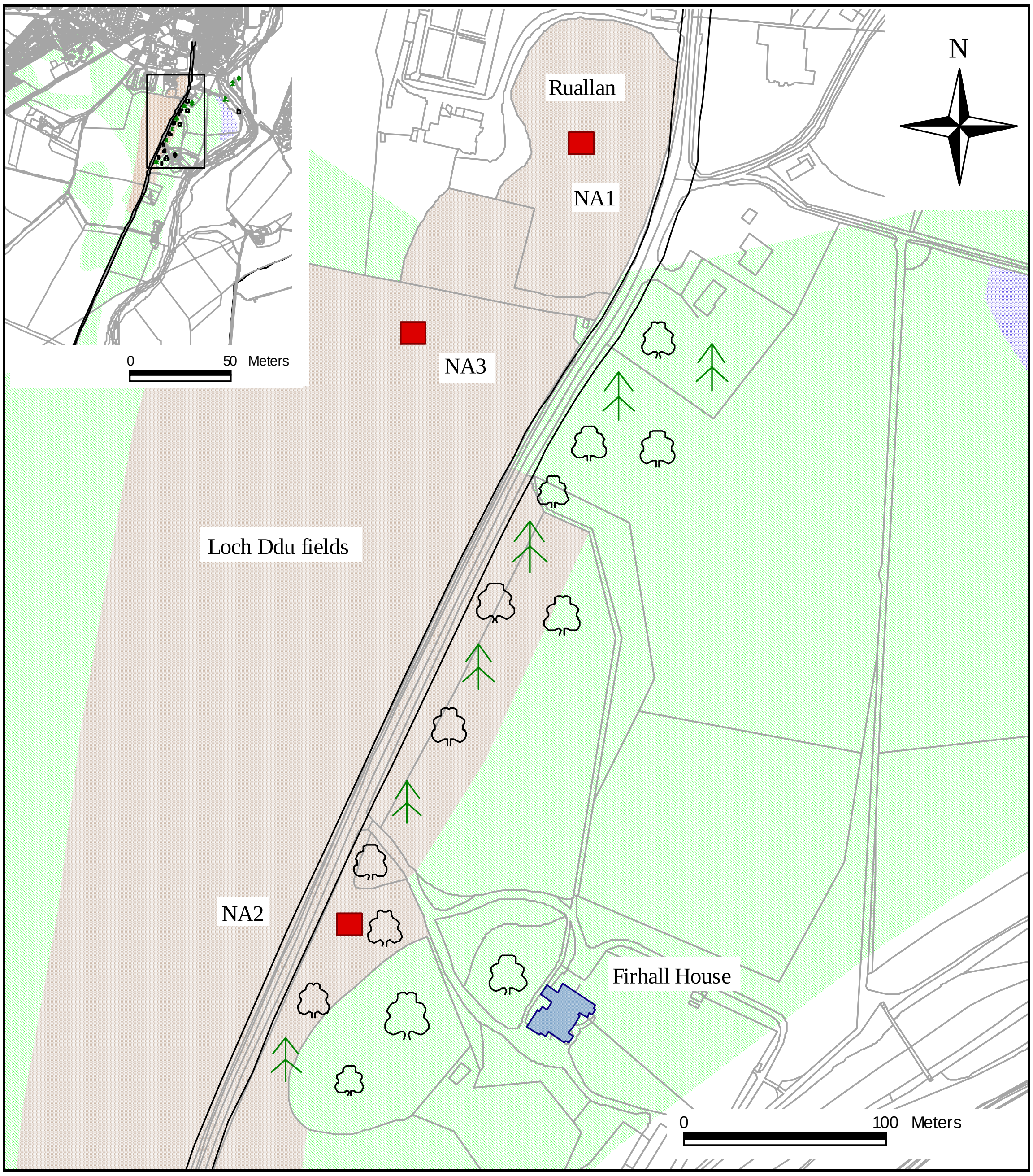


Figure 5.4: Position of sample pits within Nairn deep anthropogenic topsoil polygon

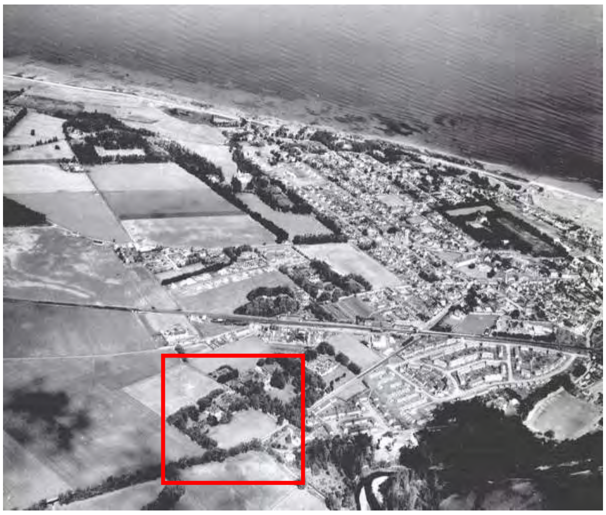


Plate 5.2: Aerial view of Nairn looking north, showing Ruallan field, arable and wooded areas (*boxed*)

Plate 5.3: Ruallan Field: location of long-term pasture profile NA1

Plate 5.4: Loch Ddu Farm: location of arable profile, with Firhall woodland - location of woodland profile - to the east

5.2.2 Survey 2: A selection of parishes near Dundee, Angus

5.2.2.1 Site selection

The Angus survey area was selected to investigate the potential for correlation of the historical dataset with the second Soil Survey dataset: that of the topsoil points taken from the original auger point record of the Soil Survey. As with the Soil Survey 'deep phase polygons' record, this dataset provides good coverage only for certain areas of Scotland (Section 4.3.3.1). From these, the Aberdeenshire dataset was ruled out due to poor alignment of the topsoil points (Section 4.3.3.2). From the remaining areas, a survey location was chosen with, firstly, a good coverage of deeper topsoil points (i.e. over 15 inches); secondly, a selection of parishes with varying potential to develop deep anthropogenic topsoils according to the historical dataset; and finally, a geographic and agricultural setting different to that already explored at Nairn.

The Angus area is one for which there is almost complete Soil Survey auger point coverage. Within this region, areas within seven parishes of different ratings were selected for survey, within which there were also a high number of deep (over 15 inches) topsoil points noted.

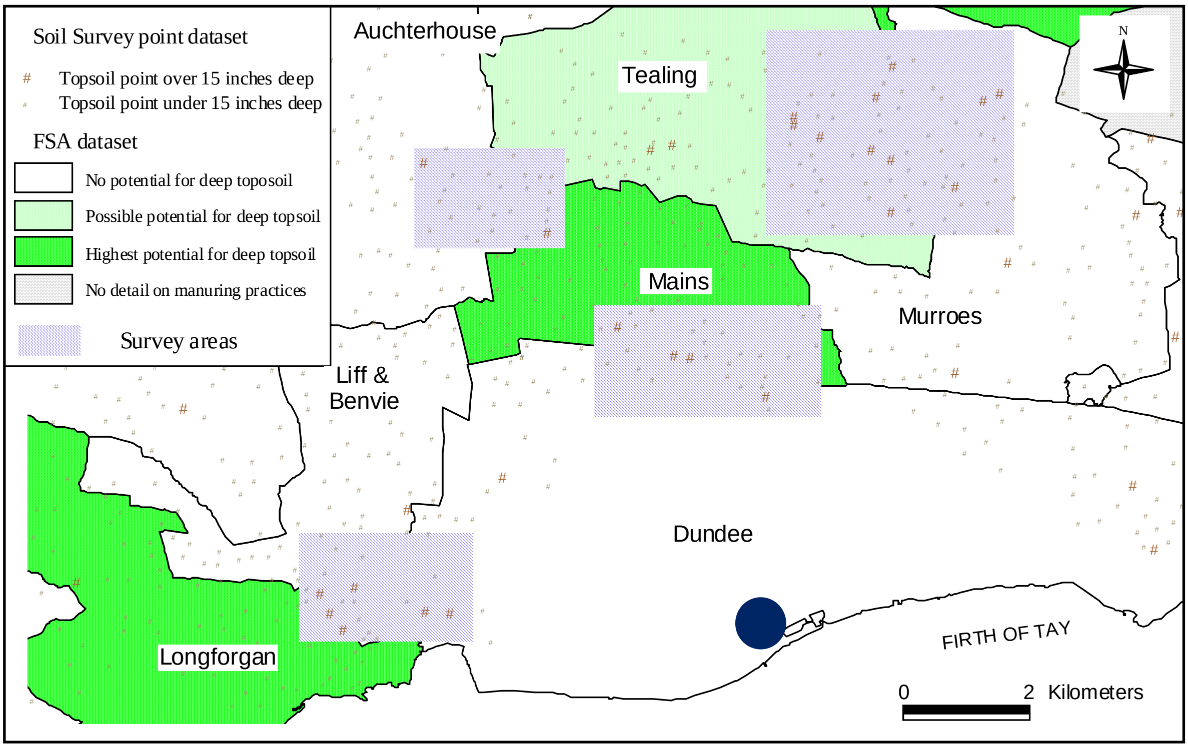


Figure 5.5: Integration of parish and Soil Survey topsoil point data in Angus

These included the parishes of Auchterhouse, Murroes, and the northern part of Dundee (unlikely to be deep), Tealing (possibly deep), and the parishes of Liff and Bervie (or Benvie), Longforgan, and Mains and Strathmartine (very possibly deep) (Figure 5.5).

This survey fulfils the requirement to undertake a survey in a Central Scotland region. In addition, the parishes included can be said to represent a semi-rural context, both in the present day and during the pre-Improvement period. Fairly near to the important industrial centre of Dundee, the parishes themselves are nevertheless located in an area characterised by relatively small village centres surrounded by both arable and pasture land.

5.2.2.2 Auger survey

Auger survey was undertaken throughout the areas within the six selected parishes adjacent to the deep topsoil points indicated by the Soil Survey dataset (Figure 5.5). Auger points were taken on a largely random basis, subject to access to land, and were aimed at locating the deep points shown by the Soil Survey. Approximately 100 auger points were taken. However, very few of these deep topsoil points were located. This could be another indication of the possible problems with alignment of the Soil Survey data (4.3.3.2). This of course made for an uneven correlation between the Soil Survey points and the ratings given to each parish by the historical dataset. Although Mains and Strathmartine – the highest rated parish – did show on average deeper topsoil points than either Auchterhouse or especially Murroes (where none of the deep points were identified), overall there was little agreement between the parish ratings according to the historical dataset, and the Soil Survey deep point record. With one exception, no deep point recorded reached a depth of over 50 cm, and could therefore not be considered a true deep anthropogenic topsoil.

This exception was the parish of Tealing, located approximately equidistant between Forfar and Dundee. Several deep topsoil points were recorded within this parish, mainly located around the village of Tealing itself. Auger survey identified these as deep anthropogenic topsoils of approximately 50-70 cm depth. Almost all of these were located within what, on more detailed survey, was identified as two relatively small polygons of deep topsoil located upon land belonging to Tealing House, a late sixteenth/early seventeenth century estate.

Following identification of these deep points, a more detailed auger survey was undertaken through the arable lands surrounding Tealing House and the grounds of the House itself (Figure 5.6). Augmented topsoil, of an average depth of 35-75 cm, was located throughout both the arable

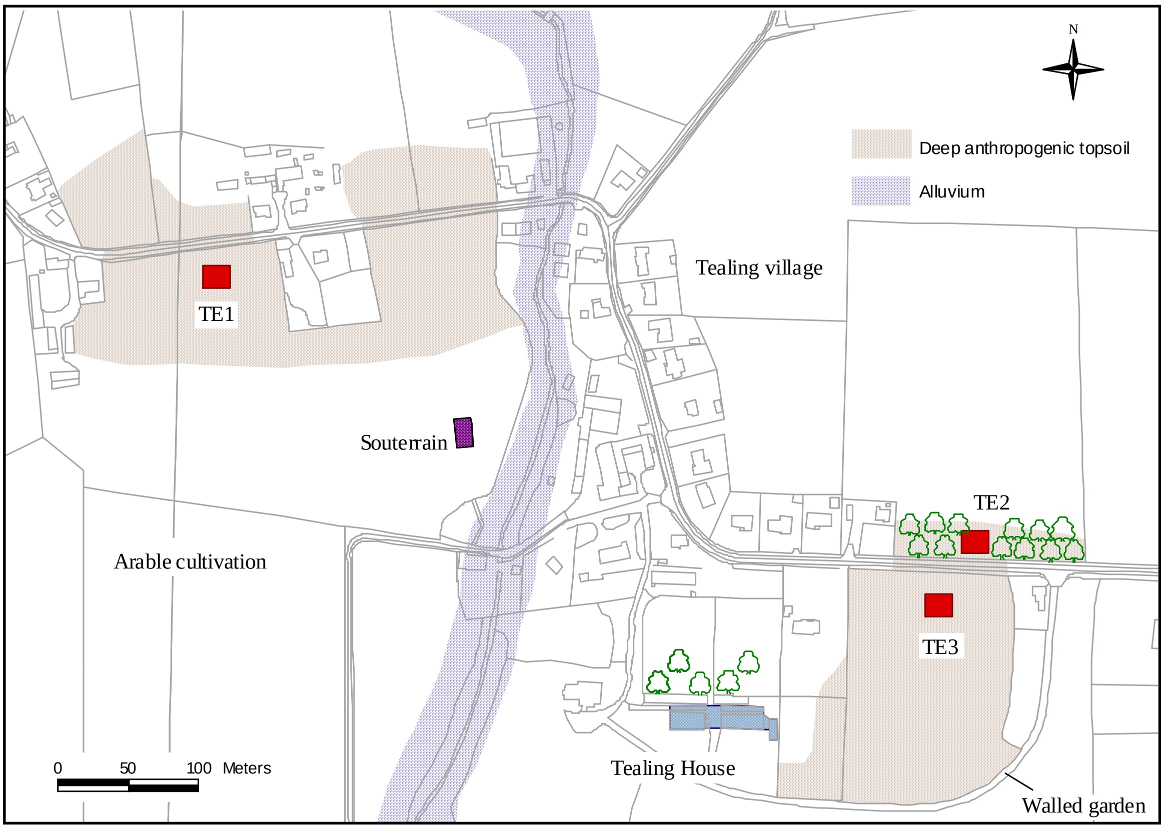


Figure 5.6: Auger survey around Tealing House and surrounding arable and woodland, showing positions of sample profiles TE1, TE2 and TE3

areas and the grounds of Tealing House. On average, this topsoil was deeper in the arable areas surrounding the House than in the grounds of the House itself (average 65-75 cm, falling to 35-55 cm within the grounds), but the deepest point of all was located within the walled 'garden' area of the house (Plate 5.8), which reached a maximum depth of 80 cm. Within this generally augmented soil area, two distinct polygons of deep anthropogenic topsoil of over 50 cm were mapped, one within the arable area, and one largely contained within the walled 'garden'. These polygons were separated by an alluvial deposit running north-south, the extent of which is mapped upon the Soil Map for the area and is not to be confused with any portion of the deep anthropogenic topsoil identified by the survey.

5.2.2.3 Historical and archaeological context

a. Tealing and surrounding area

Despite the fact that Tealing is one of the larger settlements in this area of Angus (the village is one of the few marked, as *Telen*, on Robert Edward's 1678 survey map of the region) (Edward 1678b), there is little information for manuring practices available in the historical record which can be directly related to the parish of Tealing. This may be connected to the 'strong pastoral tradition' ascribed to the Angus region by Edward and later agricultural writers (Lenman 1976: xxvii). Black cattle, rather than crops, were the main agricultural product of this region, and it is therefore not surprising that the First Statistical Account for Tealing lists dung, as well as marl and lime (FSA IV: 97) as the manures in use in the parish. In addition, the County Agricultural Report for Angus describes the practice of *'mingling a quantity of earth with lime or marl in dunghills'* (Roger 1794) – a description which, however, need not refer to Tealing itself.

However, while it would appear that bulk manures were very possibly a part of the manuring system in the Tealing area, it seems less likely that turf would have been used for this purpose. The First Statistical Account for Tealing lists turf as '*the fuel commonly used…which is brought from the neighbouring hills*.' Robert Edward, in his account of the County of Angus, describes the paring of turf from '*places unfit for cultivation*', the harvesting of long heath grass '*so high as to reach a man's middle*' and even the cultivation of '*broom'* by Angusians, all in the pursuit of fuel (Edward 1678a: 23). It would appear unlikely that significant amounts of these materials reached the byre prior to being burned, and therefore a plaggen-type manuring system is not indicated.

Despite its rural location, it would appear that Tealing was situated close enough to the urban centre of Dundee for the waste products of the city to find their way into the local manuring system, at least within the immediately post-Improvement period. The Second Statistical Account for Tealing describes the commercial benefit of this '*ready and eligible market'* for their produce, and in return, '*the transportation of manure from the town to the country is carried on to a great extent*.' (SSA XI: 380) There is no reason to assume that this arrangement would not have existed, in one form or another, from much earlier in Tealing's history. Tealing's proximity to the town of

Forfar to the north may also have acted to increase the amount of manure available to the village. 1790 saw legal obligations placed on the inhabitants of Forfar to remove dung from in front of their houses, and the employment of officials to rake dung from the streets, to oversee raking of the 'backlands' of the houses of the town, and to organise the removal of wastes to a designated area, from which they were sold annually (Adam 1967: 35-36, in Dennison and Coleman 2000: 28).

Manure from these sources is likely to have been composed of a variety of materials. As discussed in Section 3.3.2, 'town' manure could refer to street sweepings, ashes or even the mucked-out bedding and dung of the stables kept at urban inns and houses (Sinclair 1814: 525). Dundee in particular was a centre of manufacturing throughout the sixteenth and early seventeenth centuries (Stevenson and Torrie 1988: 43) and the First Statistical Account for Dundee lists linen, canvas for shipping, bagging for cotton wool, cotton thread, woollen mills, leather, cordage and ropes, soap, glass, tobacco and snuff, sugar, cast-iron, and salt among its trades (FSA VIII: 216-219). It is possible that some of these urban imports may have contributed a bulk manure component to the soils at Tealing.

Archive research has so far uncovered no other information relating to the manuring tradition in Tealing. It would seem, however, that while compost manures, and perhaps large amounts of imported town-based waste, may have been available to add bulk to the system, evidence for a plaggen-style manuring tradition, certainly one involving the use of unburnt, composted turf, is absent.

b. The deep topsoil polygon area.

Tealing House dates from c. 1600. Initially constructed as a fortified house, eighteenth-century additions to the property created a pedimented classical mansion surrounded by extensive gardens (Historic Scotland 2005) (Plates 5.6 and 5.8). Tealing House was owned by the Maxwells of Tealing from the fifteenth century until passing to the Scrymsoure/Scrymgeour family in 1704. The house fell into disrepair in the early twentieth century and has only recently been restored (www.scotnet.co.uk/sct).

In the absence of estate or farm diaries, there appears to be little specific information available for manuring traditions either for the land surrounding Tealing House, or the grounds and gardens of the House itself. But as the deep topsoil polygon appears to be centred on the immediate area of the House and its grounds, it seems likely that activities connected with Tealing House itself as well as with the wider agricultural system would have contributed to the deep anthropogenic topsoil identified here. Waste products from the House economy, such as ash, are likely to have become part of the manuring system. A particular desire to augment soils around the House, perhaps for the purposes of kitchen-gardening or other planting activities, may have prompted the creation of a localised plaggen-type manuring system. Documentation from other Angus estates from the sixteenth and seventeenth century, such as those of Airlie, indicate that bulk manures such as dung and 'muck' from urban areas were regarded as highly important, and were being bought and transported in large quantities in order to improve the productivity of the estates (McFaulds 1980: 163). The location of the estate at Tealing is likely to have influenced the amount and nature of manure coming into the area, and it would appear that much of this may have been purchased bulk manure, a good portion of which may have been expended on the lands immediately adjacent to the House.

Tealing can thus be considered a 'semi-rural' system – rurally situated, but supported through an estate which would perhaps have had access to a variety of manuring inputs, relying on locally produced 'composts', but also able to afford importation of both 'new' manures, and a generous amount of organic waste, from a comparatively early point.

A further point to consider is that the sample area appears to have been a focus for activity, and thus presumably agricultural activity, since prehistoric times. A large souterrain, discovered c. 1725 (FSA IV: 101) and re-discovered in 1871 in a field to the north-west of Tealing House (Warden 1885: 228) may even indicate an Iron Age date for the commencement of deep topsoil formation around Tealing House (Plate 5.6). While this can only be conjecture, it seems possible that the soils of the Tealing sample area have some archaeological complexity.

5.2.2.4 Assessment of the manuring database

The Tealing survey, although successfully identifying a deep anthropogenic topsoil, indicated that, unlike the deep phase polygons on the final Soil Maps, the Soil Survey deep topsoil point record may be a relatively unreliable location method for deep topsoils. It is likely that this may be related to the condition of the original Soil Survey maps, and the difficulty of locating these correctly. Attempting to re-locate these points, and perform additional comparative surveys using the topsoil point records from other areas, would be a valuable exercise.

The historical component of the database proved more effective, with the deep topsoil polygon identified within a higher-rated parish within the sample set. Despite the information provided on the agriculture of Tealing by the First Statistical Account, however, it can be seen that Section 5.2.2.3 is strongly reliant upon historical sources other than this for much of the manuring information used to interpret the likely context of the deep topsoil polygon – also a feature of the Nairn desktop archaeo-historical investigation. It would seem that in terms of contextualising these soils, the First Statistical Account data is likely to provide only a starting point for the in-depth historical investigation required to understand what increasingly appear to be individualistic soil features. This is discussed further in the assessment of the manuring database in Chapter 8.

5.2.2.5 Site survey and sampling programme

Three different land use types were identified within the deep topsoil polygon area identified at Tealing, making the site suitable for the sampling programme. These consisted of ploughed arable in the fields surrounding Tealing House (Plate 5.7), and areas of both woodland and long-term pasture within the present-day grounds of the House itself (Plate 5.8). Although an alluvial deposit bisected this polygon, the Soil Map for the area confirms that the entire polygon is located on one soil association (Balrownie). The sampled points are described as follows:

1. Ploughed arable. Several of the arable fields surrounding Tealing House were auger surveyed. The deepest, located in the northern part of the village and across the road from Tealing House, had not been in arable cultivation for over six years (G. Christie pers. comm.). It was therefore decided to take the arable profile form the second deepest field, located approximately 70 metres from Tealing House. Within this field is a large Iron Age souterrain.

The field, although owned by the Tealing Estate, is farmed on lease, and is in a typical 8-10 year cereal/grass rotation. It is fertilised with lime and an artificial N:P:K mix, and at the time of excavation was planted with winter barley (W. Millar pers. comm.) (Figure 5.6; Plate 5.7). See Appendix 5, Profile TE1.

2. Woodland. The grounds of Tealing House are shown on both Ainslie's map of Angus (Ainslie 1794), and Thomson's map of Angus (Thomson 1825) upon which woodland is clearly marked in various parts of the grounds (Plate 5.5). The second profile was taken within in a narrow stretch of woodland between the walled garden and the road, where localised tree felling provided a small clearing (M. Thompson pers. comm.). Here, the topsoil was shallower than within the arable and pasture areas, but still on average 60 cm deep (Figure 5.6; Plate 5.8). See Appendix 5, Profile TE2.

3. Long-term pasture. The deepest survey points were recorded within large walled 'garden' area located to the east of Tealing House itself (Plate 5.8). Although the area is referred to as the 'walled garden' by the present occupiers of Tealing House, the area has not been planted for at least two decades. Prior to this, several greenhouses for fruit stood on part of the area (M. Thompson pers. comm.). The area is now leased for silage production, but is unfertilised (G. Christie pers. comm.).

Although it is possible that some of the particularly deep topsoil within this walled garden has developed as a result of intensive 'garden' manuring practices suggested in Section 5.2.2.3, it seems unlikely that this alone can account for the level of soil augmentation seen in this eastern area of the grounds. The wall of the garden post-dates the house to some extent and (especially) the near-comparable depth of the woodland profile, situated immediately outside the wall, indicates that the deep topsoil deposit is not specifically contained within the walled area.

However, archaeological excavations at Kinross House – a mansion of similar date to Tealing House and located approximately thirty miles to the south-west – have identified 'garden soil deposits' up to a maximum depth of 90 cm located within a similarly walled garden area (Cox 2002: 173). It would seem that the apparent association of deep anthropogenic topsoils with garden cultivation of this kind may not be unique to Tealing. The darker, slightly deeper profile within the walled area makes it likely that, although this deep anthropogenic topsoil extends beyond the limits of the walled garden, later cultivation within this area, and the fertiliser inputs that are likely to have accompanied it, have had a more recent impact on the nature of the profile at this point (Figure 5.6; Plate 5.8). See Appendix 5, Profile TE3.

Plate 5.5: Detail of Thomson's *Map of Angus-shire* (1825) showing Tealing House and its adjacent woodland (boxed)

Plate 5.6: Aerial view of part of the Tealing estate looking south. *Note Iron Age souterrain in the field from which profile TE1 was taken. Tealing House is out of shot to the left (RCAHMS)*

Plate 5.7: Tealing: field to the west of Tealing House, as seen above. Location of arable profile

Plate 5.8: Tealing: grounds of Tealing House showing location of long-term pasture profile, with Tealing House and woodland in the background

5.2.3 Survey 3: Unst, Shetland

5.2.3.1 Site selection

The island of Unst, Shetland, was selected as the third survey location from the wide range of parish areas for which the manuring database only provides information from the First Statistical Account dataset, possessing no relevant secondary locational datasets to resolve manuring information past this parish level. Many parishes fit into this category, and exploring ways in which these areas of limited information may be investigated through the use of the manuring database is an important concern for the applicability of the database in a Scotland-wide context. Shetland, as an isolated area split into a handful of large parishes, often representing entire islands, is a good example of how problematic this lack of resolution can be.

Of a total of twelve Shetland parishes, only two were rated as likely to have deep topsoil development, the island of Unst, and Sandsting in the West Mainland. It was decided to select one of these parishes by attempting to use the same criteria as would be applied were there Soil Survey data for the areas: i.e. by investigating the known qualities of the soils for these two regions. It was suggested that for suitability for agriculture, the soils of Unst were superior to those of Sandsting (G. Petrie, SEERAD Shetland pers. comm.). Historical sources agree:

> *'…its agricultural capability is generally superior, owing to the improvable character of the soil and the ease with which it may be worked'* (Evershed 1874: 192).

As the northernmost island in the Shetlands, Unst has traditionally supported a crofting community. The survey therefore fulfils the requirements of the survey methodology to undertake a survey within the Northern Isles, within a rural context, and within a crofting landscape.

In the absence of Soil Survey data to highlight a possible sample area, an area of reasonable size with a variety of land cover types had to be chosen to host an auger survey on a similar scale to that undertaken for the previous two surveys. Scientific and historical evidence was correlated to decide on a survey through the Westing (Figure 5.7). This area was confirmed by SEERAD as the most productive in Unst and thus most likely to have seen past cultivation (G. Petrie, SEERAD Shetland pers. comm.), a view shared by the various crofters interviewed during the survey (R. Hughson, B. Hunter pers. comm.). The Westing was also confirmed by the Sites and Monuments Record to have the highest incidence of (especially) Norse ‘farmstead’ settlements and Iron Age brochs on the island (Figure 5.7). The Westing appeared to display the most extensive evidence for continuous cultivation, and therefore the likelihood of deep topsoil development, within the island. However, in contrast to other deep anthropogenic topsoil areas in Shetland, such as Papa Stour and Scatness, patterns of settlement appear more dispersed, with discrete rather than multi-period settlement remains seen throughout the area. This may provide an interesting point of contrast in terms of opportunities for the development of deep anthropogenic topsoils.

5.2.3.2 Auger survey

An extensive auger survey was undertaken through the Westing (Figure 5.7). Approximately 70 auger points were taken along a north-south line which aimed to incorporate the maximum area of land adjacent to the various settlement types recorded in the area. This was occasionally hampered by access to certain areas of land.

Cultivated topsoil dominated the area surveyed, but the depth of this topsoil varied greatly, from 5 cm to a maximum of 110 cm. The average topsoil depth was 15-30 cm. Several small (less than 5 m2) polygons of deeper than average topsoil were identified, none deeper than 55 cm, which presumably may relate to small, intensive episodes of ‘garden’ or ‘kailyard’ cultivation. The only area which showed an extensive and continuous deep anthropogenic topsoil was that recorded in the Underhoull area (Figure 5.7; Figure 5.8). Interestingly, this showed a broad correlation between soil depth and settlement density (Figure 5.7), and also a correlation between soil depth and Iron Age activity. The Underhoull area is well known in Unst for the presence of a large and well-preserved broch and a Viking/Norse-period longhouse, excavated in the 1960s (Small 1966; Plate 5.9; Plate 5.12) within close proximity to one another. Near to these sites are several Norse period farmsteads, plus a continuation of the network of abandoned croft houses which testify to the intensive cultivation of the area during the nineteenth and early twentieth centuries.

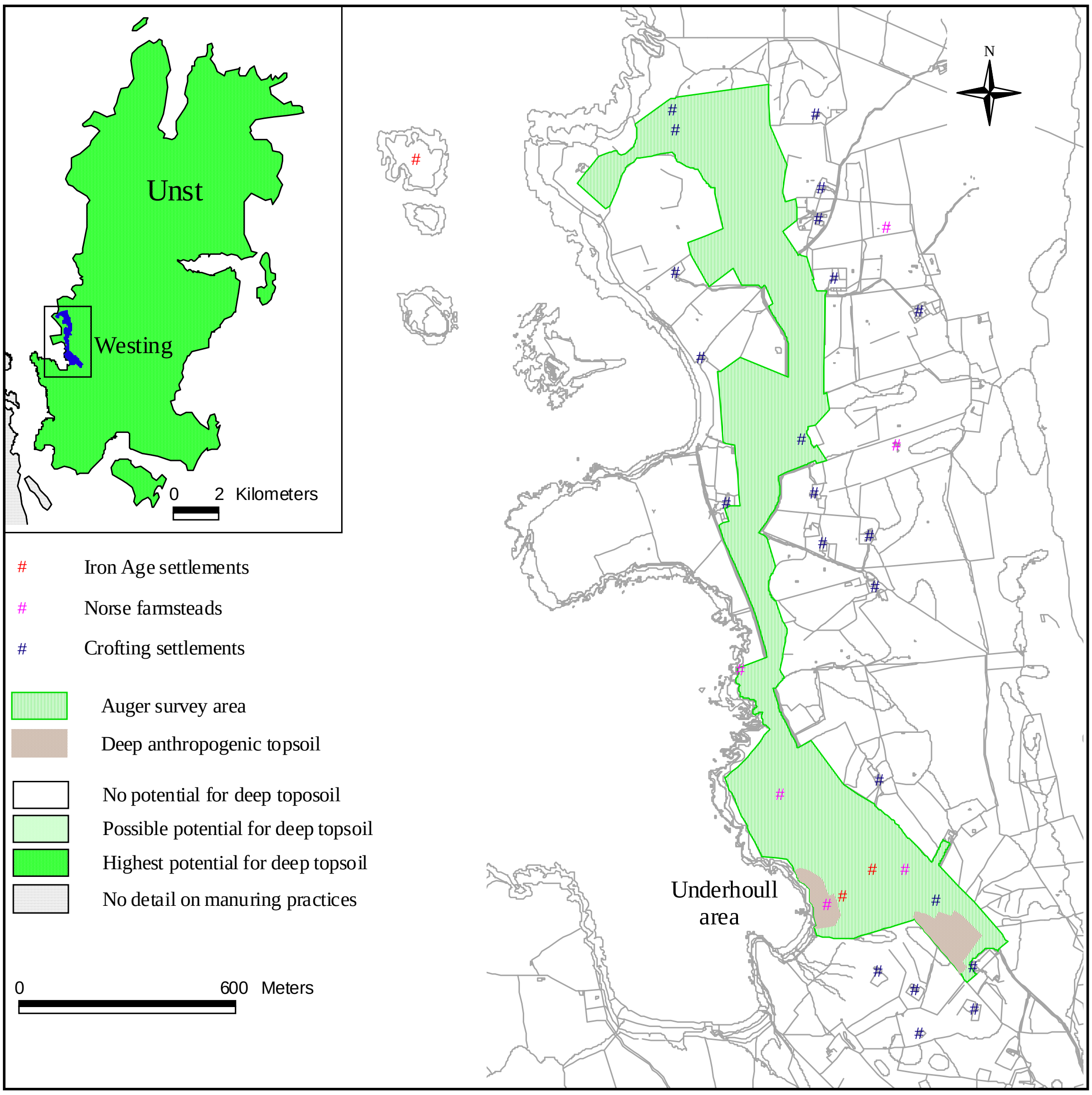


Figure 5.7: Location of survey area through the Westing, Unst, and its relationship to patterns of farming settlement

A more detailed auger survey was taken throughout the Underhoull area at 5-20 m intervals, in order to further define the depth and extents of the deep topsoil. This proved to form two discrete polygons, one adjacent to the Iron Age and Viking settlement areas to the south-west of Underhoull Broch, and one within two fields adjacent to the crofting period settlements of North House and New House (Plate 10; Plate 11). Both topsoil areas had a maximum depth of 115 cm.

On average, the North/New House polygon was slightly deeper than the Underhoull polygon. As regards depth, however, it should be noted that both deep topsoil polygons are located at the feet of slopes. It is therefore possible that colluvial action may be responsible for some of the depth of topsoil recorded. However, this in itself may be interpreted as a part of the anthropogenic formation process of the deep topsoil, in that cultivation activity in sloping areas, especially ploughing, will result in some colluvial activity, in the manner of lynchet formation. This is discussed further in Section 5.2.3.3.b.

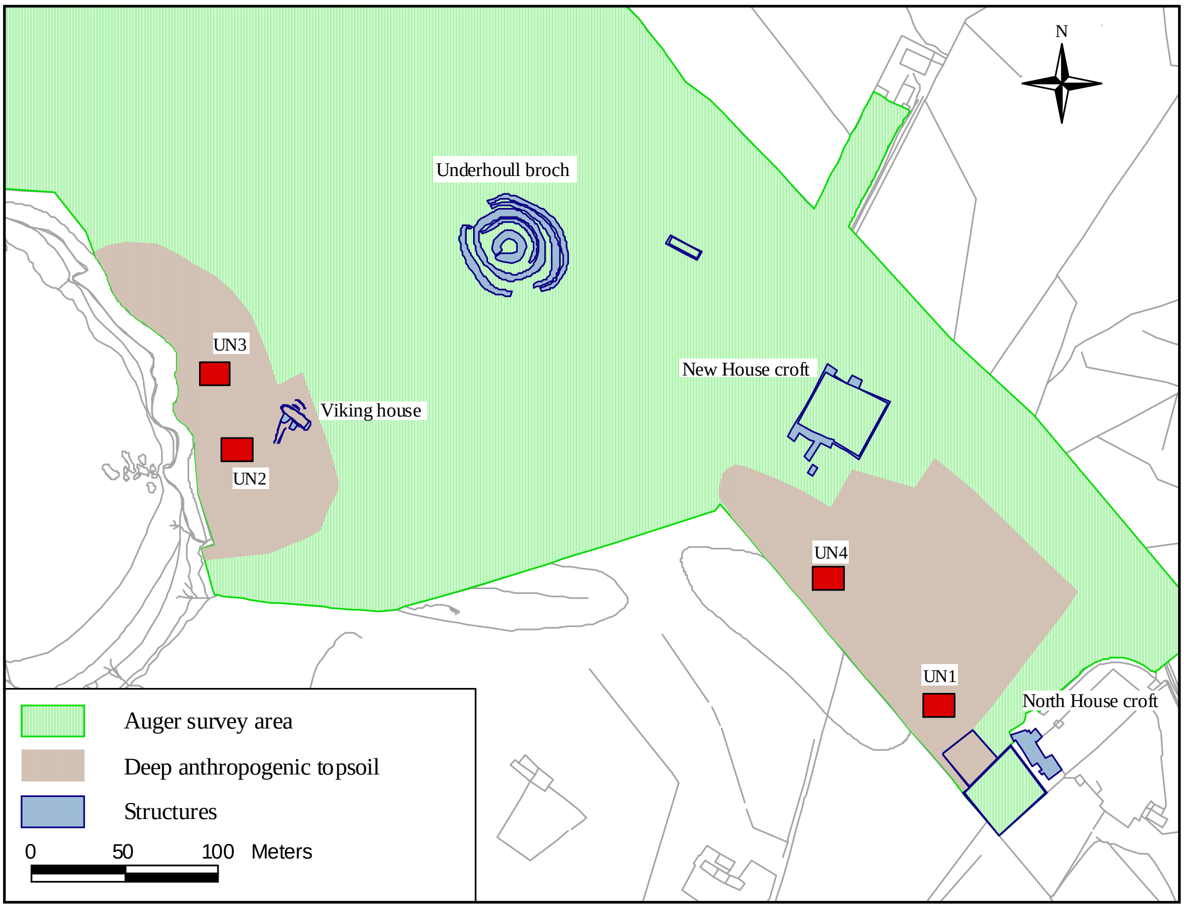


Figure 5.8: Detailed auger survey through Underhoull area, showing relationship of deep topsoil areas to extant structures and positions of sample profiles UN1, UN2, UN3 and UN4

Unlike Tealing, where the two deep topsoil polygon areas were located within one ‘activity area’, that of the Tealing estate, the two polygons in the Westing are clearly the result of separate episodes of cultivation, possibly even separate archaeological periods. Therefore, they cannot be considered one deep topsoil unit. This has implications for the analytical programme and the use of comparable topsoil profiles to compare current land cover effects. This is discussed further in Section 5.2.3.5.

5.2.3.3 Historical and archaeological context

a. Unst

Research into anthropogenic deep topsoils in Scotland has been almost entirely focused on the Northern Isles (see Chapter 2). However, research in Shetland is still limited to individual site investigations, such as those at Scatness (Dockrill *et al*. 1994) and on the island of Papa Stour (Guttmann 2001). No investigation into deep topsoil formation on Unst has previously been carried out, but historical and archaeological sources point to the area as one in which ‘plaggen-style’ manuring systems would be expected to exist.

The County Agricultural Report for Shetland (Sinclair 1794), makes no specific reference to the Unst manuring system and gives only a brief mention of ‘dung, dunghills and seaweed’ being used throughout the country. However, the First Statistical Account for Unst describes the island mode of manuring thus:

> *‘The people in this parish have a singular mode of preserving the dung for manure. It is not, as in other places, carried daily out of the stalls or byres in which the cattle stand, but is spread through the whole area of the house, and left to accumulate, till the cattle can no longer find entrance between the floor and the roof. Dry earth is sometimes carried in, and strewed as a mixture among the dung. And quantities of grass and short hearth are…every year mown upon the hills, and after being left for some time to wither, carried home…and used from time to time in spreading the byres so as to keep the cattle warm amidst the dung accumulating under them. When the house is filled, the dung is carried out to be spread upon the fields.’* (FSA V: 193).

This practice, which almost exactly parallels the plaggen system (however, with less emphasis upon mineral additions to the soil), was prevalent throughout the Westing area (A. Smith pers. comm.). In addition to earth, the Westing crofters would, as in the plaggen regions, take peat and heather turves from the hill land for bedding (B. Hunter pers. comm.). This system would undoubtedly result in augmentation of the soil: however, local evidence also points to this system admitting a wider variety of inputs than those described in the Statistical Account. Seaweed, ash and the remnants of peat turves (*moldicoos*) are also cited as being used in the byre. The inclusion of seaweed is consistent with research undertaken throughout Shetland: unlike in Orkney and the Western Isles, seaweed manure in Shetland was generally used within a compost, rather than as a sole manure (Fenton 1978: 283).

Due to its long formation process – the cows were housed for up to eight months of the year – the resulting compost would be dry, and would be cut like peat and carted by horses to the fields. Locally, this was considered the best way to fertilise the fields – unlike wet dung, the mixture would not be broken up and washed away by the rain (R. Hughson pers. comm.). Again, this points to the Unst system contributing to a plaggen-like augmentation of the soil.

The isolation of Unst also makes it more likely that, as documented for Papa Stour, these traditional manuring systems would have stayed in place for longer. This is supported by the survival in Unst, even into the mid-20th century, of elements of the ancient system of common land tenure (Wheeler 1964: 20), among which are recorded the continuing recognition of rights to gather seaweed for manure along certain sections of the coast as late as the 1960s (Sandison 1968: 13-14).

b. The deep topsoil polygon areas.

In the manner of its time, Small's excavation of the Viking House at Underhoull (Small 1966) provides little information on the area surrounding the immediate excavation site, and makes no mention of deep anthropogenic soils surrounding the settlement. However, the recording of 'about 5 to 7 inches of barren soil' separating the Iron Age and Norse period occupation layers, suggests perhaps that natural colluvial accumulation may not have been extensive (*ibid*.: 235).

In the absence of archaeological information for pre-crofting manuring systems in the deep topsoil areas, the only evidence for deep anthropogenic soil formation for the Unst site comes from more recent sources. Both deep topsoil polygon areas, although discrete, are located within a crofting landscape which, we can assume, would at least partly have employed the manuring system described in the previous section. Evidence from the standing croft houses adjacent to the second deep topsoil polygon supports this. The byre attached to North House croft is of nineteenth century style (I. Tait, Shetland Museum pers. comm.; Plate 5.11), and has various features, such as '*vegwalls*' – vertical sets of wall pegs used to periodically raise the tether level of the cattle as the bedding layer rose – which suggest that the byre was once used to mass produce plaggen type manure in the manner described above.

This was confirmed through interview with Mr. Alexander Smith (aged 87), the last crofter to work North House, who also provided detail of the cultivation methods employed at North House. His testimony supports the view that colluvial movement on the Unst deep topsoil polygons may be anthropogenic. In describing the pattern of manure application to the fields in the early days of his tenancy, Mr. Smith revealed that when using the traditional method of '*dellin'* (turning the manure into the topsoil by spade), the crofter would naturally 'dell' downhill, which was easier. This would result in the majority of manure material ending up at the bottom of any slope within a 'delled' field. To compensate for this, when manure was taken from a byre or dunghill into a sloped field, the pile would be deposited at the top of the field (A. Smith pers. comm.). The gentle slope of the North House UN1 profile shows a significant increase in topsoil depth toward the bottom of its slope, and it is possible that this cultivation method could account for this. A comparison may also be made between this formation and that noted in Irish plaggen soils, which 'tend to have a flat surface with a convex slope towards the field boundary' (Conry 1974: 319).

5.2.3.4 Assessment of the manuring database

This is largely redundant for the Unst survey. While the collation of historical, ethnological and archaeological evidence clearly provided a methodological structure to discovering the deep topsoil polygon at Unst, information from the manuring database formed only a small part of this. The value of this survey in assessing the manuring database is to provide a caution: Unst is only one of many parish areas for which the manuring database cannot be used to resolve the evidence for deep anthropogenic topsoils beyond the very basic. This is discussed further in Chapter 8.

5.2.3.5 Site survey and sampling programme

The discrete nature of the two deep topsoil polygons recorded at Unst meant that they were treated as distinct soil units within the analytical programme. With this in mind, sampling focused on identifying two pairs of land use types, one within each of the polygons. Unfortunately, as woodland is absent from Unst, this cover type could not be assessed.

Deep topsoil polygon 1: the crofting area

1. Ploughed arable - recent. The area around Underhoull, and across most of the Westing, is one of arable abandonment following the contraction of the traditional crofting system (infield cultivation around a small farm in addition to a share of the grazing area). Today, most crofters keep sheep in preference to cultivating, often as a supplement to other employment: Unst now grows only ¼ of the cereal grown 50 years ago (B. Hunter pers. comm.). However, the nearest of the abandoned crofts to Underhoull, North House, cultivated surrounding land until the early 1990s and was the last in the area to be abandoned (A. Smith pers. comm.). The land was last ploughed during this time, and the field adjacent to this is still fertilised by the present owner for hay cropping (D. Johnson pers. comm.). Following detailed auger survey through the field, the profile was located in an area near the kailyard (Plate 5.10; Figure 5.8). See Appendix 5, Profile UN1.

2. Ploughed arable – not recent. The portion of the 'crofting area' deep topsoil polygon not in the recently ploughed area of North House is upon land once cultivated by New House croft to the west (Figure 5.8). This croft was abandoned in the early 20th century, and the land where the profile was located has not been ploughed or cultivated since (Plate 5.10). See Appendix 5, Profile UN4.

Deep topsoil polygon 2: Underhoull

1. Unimproved pasture. The deep topsoil polygon runs through the field within which the

Underhoull 'Viking House' is situated. This field, although used for grazing sheep, has not been ploughed or had fertiliser application within memory of the local crofters and is considered inaccessible, scattered with large stones displaced from the Viking settlement (P. Peterson pers. comm.). It has therefore also escaped improvements such as re-seeding and fertiliser application for hay cropping. Detailed auger survey revealed distinct undulations in the topsoil, likely to relate to settlement activity. The profile was taken at the deepest topsoil point, and sufficiently far from the excavation to avoid disturbance (Plate 5.12; Plate 5.13; Figure 5.8). See Appendix 5, Profile UN2.

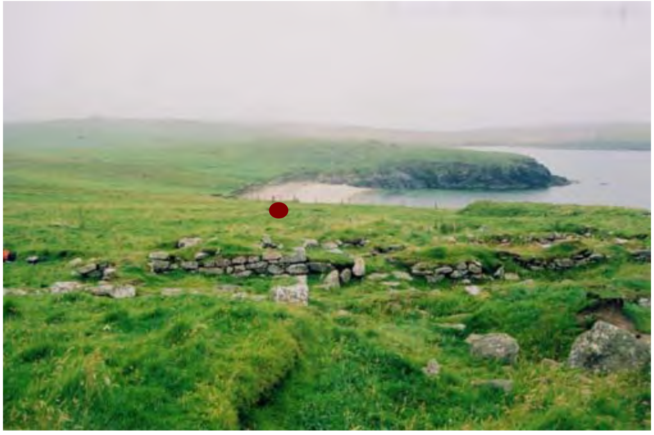
3. Improved pasture. The more accessible field to the west of the unimproved pasture field, and within the deep topsoil area, has been re-seeded during the last two decades, and had a fertiliser addition four years previous to the survey in order to maintain productivity for grazing. It has therefore seen cropping activity in the form of hay removal (P. Peterson pers. comm.). Although it is also officially used for grazing, the impact of this should not form part of the interpretation of the profile, as some sheep were seen grazing throughout the Viking House field during the sampling, despite the resident crofter's description of the field as not part of the maintained grazing area. A sample was taken of the deepest area of this field within close proximity to the unimproved grassland profile (Plate 5.13; Figure 5.8). See Appendix 5, Profile UN3.

Plate 5.9: Aerial view showing the excavations at Underhoull (1965), looking east. *Part of Underhoull broch can be seen to left of shot. In the top left-hand corner, the still-cultivated fields of North House can clearly be seen (RCAHMS)*

Plate 5.10: View of North House and New House fields from North House croft. Profiles UN1 (near) and UN4 (far) are marked. Underhoull broch is visible in the background

Plate 5.11: North House croft and 19th century byre

Plate 5.12: Remains of Underhoull Viking House, with position of profile UN2 marked



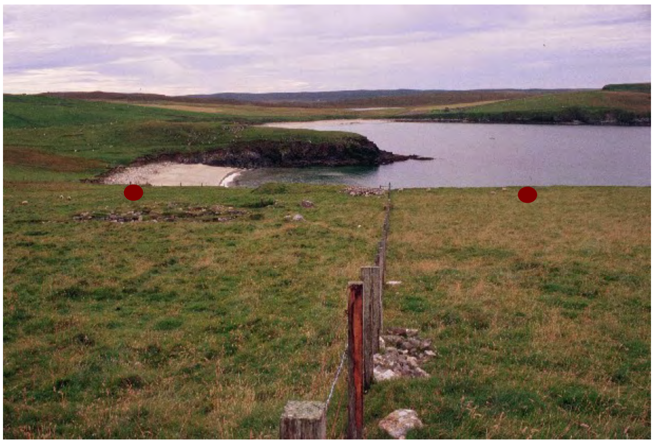


Plate 5.13: View along boundary between improved and unimproved fields at Underhoull, showing positions of profiles UN2 and UN3

5.2.4 Survey 4: Tiree, Inner Hebrides

5.2.4.1 Site selection

The island of Tiree, located in the Inner Hebrides, was selected as the fourth survey location for this project. In addition to fulfilling the requirements of the survey methodology to survey an area in the Western Isles, Tiree was selected as an opportunity to investigate the contribution that additional, area-specific datasets, particularly the archaeological datasets incorporated into the manuring database, could make to the identification of deep anthropogenic topsoils. As is the case with Unst, the island of Tiree is a single parish, and therefore the First Statistical Account dataset provides no information specific to separate areas within the island.

Unlike Unst, however (at the time of receipt of data), Tiree is one of the areas included in the First Edition Survey Project, a digitisation of unroofed rural settlement remains shown as still extant on the Ordnance Survey first edition map of Scotland (1843-1878) (Section 4.1.4). As the earliest mapped record of pre-Improvement rural settlement patterns, initial studies incorporating the FESP dataset have already indicated the usefulness of this resource to the field of MoLRS research (RCAHMS/Historic Scotland 2002: 61-68). As the FESP dataset maps not only settlement structures but also those features more directly related to cultivation activity, such as enclosures and field systems (*ibid*.: 33; 37) it is suggested that this dataset could prove a valuable tool in resolving parish areas in order to identify suitable survey areas for this project.

In addition to the FESP dataset, another mapped dataset available for Tiree is the 1768 Argyll Estate Survey drawn up by James Turnbull (Turnbull 1768). This survey was undertaken as a valuation of the estate holdings, and is presented as a detailed map showing not only the extents of each individual farm-holding in Tiree, but also the division of these into areas of infield, outfield, pasture, and other demarcated areas such as moss, blown sand areas (a particular and problematic feature of the Tiree landscape) and lochs (Figure 5.9). A legend provided with the map details the acreage of each of these divisions per farm.

As a map specific to Tiree, the Turnbull Survey map clearly contains a greater, and more specific amount of data relating to the island. By incorporating both of these datasets into the Tiree survey, it was hoped firstly, that the usefulness of applying above-ground mapped data to soil-based survey of this kind could be assessed; and secondly, that the value of the digital-ready FESP dataset for individual area surveys could be assessed in relation to more traditional historical mapped data sources.

5.2.4.2 Auger survey

A scanned image of the Turnbull 1768 map was obtained from RCAHMS, with the permission of the Argyll Estate (Figure 5.9, base image). This was introduced to the manuring database and geo-referenced using current Ordnance Survey digital data for Tiree. A simple map overlay, aligned using the Tiree coastline taken from the digital parish dataset, allows the information provided by these two datasets to be compared (Figure 5.9, overlay).

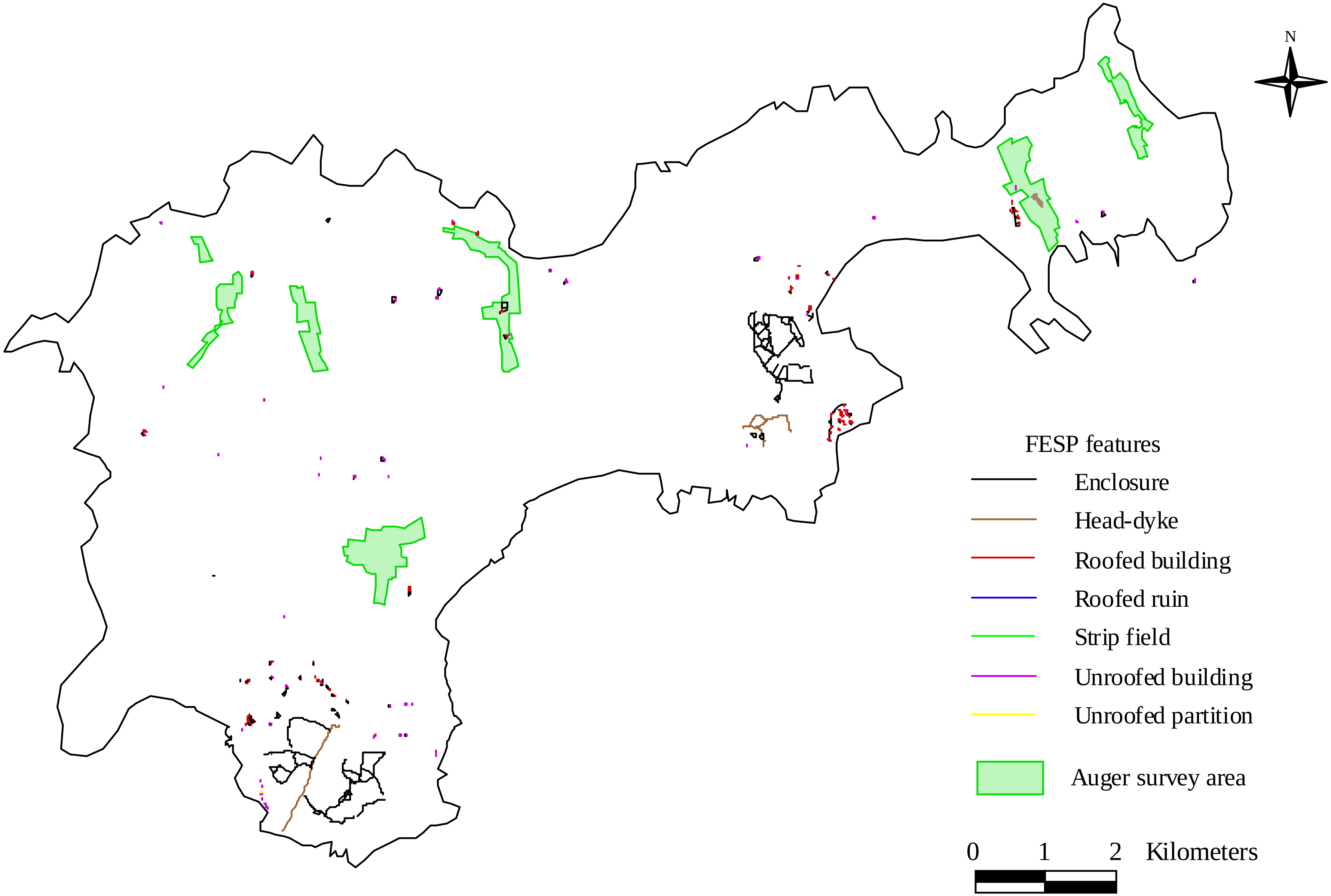
Set against the Turnbull survey map, the FESP survey data appears fairly meagre in the amount of information it provides on landmarks relevant to the investigation of soil features. Particularly useful are the demarcations of infield – i.e. manured – land given by the Turnbull survey. In addition to this, it can be seen that the Turnbull survey provides a *complete* record – of the pattern of townships, farms and their cultivated lands, at this precise point in history. This is not possible for the FESP data, which is simply a record of features surviving at a certain date. For the purpose of the survey, this results in an illogical dataset – for example, there is of course no correlation between the location or frequency of the features shown and factors that may prove useful to the survey, such as the size of a farming township, or the land use history of an enclosure (Figure 5.10). Therefore, while the FESP dataset is clearly of great value as a source of information on the settlement-related features it shows, its potential usefulness is much more limited for investigations into aspects of the wider historic landscape, such as the location of deep anthropogenic topsoils.

The auger survey programme was therefore designed with reference to Turnbull's survey map. The most potentially useful dataset provided in the map legend is that relating to infield areas per township. The five townships with the largest infield acreages were therefore identified, and the survey designed to concentrate on the central areas of these townships. A sixth township with a relatively small infield area (Caoles) was also included in the survey in order to see if there was a tendency to variation in topsoil depth between large and small infield areas (Figure 5.10).

The survey proved generally disappointing. An average of 30 auger points were taken through each township area, and topsoil depths recorded for these ranged from 15 cm to a maximum of 35 cm. There was no difference in overall topsoil depth between Caoles and the townships with a larger infield area. There was also no one township with measurably deeper topsoil overall.

The only example of deep anthropogenic topsoil identified was within the township of Ruaig, which had the smallest infield acreage of all of the five townships. This consisted of a small polygon of deep topsoil, approximately 150 metres at its longest, which showed a maximum depth of 55 cm (Figure 5.10, inset). However, this dropped to only 35 cm at the extents of the polygon. This deep topsoil could not be considered for the sample: firstly on account of its size, and secondly due to the fact that entire topsoil area was located upon a single current land use type (arable).

Figure 5.9 (following page): Turnbull's 1768 survey of Tiree, overlain by First Edition Survey Project digital data


N
FESP features
Enclosure
Head-dyke
Roofed building
Roofed ruin
Strip field
Unroofed building
Unroofed partition
Auger survey area
0
1
2
Kilometers

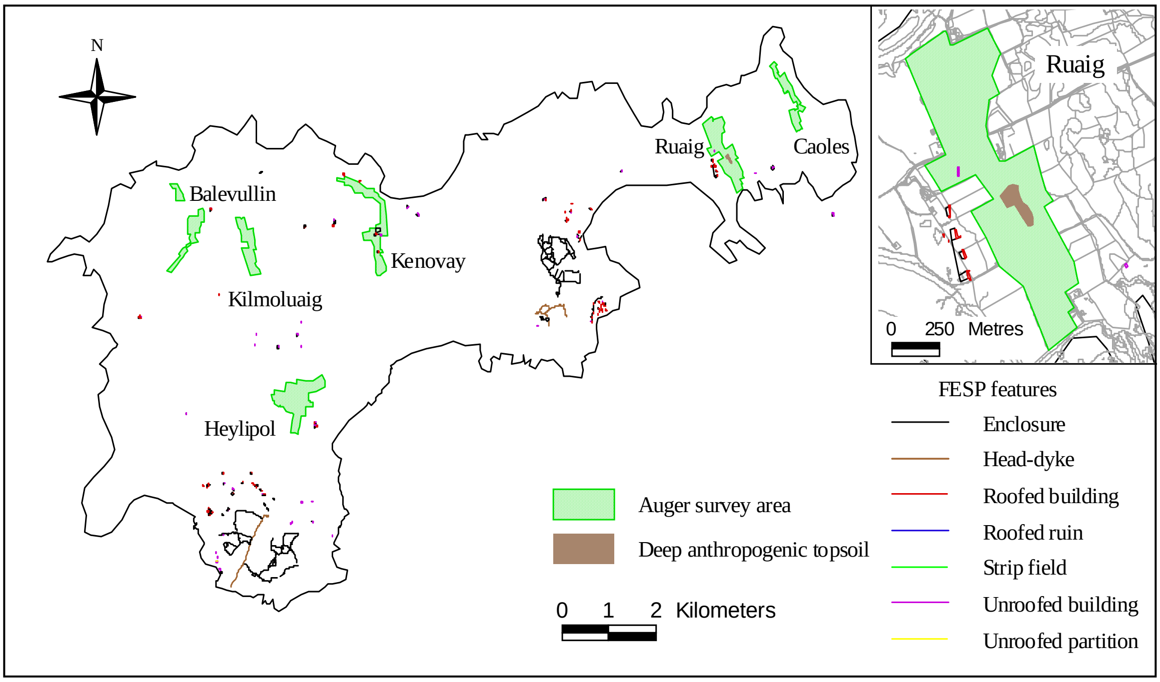


Figure 5.10: Tiree, showing auger survey areas through parts of the townships recorded as having the largest acreages of infield land according to Turnbull's 1768 survey. The Tiree FESP dataset is also shown, as is the topsoil identified at Ruaig (inset)

5.2.4.3 Historical and archaeological context

a. Tiree

Tiree is generally perceived in the early historical record as being an extremely productive island, consisting of fertile, easily worked soils, and known in Gaelic as *Tir an Eorna* – the land of barley (Martin 1695; Walker 1771). However, even from the early eighteenth century this reputation appeared to be on the wane, as a rising population as well as, according to some writers, inefficient cultivation methods saw a drop in Tiree's productivity (Martin 1695: 267). By the mid nineteenth century, a continued rise in a population that could no longer be accommodated on the arable land available, coupled with a crop failure, brought famine to the island (Highland Relief Board 1849: 21-23).

Among the many reasons cited for Tiree's agricultural decline, the Second Statistical Account identifies the manuring tradition on the island as being partly responsible, stating that 'Sea-*weed is chiefly used in its simple state, which is not considered a good manure…*' (SSA VII: 210). Seaweed appears to have been the dominant manure material on the island from the earliest times: the First Statistical Account records that '*above two-third of the manure are sea-weed*' (FSA X: 396). The importance of this manure resource, probably the most extensive available to an island population, cannot be overestimated. Even the shape of the townships themselves were influenced by the importance of the seaweed resource: Turnbull's survey map shows how houses are sited and farm boundaries set so as to give as each direct access to a portion of the sea-shore for which gathering rights could be held (Cregeen 1964: xvii). The importance attached to the seaweed resource is noted throughout the western Scottish islands, and has even been recorded as the subject of satirical verse (MacArthur 1990: 292-293).

Here, then, may be an example of the possible role of seaweed, used in place of mineral bulk manures and/or dung as the primary manure resource, in discouraging the formation of deep anthropogenic topsoils. The soils of Tiree are light and sandy, similar to the *machair* areas of other parts of the Western Isles for which, it is recorded, seaweed was preferred to the 'too heavy' effects of dung and earth (Smith 1994: 99). Machair areas, like Tiree, are popularly noted for their fertility. It would appear that islands and/or areas of this type, when fortunate enough to rely on a steady supply of seaweed, were in the pre-Improvement period, possessed of a successful 'closed' system for manuring within which the adoption of a plaggen-type system would have offered no benefit, as suggested in Section 3.3.5.

b. Iona – the monastic connection

A contradiction to this theory is the identification of extensive deep anthropogenic topsoils on the island of Iona, approximately 25 kilometres to the south-east of Tiree (Barber 1981; Haggarty 1988). Despite making equally good use of its seaweed resources (MacArthur 1990: 191), Iona clearly saw a radically different manuring system in place to that in evidence on Tiree for a good portion of its pre-Improvement history.

The explanation offered for the presence of these soils at Iona hinges on their location within the island – on the lands cultivated by the monks of the early Christian abbey for which the island is famous. It is currently hypothesised that a plaggen-type, turf-based manuring system was first introduced to Scotland by way of early Christian monks coming from Ireland, and that this originated at Iona (Simpson and Guttmann 2002). Current research into this phenomenon has successfully identified additional deep anthropogenic topsoil areas on several Scottish islands with an historic link to the early Christian missionary spread from Iona (Section 2.4.3). Research is continuing in this area; but as concerns Tiree, it may be considered that the *absence* of deep anthropogenic topsoil in this productive island - only a short distance from Iona but with no history of monastic cultivation – may also support this theory.

c. Ruaig

No relevant information regarding the manuring tradition of the Ruaig township has been identified. Argyll estate records make no special of the area being particularly productive – on the contrary, for the period of the Turnbull survey the settlement was in the hands of sub-tenants and cottars (Cregeen 1964: xxiv). There appears to be no historical data available to account for the small deep topsoil polygon at Ruaig – not surprisingly, as the area covered is so small as to be most likely the result of very localised manuring activity.

5.2.4.4 Assessment of the manuring database

Although lacking in a sample site, the survey at Tiree proved valuable for the opportunity it provided to assess the usefulness of spatial archaeo-historical datasets to the manuring database. The usefulness for this project of features within the Turnbull survey map and legend, such as township acreage, boundaries and percentages of infield to outfield and waste land, highlights the importance of detailed and localised source data in locating non-visible elements of the historic landscape, such as deep anthropogenic topsoils: a fact already noted in assessing the performance of other elements of the database.

In this, the First Edition Survey Project dataset is shown to be somewhat lacking. Although providing a richly-detailed data source in a Scotland-wide context, the FESP content is seen to be relatively limited at a local level, providing a coverage dictated by the survival of individual structures which does not necessarily represent original settlement patterning or density. This provides a dataset which is a step removed from the landscape-representative coverage required to investigate more elusive, sub-surface elements of the historic landscape. This is discussed further in the assessment of the manuring database in Chapter 8.

Plate 5.14: Seaweed spread fresh as fertiliser upon arable land at Ruaig, Tiree, Spring 2003

5.2.5 Survey 5: Ecclesiastical sites on the Solway coast– Dundrennan and Whithorn

5.2.5.1 Site selection

The final surveys carried out for the project were centred on the Solway coast towns of Dundrennan, to the south-east of Kirkcudbright, and Whithorn, located approximately 30 kilometres further to the west, both within the Dumfries and Galloway region (Figure 5.11). With the Border/Lowlands as the remaining region for which no survey had been undertaken, locating this final investigation within the predominately pastoral Dumfries and Galloway area fulfilled the outstanding requirements of the survey methodology detailed in Section 5.1.3.

Although famed for its livestock production, the Dumfries and Galloway region also has a history of high arable productivity (see Section 5.2.5.3) especially along the lower-lying coastal fringes into which, we can assume, much of the moveable volume of manure created by this stock base would have been channelled. Within this coastal fringe, the dominant agricultural influence throughout much of the region's history has been that of the Church – from the earliest record of missionary activity in fifth century Whithorn, to the final disposal of the vast land holdings of the monasteries dotted along the Solway Firth in the sixteenth century.

In view of the importance of these monastic centres to the agricultural history of the Dumfries and Galloway region, and of the possible significance of monastic influence to the development of deep anthropogenic topsoils (already touched upon in the Tiree survey), it was decided that this final survey would consist of two investigations, centred on two of the best known ecclesiastical centres in the region. These are Whithorn, a Christian centre since the fifth century that saw periods of native British, Northumbrian, Irish, Norse, Anglo-Norman and Scottish control (Figure 5.12), and Dundrennan, a Cistercian monastery established in 1142 which, like Whithorn, saw its lands sold with the advent of the Reformation four centuries later (McCulloch 2000: 314-324) (Figure 5.13).

In the context of the posited monastic link to the distribution of deep anthropogenic topsoils in Scotland, both of these sites are potentially of great interest. Several Irish texts purportedly describe strong links between Whithorn and Ireland, specifically, that St. Finnian, the mentor of Columcille, was educated at Whithorn, thus establishing a possible ideological link between Whithorn and Iona (Hill 1997: 3; 15). Dundrennan, although separate from this tradition, offered a chance to investigate the different dynamic of the Cistercian order: best known for their extensive farm 'granges' and sheep and wool industries, arable farming was nevertheless a strong feature of their (at one time extremely richly endowed) agricultural tradition. Irish links may continue into this region of Galloway: Kirkcudbright, the neighbouring parish and closest town to Dundrennan, takes its name from St. Cuthbert, the Irish prior of Melrose and Lindisfarne, and approximately equidistant between Dundrennan and Whithorn, in the parish of Minigaff, the place name *Papy Ha* survives - identified as relating to the Papar priests, discussed in Sections 2.3.2.2 and 5.2.4.3 for their likely connection with the development of deep anthropogenic topsoils (Maxwell 1930: 221).

Finally, survey within this region also provided an opportunity to assess the usefulness of the second archaeological dataset incorporated into the manuring database – the Historic Land Use Assessment (Section 4.1.4). The possibly limited usefulness of this dataset as a tool for highlighting deep anthropogenic soils has already been discussed; however, with HLUA coverage available for one of the sites selected (Dundrennan) but not for the other (Whithorn), a practical assessment of this dataset is included in this report.

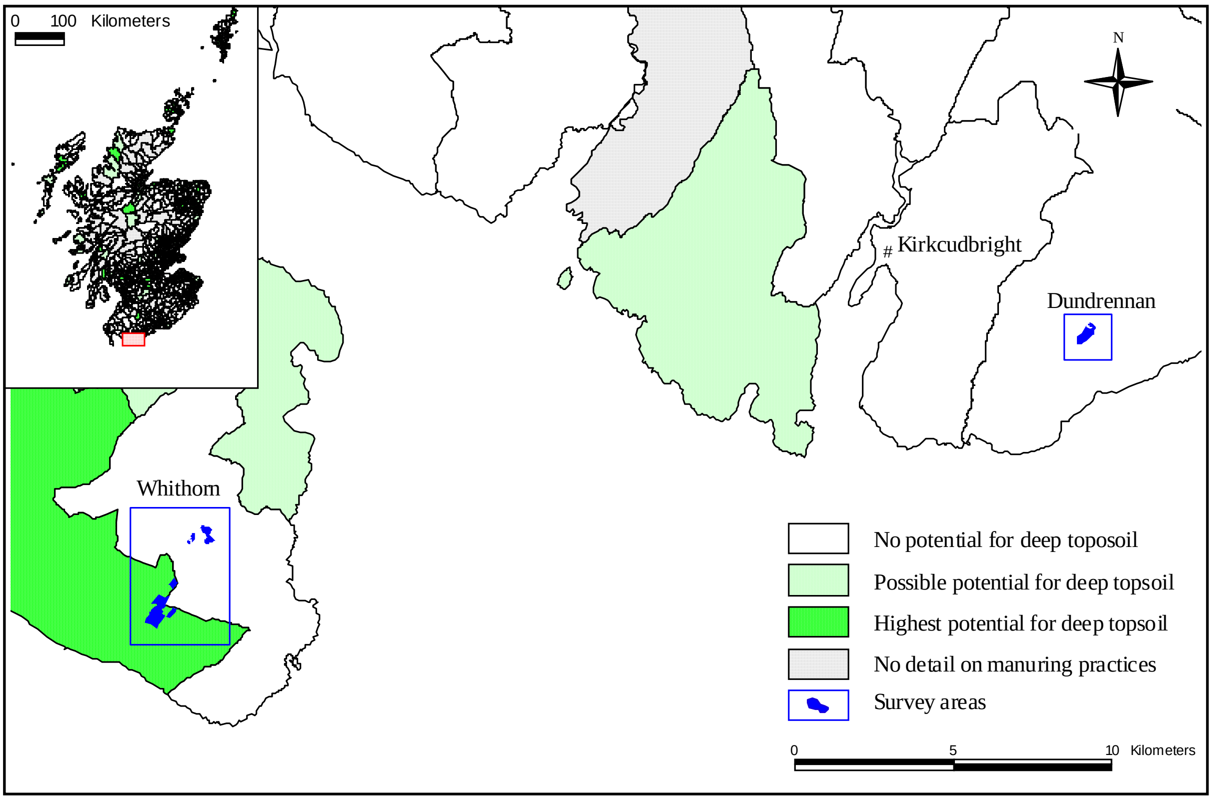


Figure 5.11: Location of Solway coast survey area survey

5.2.5.2 Auger survey

a. Dundrennan

The area around the ruins of the abbey of Dundrennan is rural in character, with Dundrennan itself a relatively small village. Auger survey could therefore be undertaken immediately outside of the scheduled area covering the Abbey ruins and immediate precincts, yet still adjacent to the Abbey itself. Unfortunately, due to access restrictions, the final area covered by this survey was relatively small (Figure 5.13). Auger points were taken on average 10-30 metres apart, on a largely random basis, to a maximum of approximately 40 auger points. All topsoils within the undeveloped land surrounding the Abbey measured 15-25 cm in depth. The sole exception to this was an apparently small area of deep anthropogenic topsoil, located within one of the closest fields to the Abbey available for survey, to the south-east (Figure 5.13; Plate 5.15).

Although only identified within this one field, access restrictions make it impossible to know whether the deep topsoil was contained within this field, or was part of a larger spread – specifically, whether this deep anthropogenic topsoil continued to the west and into the scheduled Abbey grounds. As this topsoil was not located on more than one land use parcel – current pasture – permission to continue this survey within the scheduled area was not sought.

b. Whithorn

At Whithorn, the presence of a substantial small town around the Priory site, in places contemporary with significant periods in the Priory's history, necessitated a different approach to the survey. With only a limited survey possible in the remaining farmland around the Priory (Figure 5.12), the manuring database was consulted for consideration of a wider relevant area into which to take the investigation. Research within the parish of Glasserton, a high-rated parish

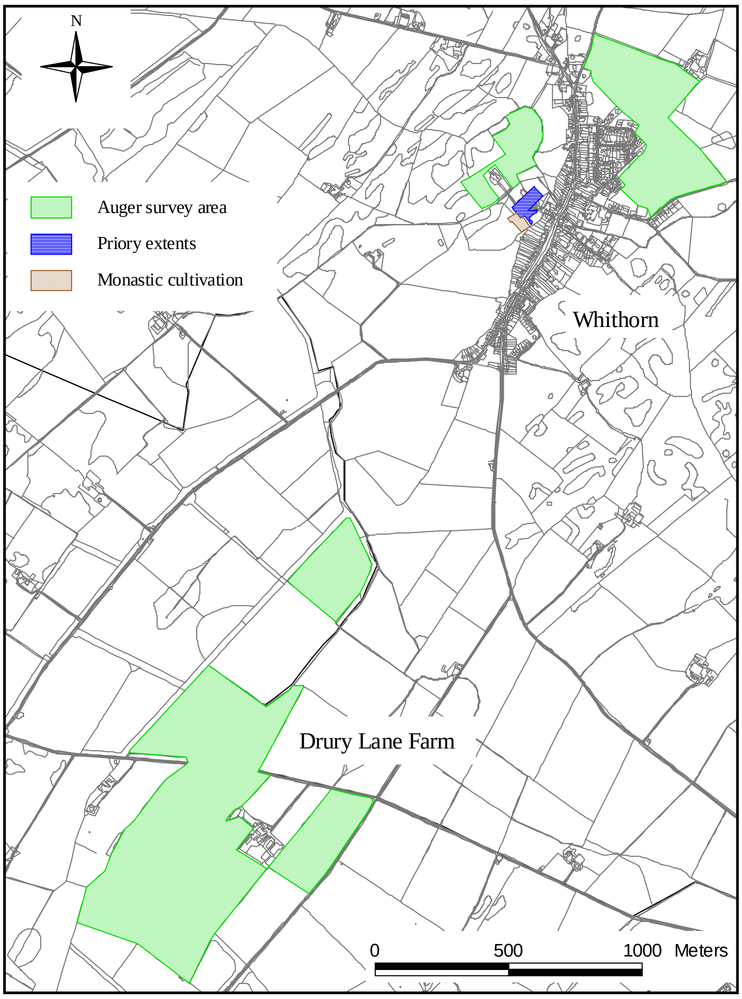
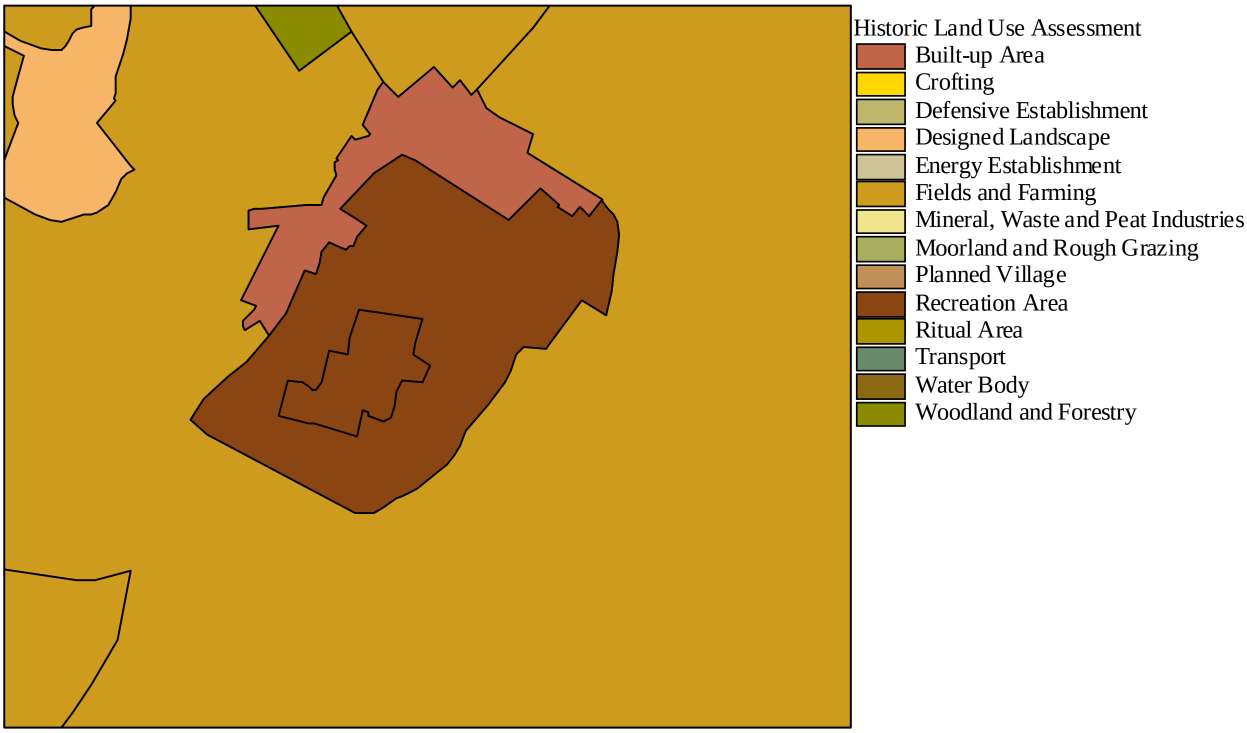


Figure 5.12: Survey at Whithorn

adjacent to Whithorn, established that the network of farms within the south of the parish – the fertile Isles of Whithorn – had been largely owned by the Church, including that at Whithorn (http://www.isleofwhithorn.com). One of these, the Physgill Estate, was by the seventeenth century in the hands of the prominent agriculturalist Robert Hawthorn Stewart (FSA XVII: 589). A second, more extensive survey area was therefore selected from among these previous holdings of the Whithorn Church, located between the Physgill Estate and the modern village of Whithorn, at the present-day Drury Lane Farm (Figure 5.12). Within the Priory area itself, the survey extended through the enclosed, 'infield' areas surrounding Whithorn shown on Roy's map of 1750 (Donnachie and Macleod 1974: 18) excluding those encroaching into the scheduled area. Approximately 50 auger points were taken, split more or less equally between Drury Lane and Whithorn, on a regular yet random basis, and restricted to a small extent by problems of access. Neither site identified any topsoil deeper than 25 cm.

With HLUA coverage available for the Dundrennan survey area, a series of overlays for the region were created utilising each information category within the HLUA dataset in order to see if this could refine the survey design and/or contribute to understanding of the area. The results were disappointing. Firstly, the resolution of the dataset – to one hectare – proved an immediate limiting factor. In addition to this, however, the categories which the HLUA database describes are by their very nature too broad to offer much scope for contribution to a survey of this kind.

An illustration of this is provided at Figure 5.13. Three categories of potential relevance to the survey programme can be isolated in the HLUA dataset: 'Historic', 'Type' and 'Period'. Figure 5.13 shows the Dundrennan survey area overlain by the HLUA dataset sorted using the 'Historic' categorisation. It can be seen that the area of the Abbey grounds is listed only as 'Recreation' and 'Built Up Area', while the rest of the entire survey area is resolved into only 'Fields and Farming'. The other categories provide a similar level of information. 'Period' shows this area of 'Fields and Farming' under the single category of '18th- 19th century', while 'Type' categorises this same area into 'Rectilinear Fields'. While clearly providing an impressive data source at a regional scale, it would appear that the HLUA dataset, like the First Edition Survey, can be of only limited practical use in locating and characterising deep anthropogenic topsoils.


Historic Land Use Assessment
Built-up Area
Crofting
Defensive Establishment
Designed Landscape
Energy Establishment
Fields and Farming
Mineral, Waste and Peat Industries
Moorland and Rough Grazing
Planned Village
Recreation Area
Ritual Area
Transport
Water Body
Woodland and Forestry

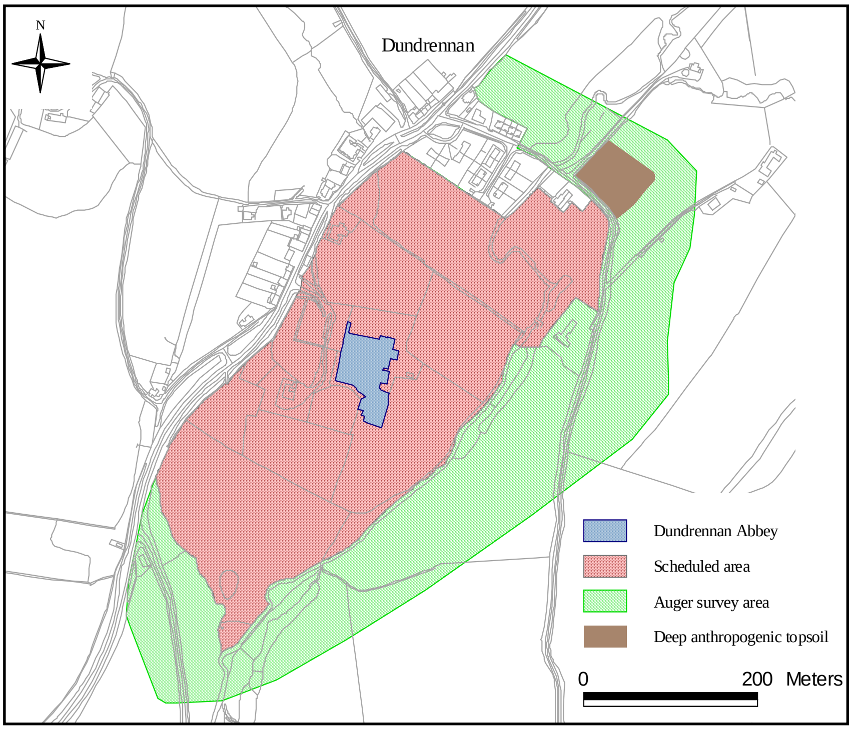


Figure 5.13: Dundrennan, showing auger survey area around the scheduled Abbey and grounds, with overlay (film) showing Historic Landuse Assessment data for the area

Plate 5.15: Dundrennan Abbey, viewed from the field showing deep anthropogenic topsoil (foreground)

5.2.5.3 Historical and archaeological context

Although the Dumfries and Galloway region is famed as a pastoral area, the economy was mixed and the agriculture varied. Sheep predominated in the upland parishes, elsewhere, black cattle were the staple livestock, but in the coastal parishes a surplus of cereals were grown and exported to the North of England and the Clyde (Hume 1983: xiii). Oxen were popular from an early time, which were '*not so expensive by far in keeping as four horses, which must be fed dayly with corn; besides the oxen yeeld much more dung*' (Simson 1684: 75). The setting was one of general productivity which characterised the whole southern region: in 1854, the south-western counties of Scotland comprised 15.6% of the total land acreage, but 26.7% of the arable land, 30.5% of the cattle stock and 21.4% of the total sheep population (Dodd 1979: 137). An early and extensive utilisation of artificial fertilisers such as lime, but also the marl and shelly sand abundant in the region, saw this productivity continue to rise into the nineteenth century. Marl was adopted in Galloway as early as 1730, and by the nineteenth century, a huge variety of materials such as guano, grass ashes and ground bones were being used as fertiliser (Maclelland 1875).

While direct evidence for a plaggen-type manuring system is absent from this large region, early historical records allude to the utilisation of turf as byre bedding and the subsequent use of this as manure (see below). However, as has been established elsewhere in this thesis, this is no indication that a widespread turf manuring system of the kind seen on the Continent was in place.

Interestingly for a coastal area, seaweed does not generally appear to feature prominently in pre-Improvement records: Simson, in a lengthy description of the manuring of the 'bier- (bear)-fey', which in so many coastal areas was popularly manured with seaweed, only refers to this crop being 'dunged' (Simson 1684: 76).

a. Dundrennan

Dundrennan was the second Cistercian monastery established in Scotland, in 1142. The Cistercian monastic order was famous for its 'sheep-granges': large pastoral holdings that supplied wool for trade. That monasteries such as Dundrennan may have concentrated on sheep farming at the expense of arable cultivation is indicated in the issuing of permits to the monastery to buy grain from England and Ireland during the 1260s (McCulloch 2000: 134). But the Cistercians were also noted land improvers, engaged in draining, reclaiming and cultivating lands through the same periods (*ibid*.: 135).

Direct evidence for manuring practice is, however, absent from Dundrennan, with its parish of Rerrick offering no manuring information in either its First or Second Statistical Accounts. Likewise, excavation at Dundrennan, undertaken at various points throughout the Priory grounds and at various times (e.g. Ewart 2001), shows no investigation of the agricultural history of the area immediately adjacent to the monastery.

b. Whithorn

Whithorn was established as a bishopric in the early 5th century by St. Ninian, and saw successive monastic regimes from the 8th to 11th centuries before being rebuilt as a cathedral and priory church in the 12th century. Although designated a Royal Burgh in 1511, Whithorn nevertheless remained a relatively small settlement of only local importance.

The site of the many phases of Whithorn priory was the subject of a large excavation programme from 1984-1991, through which significant details of monastic cultivation practices have been established. Early, and possibly extensive, cultivation is indicated by the identification of large numbers of plough pebbles dating from the sixth and seventh centuries. These artefacts are associated with the design of the mouldboard plough and thus the tillage of heavy ground, or possibly, the breaking in of new ground (Hill 1997: 161; Hill and Kucharski 1990). Ploughsoils identified from this same period show artefact concentrations indicating that they were probably deposited within bulk manure material (*ibid*.: 80). Similar ploughsoils and attendant pebbles survive from the eighth and ninth centuries, as do much later, fourteenth century cultivation ridges dug through part of the earlier Northumbrian phase of the site (Hill 1997: 62). A part of this same area continued in cultivation, as a market garden, into the mid 20th century (Hill and Pollock 1992: 35).

Despite this, there is no evidence for deep topsoil formation within the vicinity of Whithorn Priory. A recent excavation in the location of the cultivated areas identified topsoil only up to 20 cm deep (Lowe 2000: 2), and micromorphological analysis of soil samples taken from cultivated areas found no evidence of plaggen type cultivation (Davidson 1990: 6). Likewise, there is little information available from the historical record: both the First and Second Statistical Accounts for Whithorn itself provide little information on traditional manuring methods.

c. Drury Lane Farm

In contrast to Whithorn, the parish of Glasserton, location of the Drury Lane sample area, provides significant detail on manuring practices in the area. Marl and seaweed are both mentioned, but more detail is reserved for the description of the care of the all-important Galloway black cattle:

> *'They are here and there wintered in sheds, and cow-houses, as well as to preserve them from suffering by the inclemency of the season, as that the refuse of their forage and litter, mixed with their dung, may accumulate for manure to the ground under tillage….Lime imported from Whitehaven; marl dug from those pits which are now nearly exhausted: dung; and composts of dung, earth, and lime, are the manures employed to fertilise the soil.'* (FSA XVII: 584).

No further manuring detail exists for the area specific to Drury Lane Farm, but this reference certainly indicates a tradition of bulk manuring likely to have been at least partly responsible for creating the rich arable landscapes which proved so amenable to the improvements of Robert Hawthorn Stewart at the Physgill Estate. With several centuries separating the cultivation evidence from the Whithorn Priory area and this eighteenth-century account, what the Glasserton manuring system owes to the monastic agricultural tradition at Whithorn remains unknown.

5.2.5.4 Assessment of the manuring database

Although the practical application of the HLUA data to the discovery of deep anthropogenic topsoils was found to be negligible (Section 5.2.5.2), this survey nevertheless provided a useful illustration of the value of the historic dataset in both survey design and desktop research. By highlighting the discrepancy in manuring information between the parishes of

Whithorn and Glasserton, the survey was inspired to look at the wider area for more detail on the manuring tradition for pre-Improvement Whithorn. This has resulted in both a more detailed survey and a more comprehensive body of research. Both this and the implications of the HLUA assessment for the development of the manuring database are discussed further in Chapter 8.

5.3 Summary

5.3.1 The sample sites

Of the five surveys undertaken, three successfully identified areas of deep topsoil suitable for inclusion in the sampling programme. Within the final two survey areas, limited areas of deep topsoil were identified (at Tiree and Dundrennan). While this appears to be a relatively high rate of identification, in a Scotland-wide context, the very small overall sample area covered in this project means that it is not possible to use this identification ratio as a measure of the likely frequency of deep anthropogenic topsoils in Scotland.

However, a closer look at the survey results gives a more meaningful analysis. In spite of the successful identification of sample sites through the Nairn, Angus and Unst surveys, it becomes clear from consideration of these survey results that deep topsoil cover in each of these regions is likely to be minimal. Despite equally strong indicators for deep topsoil throughout the wider surveyed area in these regions, survey established that most of these did not show deep topsoils.

Secondly, the fact that these five survey areas were selected specifically for their increased likelihood of showing deep anthropogenic topsoils should not be forgotten. If a relatively low identification rate from even these areas is achieved, then the conclusion that deep anthropogenic topsoils may be relatively rare in Scotland becomes more likely still.

5.3.2 Thematic interpretations

A logical continuation to the discussion above – that deep anthropogenic topsoils may be relatively rare in Scotland – is to return to the factors which have been posited throughout this thesis as possibly responsible for the distribution and frequency of deep anthropogenic topsoils in

Scotland. If these topsoils have a limited distribution, what issues contribute to make it so?

The survey programme has provided several valuable insights in this area, allowing the suggestions arising from the historical research and spatial analysis undertaken in Chapters 3 and 4, and presented at the beginning of this chapter, to be explored. The first of these was the likely central role of *significant* bulk manure use in the development of deep anthropogenic topsoils. Desktop research into the manuring system within each area provided the strongest evidence for this at Unst. That the deepest of the topsoils were recorded from here (Appendix 5) is of interest; however, it must be presumed that bulk manures must have been in use at all sites where a significant depth of topsoil was identified.

The second proposition presented for consideration was the role of seaweed in discouraging deep anthropogenic topsoil formation. The survey at Tiree generally appeared to support this, with no significant evidence for deep topsoil formation.

The structure of the survey programme, designed to provide a comprehensive coverage of cultural and geographical variation throughout Scotland, allowed exploration of a further two factors: the potential connection between deep topsoil formation and the Irish-origin monastic influence in Scotland (the Tiree and Solway Firth surveys); and the connection between patterns of urban settlement and increased frequency of deep anthropogenic topsoil formation (the Nairn and Tealing surveys). While exploration of the first of these could only provide a relatively limited comment on a wide-ranging and ongoing programme of research (Simpson and Guttmann 2002), the second identified a potentially strong link between urban settlement and deep anthropogenic topsoils, with two of the three sampled sites indicating an urban-influenced context.

5.3.3 The manuring database

The appraisal of the manuring database provided by the survey programme proved to be of considerable value, with both positive (elements of both the Soil Survey and historical datasets) and negative (the FESP and HLUA datasets) aspects of the database identified. In addition to this, the value of tailoring the database by the inclusion of small, area-specific datasets, such as that used for Tiree, was amply illustrated. A final appraisal of the contribution of the manuring database, not only to this survey series but to the wider field of deep anthropogenic topsoil research, is provided in Chapter 8.

5.3.4 Recommendations

Overall, the survey programme has – in addition to providing sample sites – allowed considerable insight into the position of deep anthropogenic topsoils in the Scottish landscape, and thus more detailed comment to be made on an appropriate conservation methodology. Above all, the design of the survey programme, with its emphasis on desktop historical and archaeological research, has most successfully established the *individuality* of deep anthropogenic topsoil areas in Scotland. Rather than representing examples of a large-scale, homogenised manuring tradition as seen in areas of the Continent, what has been emphasised through the research undertaken for these surveys is the unique combination of cultural and environmental circumstances that have contributed to the formation of these soils in their Scottish locations. Discussed further in Chapter 8, this is a vitally important consideration for a conservation methodology which, it would seem, is required to look at these soils as local, as well as national, cultural artefacts in order to fully appreciate their contribution to landscape research.

6. Bulk samples: physical and chemical analysis and discussion

6.1 Introduction

This chapter presents the results of the physical and chemical analyses of the bulk samples taken from the three sampled deep anthropogenic topsoil sites described in Chapter 5. It discusses how these results, considered both separately and in combination, may inform upon the effect of modern agricultural activity and/or current land cover on the retention of, and our ability to interpret, the cultural information retained within deep anthropogenic topsoils.

Three soil factors were examined for this study: soil pH, soil organic matter content (SOM), and soil total phosphorus content (total P). These are not only key soil features fundamental to soil processes and development, but are also widely considered the most useful quantifiable factors reflecting past human activity upon the soil (see following). As such, these properties have long featured in geoarchaeological investigation, but also have an extensive research literature which ranges beyond this into many other areas of agricultural and environmental soil-based study, some of which themselves consider the effect of land management and land cover on essential soil properties (e.g. Korschens 1998; Ekholm *et al*. 2005). It is this wide-ranging literature which enables this discussion to take a broader perspective, moving from a discussion of the changes reflected in these three soil properties to a consideration of how current landscape conservation and management policies might help or hinder their expression, and thus advance the aim of this thesis to identify the nature and extent of the threats posed to Scottish deep anthropogenic topsoils by modern land management activity.

The structure of this chapter is as follows. Firstly, the sampling regime introduced in Chapter 5 is revisited, with a brief discussion of the range of land cover categories sampled and the sample profiles available for each. As the range of landscape situations available for assessment was necessarily decided by their presence within the rare and generally small polygons of deep anthropogenic topsoil located, the result is a fairly complex pattern of samples within a small dataset, with varying levels of comparability both between and within each site (Section 6.1.2).

Following this, the analysis of each of the three measured soil properties is, initially, discussed separately, beginning with a consideration of the property concerned, the development of the analytical approaches available (particularly for total P), and the significance of these to our understanding of the properties of deep anthropogenic topsoils. These sections provide essential context for the discussion and conclusions reached within the chapter. For all of these soil properties, variables introduced not only as a result of both man-made and natural processes but also the techniques of analysis themselves are reflected in these results and may as a result both hinder and illuminate our understanding of how these soil processes relate to the survival of cultural indicators under different landscape conditions. For phosphorus analysis in particular, a consideration of previous research in this area is key to understanding how conclusively we may accept the evidence for soil change presented by these analyses, and how confidently we can ascribe these changes to what is only one of many factors influencing soil-based chemical and physical processes. This multiplicity of variables acting to influence soil chemical and physical properties, and the challenge this poses for the interpretation of these analyses is a dominant theme within this chapter, and is discussed further in Section 6.1.1.

For the pH and soil organic matter analyses, these individual sections conclude with a relatively brief discussion of the results of each study and the relationship of these with land cover and land use variables.

The central focus of this chapter is the study into total phosphorus content presented in Section 6.4. Widely recognised as the most useful chemical indicator in archaeology (e.g. Provan 1971; Proudfoot 1976; Bethell and Mate 1989), phosphorus analysis is also by far the most complex of the analyses undertaken which has been subject to a far wider range of analytical approaches. This section therefore provides a more detailed review and discussion of the problems and issues associated with phosphorus analysis and the reasons for the choice of analytical method used in this study. The section concludes with an extended discussion of the results of the phosphorus analysis which also incorporates the pH and soil organic matter results to provide a set of integrated conclusions to this series of studies. It will be seen that, although limited by the small sample set available, interesting lines of enquiry are raised by these results which may have a bearing upon the survival of cultural indicators in deep anthropogenic topsoils.

Finally, a brief consideration is made of these results in the light of some current approaches to the issue of soil protection and conservation. This is a complex area, the vast body of research connected with which lies outside the scope of this thesis. However, as is the case in earlier chapters, some basic conclusions can be drawn on whether, in the light of these set of interpretations, current policy is likely to prove beneficial for deep anthropogenic topsoils subject to modern landscape activity. This theme is developed further in Chapter 8, in the light of the observations on the distribution, rarity and context of survival of deep anthropogenic topsoils provided by the earlier part of the thesis.

6.1.1 Soil development, formation processes and the interaction of variables

Soils are notoriously variable in their properties, even within small areas (Moore and Denton 1988: 27). In a study such as this, where an attempt is made to relate changes in soil properties to specific influences, it is vital to recognise the complexity and variability of the factors and processes which affect the formation and continuing evolution of both natural and human-influenced soils. The reality of the soil as a dynamic entity, potentially subject to a range of continuing physical, biological and chemical interactive processes, inevitably places a limit on the degree of certainty with which we can identify cause and effect by examining one or even several of these variables (Holliday 2004: 52).

A brief look at the basic tenets of the main conceptual approaches to pedogenesis illustrates the complexity of the system. The 'state factor' approach to soil genesis (Jenny 1941) defines the environmental factors which act to promote soil formation in the following equation:

$$\boldsymbol{S} = f\,(\boldsymbol{cl}, \boldsymbol{o}, \boldsymbol{r}, \boldsymbol{p}, \boldsymbol{t}\ldots),$$

where soil ***S*** is formed through the factors ***cl***imate, ***o***rganisms (flora and fauna), ***r***elief (or landscape setting), and ***p***arent material operating over ***t***ime. This portrayal of the soil as essentially a four-dimensional entity is developed further through the 'soil evolution' model (Johnson and Watson-Stegner 1987; in Holliday 2004: 47), which posits that these multiple factors combine to advance not only the 'progressive pedogenesis' of soil development (horizonation, soil deepening, and the mixing of mineral with incoming organic components) but also the inhibitive 'retrogressive pedogenesis' of soil erosion and haploidization. The multiplicity of these state factor interactions means that progressive and retrogressive pedogenesis usually operate together within the soil system (Holliday 2004: 48).

In anthropogenically modified soils, pedogenetic change caused by the interplay of these large-scale environmental factors is combined with the effects of direct or indirect human influence to create a modified, and thus invariably more complex, system of 'site formation processes', the understanding of which is crucial to the archaeologists' ability to identify indicators for past human activity from natural, and/or later cultural, events (Schiffer 1987; Holliday 2004: 261). A key part of the site formation process are those soil-based events which, though fundamentally an expression of the 'state factors' described above, take on particular significance within archaeological study as identifiable agents for modification, and even destruction, of the soil environment and the material archaeological remains within it. When expressed at the site or landscape level, these processes allow visualisation of the complex range of biological-chemical-physical interactions which can affect soil properties: for example, mixing features such as pedoturbation, root penetration, freeze-thaw disturbance and clay shrinkage; corrosion, etching and degradation of artefacts as a result of severely acid or sometimes basic soil conditions; and biological effects such as faunalturbation and decomposition of organic materials (after Schiffer 1987). Anthropogenic influence is then itself also an agent of soil change, either through human modification of one or more of the 'state factors' (e.g. change in relief through settlement activity) or by the effect of material remains themselves (e.g. the deposition of phosphorus-rich faeces or organic materials such as wood within the soil environment) (Butzer 1982: 77-78).

To take one soil property at this local level and ascribe changes in this property to a specific environmental or human influence is extremely difficult. For example, soil pH is known from *in situ* measurement to fluctuate markedly over short distances or within short periods of time, an effect which is ascribable to many factors, such as local microbial action, variations in the distribution of soil organic matter, soil water content, and even the time of year (acidity is likely to be higher in summer, due to increased microbiological activity and plant growth) (Brady 1974: 381; Pollard 1998: 63; Section 6.2.1). Here, the interaction of the 'state factors' is clearly illustrated, as is the problem of *equifinality* – the convergence of a variety of processes to produce similar end results despite differing developmental pathways (Holliday 2004: 51).

Within soil science, attempts to control this multivariate environment have been through the classification of soil types and their key characteristics, and the mapping of their occurrences and thus environmental associations, thus allowing for the concept of ‘control’ profiles against which to investigate, for example, landscape effects on soil quality (Bibby 1980). The human-influenced component of anthropogenically modified soils, however, introduces a variability which defies this mode of classification. While site-based anthropogenically modified soils may be explicable through their archaeological context, this context may be missing for anthropogenic soils in the wider landscape. This becomes even more of an issue in the study of deep anthropogenic topsoils, for which the entire topsoil is created anew by human additions, and thus for which comparative studies of the physical and chemical character of nearby ‘natural’ soil profiles are typically of even more limited value. This man-made character also poses a challenge to any attempt to chemically or physically characterise the ‘typical’ deep anthropogenic topsoil, although such classifications are generally useful (Chapter 2). To return to the example of pH, while the plaggen soils of the Continent are typically classified as having an acid reaction, the Irish deep anthropogenic topsoils (also referred to in the literature as plaggen soils) have a typically high pH, due to the fact that the main added material was not heather sods but calcareous sea-sand (Conry 1974: 323). Phosphorus content, universally described as ‘high’ in deep anthropogenic topsoils, is also seen to vary widely, again due to differences in added materials (e.g. compare Simpson 1997: 370 and Conry and MacNaeidhe 1999: 88). It can be seen that it does not seem possible to create any but the most simple ‘baseline’ characteristics for deep anthropogenic topsoils, against which to assess the effect of variables such as land cover and land use.

An additional point may further complicate this study. It should be remembered that the activities under investigation, which largely derive from agricultural activity, are similar in many chemical and physical characteristics to those activities which originally created the deep anthropogenic topsoil, and are thus likely to be chemically and physically similar in their expression in the soil record. In which ways can we distinguish a relict from a modern signal in the case of, for example, phosphorus content? While the nature of these deep anthropogenic topsoils – for example, their limited horizonation within the A horizon, the association of anthropogenic materials such as charcoal - has made it possible to apply certain archaeological criteria to this problem, the potential mobility of, particularly, the chemical signatures examined in this chapter makes this the most challenging aspect of the discussion.

6.1.2 The sample sets: organisation and comparability

6.1.2.1 The soil profiles

The samples analysed for this chapter are from bulk soil taken from alongside each Kubiena sample point in each sample profile, with the exception of profiles UN1, UN2 and UN3, where a bulk sample was taken from each recorded soil horizon. A total of 66 samples therefore represent the ten soil profiles from the three sites examined in this study, with between five and nine samples per soil profile. The stratigraphy of the soil profiles, the position of the samples and a description of each of the soil profiles is provided in Appendix 5. A full set of the results for each of the analyses discussed in this chapter is tabulated in Appendix 6.

6.1.2.2 Profile comparability

As discussed in Chapter 4, the sampling programme was significantly curtailed by the size and rarity of the areas of deep anthropogenic topsoil identified. The sample set is comprised of the following: at the Nairn site, one sample pit from a grassland area (NA1), one from a woodland area (NA2), and one from an area in current arable cultivation (NA3); at the Tealing site near Dundee, three sample pits from the same range of contexts (TE3, TE2, TE1, respectively); and at the Unst site in Shetland, one sample pit from an area of improved (re-seeded and fertilised) grassland (UN3), one from an area of unimproved grassland (UN2), and, from within a separate deep anthropogenic topsoil polygon, a sample pit from an area ploughed within the last 10 years (UN1), and one from an area last ploughed approximately 60 years previously (UN4).

This sample set is not only small overall, represented by only ten sample pits over three geographical locations, but also presents several landscape situations represented by only one sample profile, with an inevitably complex series of variables within each. For this reason, a statistical approach to the interpretation of these analyses was considered inadvisable (K. Howie pers. comm.), and the discussions presented in the following sections compare the sample profiles in a qualitative and discursive manner. It should be borne in mind that on the evidence so far presented in this thesis, the apparent rarity of deep anthropogenic topsoils in Scotland may make this a necessary approach. The deep anthropogenic topsoil sites, individual sample profiles and differing land cover situations are compared in this analysis using the approach set out in Table 6.1.

Firstly, a simple inter-site comparison of profiles under the same land cover or land management type is undertaken, for example, between the profiles under woodland or those under current arable cultivation at Nairn and Tealing (a). Are there similarities between profiles from different sites under the same land use, if so, what are these similarities, and can they be related to land cover or management?

Table 6.1 Comparative categories of the bulk soil sample set

Comparison	**Arable**	**Grassland**	**Woodland**
a. Inter-site	NA3 v TE1 (Nairn v Tealing, currently ploughed)	NA1 v TE3 v UN2 v UN3 (Nairn v Tealing v Unst: undifferentiated 'grassland')	NA2 v TE2 (Nairn v Tealing)
b. Intra-site	UN1 v UN4 (recent v past ploughing)	UN2 v UN3 (improved v unimproved grassland)	
c. Chronological	(NA3/TE1) v (UN1/UN4) or (NA3/TE1/UN1) v (UN4)	(NA1/TE3/UN3) v (UN2)	
d. Land use	Arable activity v grassland v woodland: overall differences (NA3/TE1/UN1/UN4) v (NA1/TE3/UN2/UN3) v (NA2/TE2)		

Secondly, an intra-site series of comparisons are considered (b). Given the already stated variation between individual deep anthropogenic topsoils due to their necessarily unique input history (Section 6.1.1), this is potentially a particularly valuable category, representing profiles upon discrete deep topsoil polygons whose relict cultural signature we can assume to be comparable. This category naturally overlaps with (d) – the overall comparison of land cover differences – e.g. in the individual intra-site comparison of arable, grassland and woodland profiles at Tealing. However, variability in both deep topsoil polygons and sub-categories of land use at the Unst site allows further comparisons to be made at this intra-site level, with one discrete deep topsoil polygon offering a comparison of recent and past cultivation, and the other a comparison of improved (or re-seeded and fertilised) and unimproved ('wild') grassland. Here, the analysis looks for differences between profiles whose history, prior to modern land activity, we can assume to be comparable.

A further comparative category may be termed 'chronological' (c). Here, representative profiles are available for comparative activities separated by time, for example an ongoing versus defunct activity such as ploughing, or a development in land management technique, as in the introduction of improved grassland. At its most basic, this category can be seen to overlap with intra-site comparison (b), as in the case of the comparison between plough episodes separated by c.50 years represented by UN1 and UN4. However, this category can be broadened to band together profiles from different deep topsoil polygons – for example, in the comparison of the known improved grassland profiles at Nairn, Tealing and Unst with the unimproved Unst profile. Similarly, comparison can be made between the current arable cultivation seen at Nairn and Tealing with the now defunct cultivation at Unst, or even the 'recent and current' cultivation at Nairn, Tealing and recently ploughed area represented by pit UN1, and the much earlier cultivation represented by pit UN4.

Over and above these inter- and intra-site observations, however, potentially the most interesting are those set of comparisons between the representatives of each core type of land use and cover sampled – arable, grassland, and woodland (d). Given the small sample set, this more generalised comparison with its larger number of samples forms the centre of the discussion in the following sections.

6.1.2.3 Sample preparation

Bulk samples were taken from each soil horizon recorded (Appendix 5) from a point adjacent to that of the soil micromorphology sample. These bulk samples were transported to the laboratory, laid in trays and air-dried for two weeks, then sieved to >2mm prior to the commencement of the pH, organic matter and total phosphorus analyses.

6.2 The analysis of soil pH

6.2.1 Soil pH and geoarchaeological study

Soil pH, commonly termed soil acidity or alkalinity, is a measurement of the comparative concentration of H^+ and OH^- ions in the soil. This is expressed as the negative logarithm of the H^+ ion concentration on a scale of 1-13, with ph 7 representing neutral, above pH 7 alkaline (or basic) conditions, and below pH 7 acidic conditions. pH is a so-called *master variable* – affecting all biological, chemical and physical soil properties (Brady and Weil 1999: 343-4). Conversely, it is itself affected in some way by very many of these. The pH of a soil is partly determined by the base status of its parent material, but is also a flexible soil property representative of the current chemical state of the soil, a state which can be affected by countless environmental variables.

For example, climatic variation affects soil pH, as increased rainfall encourages leaching of base-forming cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+) leaving the soil dominated by Al^{3+} and H^+ ions (*ibid*.: 343). This leaching is, however, also dependant on the drainage capacity of a soil, which also means that geological and landscape conditions, ultimately, affect soil pH. Plant growth (and therefore also ultimately climatic, i.e. seasonal, variability) also acts to lower pH, producing acids through roots and the activity of microorganisms (Eidt 1985: 167; Brady and Weil 1999: 359). Other features of soil chemistry have a bearing on pH, for example the concentrations of soil macro- and micro-nutrients such as calcium and magnesium, which raise the pH of acid soils. This brings us to human influence: nutrient concentrations are commonly altered by human land management practices, such as the addition of fertiliser such as limestone (i.e. calcium carbonate) which raises soil pH; and the planting of crops, the growth and subsequent cropping of which depletes the quantity of soluble soil nutrients and thus lowers soil pH (Eidt 1985: 156; 166). Many other factors have a bearing on, or are reflected by, soil pH, including the other properties under analysis in this chapter: a high soil organic matter component is associated with lower pH, due to its high levels of biological action leading to organic decomposition and subsequent production of humic acids (Entwhistle *et al*. 2000: 183).

Despite these myriad influences, soil pH normally has a tendency towards stability, especially in more clayey soils. This is due to a chemical resistance towards pH change known as the *buffering capacity*, in which soils of intermediate pH status minimise the impact of changes in soil chemistry through the action of reserve ions located on, especially, clay minerals and organic matter (Eidt 1985: 165; Brady and Weil 1999: 351). Thus, it follows that for anthropogenic activity to be reflected in soil pH values, the activity must be of a sufficient intensity to overcome this natural buffer (Simpson 1985: 75). Ultimately, then, pH can prove of limited value as an indicator soil property in a landscape study context, retaining values within the normal range for the soil types in question (Entwhistle *et al*. 2000: 172). However, it may be important here to remember the logarithmic nature of the pH scale - for example, a decrease of pH from neutral to 6, although only a change of 1 on the pH sale, actually represents a tenfold increase in the number of hydrogen ions present (Pollard 1998: 63), which perhaps represents a more significant change in soil conditions than may be implied from the common measurement of pH to one decimal place.

In archaeological study, the significance of pH has been chiefly related to its usefulness as a barometer of soil conditions for artefact preservation. Acid conditions favour pollen preservation, but destroy bone, shells, wood, and some metals and their alloys such as copper and bronze, and damage the surface of fired clay (Renfrew and Bahn 1996: 52-55; van de Westeringh 1988: 14; Matthiesen 2004: 1373).

For deep anthropogenic topsoils, a low pH is typically recorded, which has been reliably linked to the chemical character of the materials used to augment the topsoil – typically heather sods from acidic heathland (Pape 1970: 241; de Bakker 1980: 326; van de Westeringh 1988: 14). However, as noted in Section 6.1.1, this signature may then change as a result of the application of different materials, for example the calcareous sea-sand used to build up the Irish ‘plaggen’ profiles described by Conry (1971). On this basis, pH therefore ‘provides the potential for differentiating between functional areas receiving different imported materials’ (Smith 1994: 10). This input influence is an important consideration for the evaluation of the inter-site variation in pH examined in this study. Without being well informed as to the input history of a deep anthropogenic topsoil, it may be difficult to compare pH values between sites and attribute their variation to, for example, the influence of land cover, with certainty.

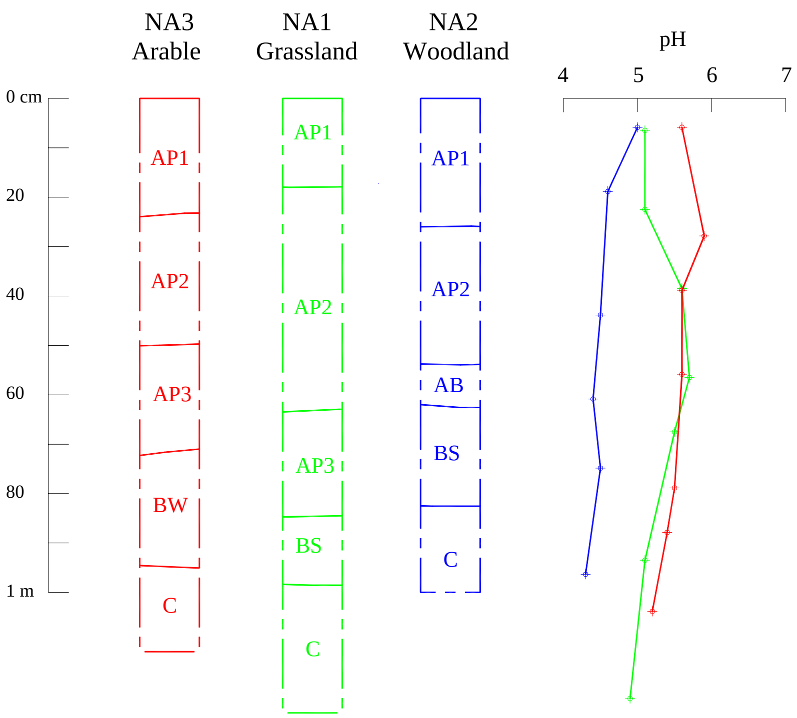
However, a second factor commonly cited when discussing the relatively low pH of deep anthropogenic soils is their good drainage capacity, generally recognised as a key reason for their creation (Pape 1970: 230) which is itself related to lower pH. The Irish plaggen soils are noted for an improved drainage capacity, attributable 'simply to the thickening of the surface horizons' (Conry 1971: 407) which would have the potential to lower soil pH despite the overwhelmingly calcareous nature of the soil. The physical qualities of a deep anthropogenic topsoil, then, can be said to support a tendency for these soils to have a lower pH than may be expected, although the intensive cultivation activity associated with these soils (see below) may offset this effect in more strongly acid soils.

Numerous studies have already investigated the relationship of pH to land cover and land management activity. The effect of modern agricultural management is well documented – for example, the lowering of pH resulting from the use of ammonium-based fertilisers (Brady and Weil 1999: 355). But more traditional agricultural activities are also known to affect pH. Land clearing promotes leaching which lowers pH. Agriculturally influenced changes in vegetation affect pH levels, as noted above. A more complex picture emerges from studies into the effect of plough activity, which generally seems to act to bring pH nearer to neutral, notably raising pH in acid soils to the medium acid range of about 6.5 within the cultivated horizon (Eidt 1985: 165; Sandor *et al*. 1986b: 180; Simpson 1985: 75). This literature on the effects of both historical and modern agricultural activity on soil pH is discussed more fully in the light of the results of this study.

6.2.2. Soil pH: results and discussion

The measurement of soil pH was undertaken following the methodology given in Appendix 7, and the results of the study are tabulated in full in Appendix 6. Figures 6.1, 6.2 and 6.3 provide a site-by-site illustration of the down-profile variations in soil pH.

Figure 6.1: Nairn: soil pH results for arable, grassland and woodland profiles



The Nairn deep anthropogenic topsoils (Figure 6.1) are all moderately acid, ranging from pH 4.3 - 5.9, with the arable profile NA3 generally showing the highest pH, and the woodland profile NA2 the lowest. Apart from a minimal overlap between arable profile NA3 and grassland profile NA1 in the lower part of the topsoil, this distinction is maintained down-profile, with all profiles showing a relatively ‘straight’ pH reading from the top to the bottom of the profile. All profiles, however, show a general lowering of pH down-profile, with the C horizon showing the most acid pH in each profile.

The Tealing deep anthropogenic topsoils (Figure 6.2) show uniformly higher pH than those at Nairn, with pH ranging from 5.4 - 7.3 – moderately acid to just above neutral. As seen at Nairn, the arable profile consistently records the highest pH, but at Tealing, the lowest pH is recorded from the grassland profile, and there is no overlap in pH between the profiles. Less ‘straight’ than Nairn, the three Tealing pits show no drastic variation down-profile. The trend towards greater acidity in the lower part of the profile is not repeated, however, with the Tealing samples showing a general increase in pH down-profile in both the woodland and the grassland sample pits.

Figure 6.2: Tealing: soil pH results for arable, grassland and woodland profiles

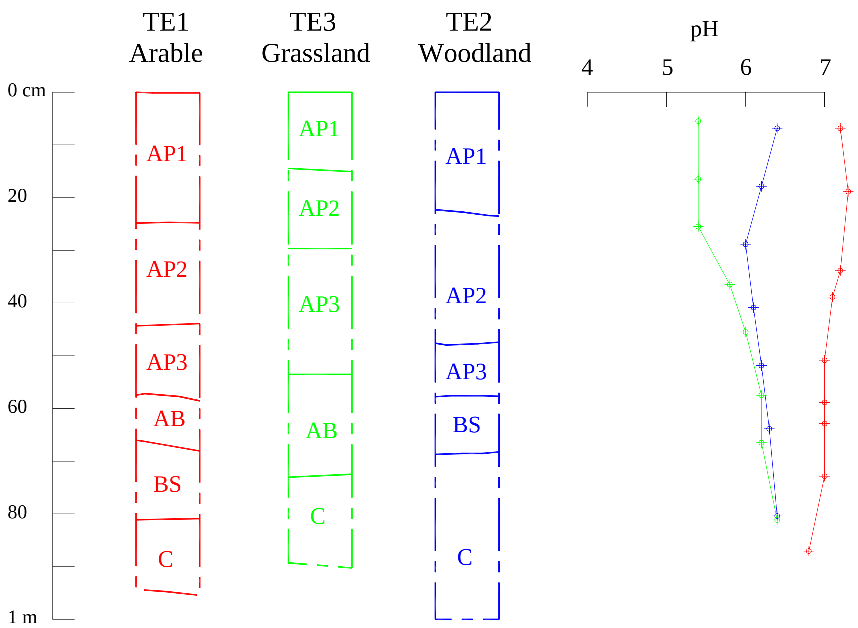
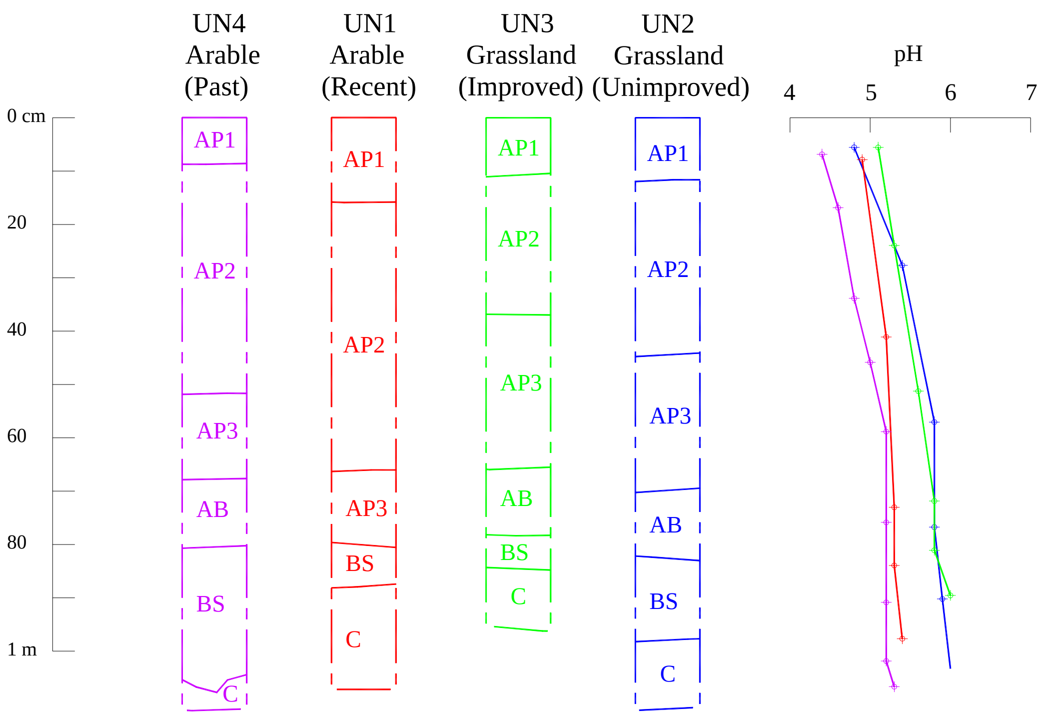


Figure 6.3: Unst: soil pH results for arable and grassland profiles



The Unst site, with its four pits over two discrete deep topsoil polygons, presents a more complex situation. All profiles are moderately to strongly acid, with pH ranging from 4.4 – 6. Uniformly higher pH values are shown by the grassland deep topsoil polygon at Underhoull, with only a slight overlap between these polygons seen in the topmost horizons of pits UN1 and UN2. Within the grassland polygon, the pH values for the improved and unimproved profiles are relatively similar, with an extensive overlap within which a clear difference in pH is really only seen in the A1 horizon of the profiles, with improved grassland UN3 showing a slightly higher pH. There is a clearer separation between the two pits representing the second deep topsoil polygon on the North House/New House relict infield areas. The recently-cultivated UN1 shows a consistently higher pH than past cultivation pit UN4, a distinction which, however, becomes increasingly less pronounced down-profile.

The clearest trend within this set of results, however, is the tendency for pH to increase down-profile seen in all four Unst sample pits. Given the near-convergence of pH in the C-horizon seen in both 'pairs' of pits from the two topsoil polygons, this appears to be related to the influence of the base status of the parent material.

What can be interpreted from these results? The first observation is that although overall there is appreciable intra-site and even inter-site variation in the sample series as a whole, there is less within-profile variation. Between all samples, the maximum variation in pH is 4.4 – 7.3: from a moderately strong acid to just above neutral status. This relatively wide-ranging pH has a bearing upon the potential for interpretation of the sample set, particularly when attempting the answer the central question: is there a greater pH variation between sites, or between types of land cover? Generally, the former is the case, with maximum variations of 2.9 (arable), 2.1 (woodland) and 1.6 (grassland) between samples within each land cover type, but maximum variations of 1.9 (Tealing), 1.4 (Nairn), 1.2 (Unst grassland polygon) and 1 (Unst relict infield polygon). If the C horizon pH is taken out of this calculation for all samples, these ranges generally narrow, to 2.9 (arable), 2 (woodland) and 1.4 (grassland), versus 1.9 (Tealing, 1.3 (Nairn), 1.1 (Unst grassland polygon) and .9 (Unst relict infield polygon). Generally, it would appear that the influence of the 'site' (ultimately, the physical and chemical characteristics of the parent material) is greater than the influence of the land cover or land management situation on soil pH (Figures 6.4, 6.5, 6.6, compared with Figures 6.1, 6.2, 6.3). This is seen most clearly in the relationship of drainage capacity to pH for each of these sites: Nairn, the most well-drained site, is also that with the most acid pH signature, the moderately well-drained Unst profiles are generally slightly less acidic, while the imperfectly drained Tealing shows the most alkaline pH, most notably in arable profile TE1, which upon excavation showed waterlogging up to 10 cm below the top of the C horizon. However, it should also be noted that Tealing was the only site to be dug in winter, when increased rainfall and thus water volume within this imperfectly-drained soil would likely exacerbate this effect. Although a well-drained profile (and therefore, more acid pH signature) is more commonly recorded for deep anthropogenic topsoils, especially on the Continent, their formation on an imperfectly-drained subsoil is not unknown in Scotland, and is seen for example at Quoygrew, whose raised soil profile shows a pH of 7.9 (Simpson *et al*. 2005: 373).

A closer look at each of the sites, however, indicates that the characteristics of the parent material are unlikely to be the dominant factor influencing pH at all levels of the profile. While the Unst profiles show a convergence of pH towards the C horizon for each deep topsoil profile (Figure 6.3), this is not so apparent in the Tealing sample set (Figure 6.2), and even less so for Nairn (Figure 6.1). At Unst, while the horizons above the C reflect the base status of the parent material, this effect quickly lessens up-profile.

Within the A-horizons of the sample profiles, the clearest observable trend, both inter- and intra-site, appears to be a tendency for arable activity to raise pH. This is seen plainly in the Nairn and Tealing profile set (Figures 6.1; 6.2), and also in a chronological comparison upon the relict infield topsoil polygon at Unst, the more recently ploughed profile showing the higher pH (Figure 6.3). This is in agreement with research into this relationship (Section 6.2.1), which shows that cultivation activity acts to raise pH in acid soils to around 6.5 in the cultivated horizon (Eidt 1985: 165; Sandor *et al*. 1986b: 180). The Tealing arable profile with its pH values of 6.9 – 7.3 in the A horizons is over this benchmark, but it should be noted that studies of deep anthropogenic topsoils in Aberdeenshire (also developed on till derived from igneous material, yet more free-draining than

Figure 6.4: pH values for all arable profiles

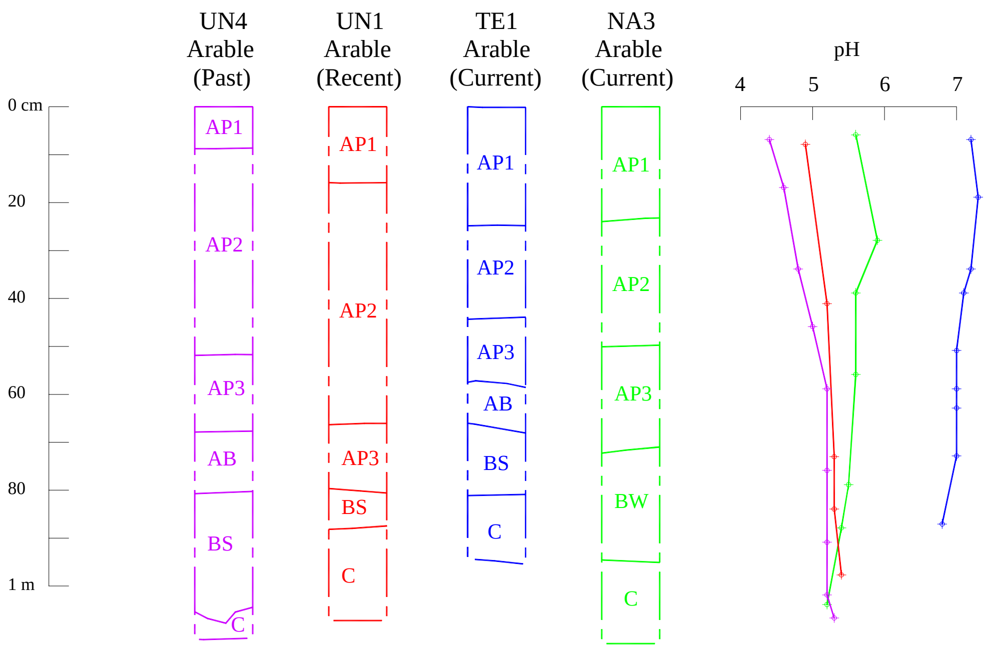


Figure 6.5: pH values for all woodland profiles

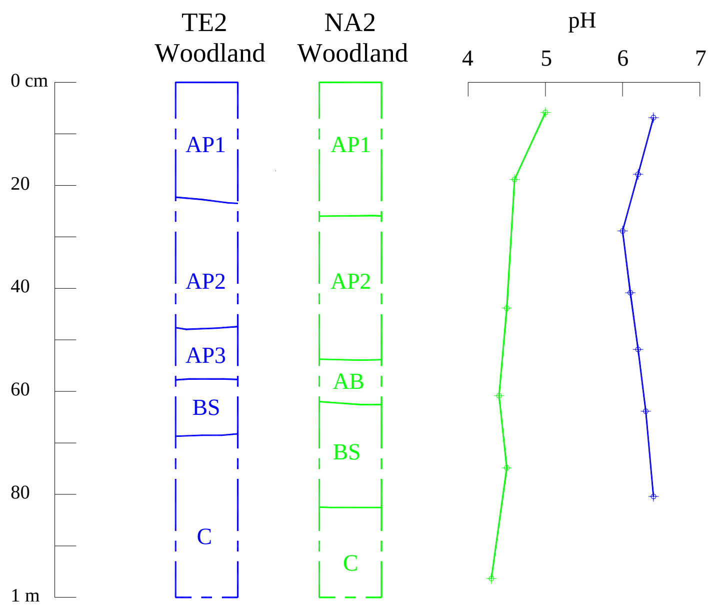
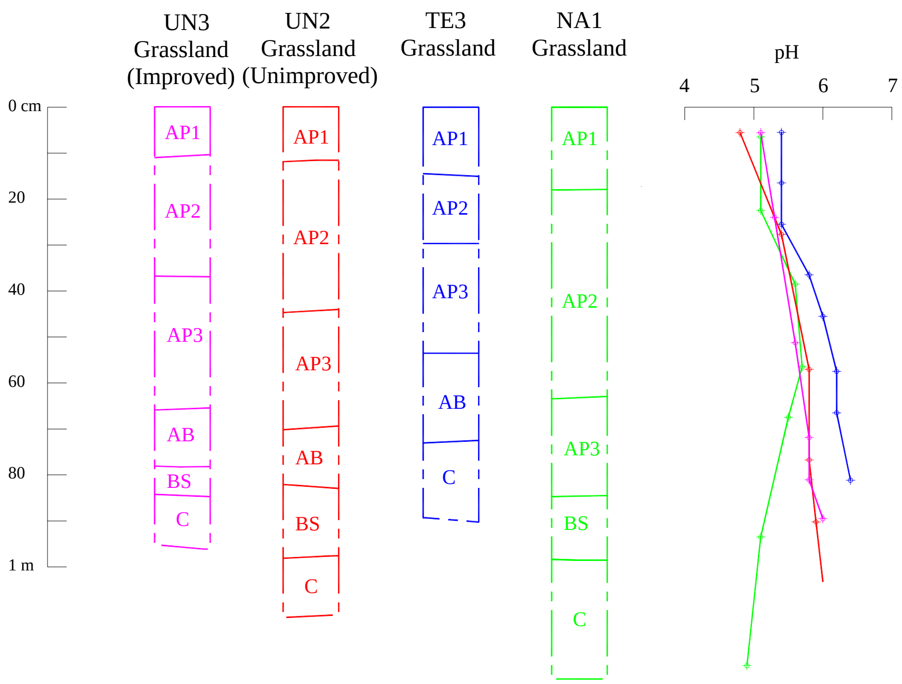


Figure 6.6: pH values for all grassland profiles



that seen in Tealing) record a pH greater than 6 for 80% of profiles (Glentworth 1944, in Simpson 1985: 75). This 'improvement' of the soil to nearer neutral status may also be observed in the comparison of the improved and unimproved grassland soils at Unst (Figures 6.3; 6.6). The effect of woodland cover on pH is unclear from this study, with woodland more acidic than grassland at Nairn, but more alkaline than grassland at Tealing (Figures 6.1; 6.2).

How far into the deep anthropogenic topsoil profile do these apparent effects of land management and land cover penetrate? This is difficult to gauge. For the grassland profiles, the overall trend, despite improvement or lack of improvement, is for pH to increase down-profile. The influence of fertilisation and re-seeding is not apparent at any stage of the profile when these four profiles are compared (Figure 6.6). The arable picture is more complex. It would appear that there is a slight trend for pH to *rise* down-profile through the A horizon, before the influence of the parent material base status appears to overtake this effect. It is possible that this is related to differences in chemical character within the plough horizon, although there appears to be little difference here between the current and past ploughed horizons. This effect – for the topmost horizon to show a different signature to the remainder of the A horizon – is seen in the other analyses, and is discussed further in Section 6.4.

A final observation from this sample set is that the results from these deep anthropogenic topsoil profiles are closer in base status to other deep anthropogenic topsoils recorded in Scotland than they are to the plaggen soils of the Continental regions, with moderately acid signatures similar to these recorded for Orkney (Simpson 1993: 5; Simpson 1997: 366), rather than the far more strongly acid signatures typically recorded in the plaggen regions (e.g. de Bakker 1980: 326).

6.3 The analysis of soil organic matter content

6.3.1 Soil organic matter content and geoarchaeological study

Soil organic matter can be defined as the portion of the soil material resulting from the incorporation of plant and animal tissues into the soil system as a part of the global carbon cycle (Brady and Weil 1999: 447) from the macro- to the microscopic scale. It therefore describes a complex collection of physical and chemical components, such as plant and animal remains in various stages of decomposition, the cells and tissues of soil organisms, and substances produced by soil microbes (Woods 2000: 117). Within the complex area of research that is soil organic matter study, these varied components are grouped by both form and function into biotic (living), abiotic (non-living, chemically derived) and abiontic (nonliving, biologically derived) (Tate 1992: 1). Although within geoarchaeology soil organic matter is commonly discussed as one soil property, these functional divisions are a useful means to understanding the multifaceted role of soil organic matter to the chemical and physical operation of the soil.

Within geoarchaeology, measurement of soil organic matter is generally undertaken using one of two techniques, loss-on-ignition (LOI) or oxidation with dichromate. The former method is the simpler and more commonly used technique, involving firing of the weighed sample at a temperature which ensures destruction of the organic matter present to carbon dioxide and water prior to re-weighing of the sample. Although sufficiently reliable as an estimate of soil organic matter for the purpose of many geoarchaeological studies, this method can carry a large degree of error. Soils also lose weight through this treatment by the loss of structural water from clay minerals, so whereas in sandy soils loss-on-ignition may give a reasonable estimate of organic matter content, in heavy clay soils the weight loss may be twice the true SOM value. At particularly high temperatures (c. 770^{o}C), calcium carbonate also loses CO_2, also resulting in sample weight loss (Rowell 1994: 48). The various oxidation methods (e.g. Eidt 1985: 185), by which soil carbon is oxidised to carbon dioxide by excess potassium dichromate, is a more time-consuming but more accurate measurement of soil organic matter content.

Soil organic matter is immensely significant to the chemical and physical soil system, playing a fundamental role in the maintenance of all main soil properties and regimes (Shevtsova *et al*. 2003: 166). Physically, the presence of soil organic matter, along with surface vegetation, intercepts rainfall and protects the soil surface from run-off and erosion, and acts as a 'binding agent', stabilising the soil through its effect on soil structure, texture and porosity. Most importantly, however, soil organic matter is a key nutrient reserve, with the decomposition of organic material through biological activity producing humic and fulvic acids which, as described in Section 6.2.1, influence soil base status and contribute to the soil's capacity for cation exchange and pH buffering (Woods 2000: 117; French 2003: 16). The rate of this decomposition, and therefore the nature of many of the chemical processes of the soil, is thus defined by the quantity and quality of a soil's organic matter content. This has been shown to have an influence on retention of soil nutrients such as phosphorus (Crowther 1997: 93; Section 6.4.1).

In soils unaffected by human activity, organic matter content is ultimately traceable to all environmental variables with an influence on vegetation growth, such as climate and relief, and its decomposition upon a variety of factors, especially temperature, moisture, and available oxygen. In soils subject to human influence, however, environmental sources of organic matter can be entirely superseded, with soil organic content largely reflecting human activity upon the soil. For this reason, organic matter content is a key soil property in archaeological study, reflecting to a greater or lesser extent the anthropogenic activity of a site. Organic refuse such as discarded food, excreta, the debris of fire-building activity, shelter construction, and various modes of artefact manufacture all contribute to organic accumulation in the soil. Analysis of archaeological organic matter has, for example, identified garbage pits and areas of manure production (Sanchez and Canabate, 1999: 48).

While these organic *sediments* are, strictly speaking, distinct from the remains of plant and animal tissues which pedology considers the source of soil organic matter (Stein 1992: 194), their measurement within and influence upon the soil system is similar.

For deep anthropogenic topsoils, subject to continuing change through environmental processes, both of these sources of organic matter are significant. Organic matter content is a key characteristic of deep anthropogenic topsoils. Largely derived from the organic component of the materials used to build up the soil, organic matter has been shown by experimental geoarchaeological study to provide information on the source and composition of these inputs (e.g. Catt 1994: 119). Organic matter values have therefore been used to research the nature and intensity of manure inputs to deep anthropogenic topsoils, and thus inform upon the sustainability of past manuring systems, for example in Papa Stour, Shetland (Adderley *et al*. 2000). On the Continent, regional characteristics of plaggen soils have been explored through organic matter content, with Pape (1970) noting that organic matter content increases from south to north, a feature probably related to input materials, but also possibly to climatic change (Pape 1970: 241-3). The relationship of organic matter content and soil colour to input materials has also been suggested as a means of identifying distinct periods in manuring history through discrete horizons in the plaggen profile (*ibid*.: 237). However, sample profiles in this study do not show this correlation between organic matter and soil colour, with the lighter Tealing soils having comparable organic matter values to those of the darker Nairn soils. That soil colour is related to the nature of input material is a recognised feature of the Continental plaggen soils (Section 2.1).

Despite its significance to deep anthropogenic topsoil research, organic matter content is not ordinarily particularly high within examples of these soils, both in Britain and on the Continent. Continental plaggen soils are typically recorded as having 5-8% organic matter or lower (Pape 1970: 233; de Bakker 1980: 326). Irish deep anthropogenic topsoil values are even lower, typically around 1.2-2.9% (Conry 1971: 412; Conry 1974: 323). In Scotland, slightly higher values of 5-7% have been recorded (Simpson 1997: 366; Simpson *et al*. 1998b: 121).

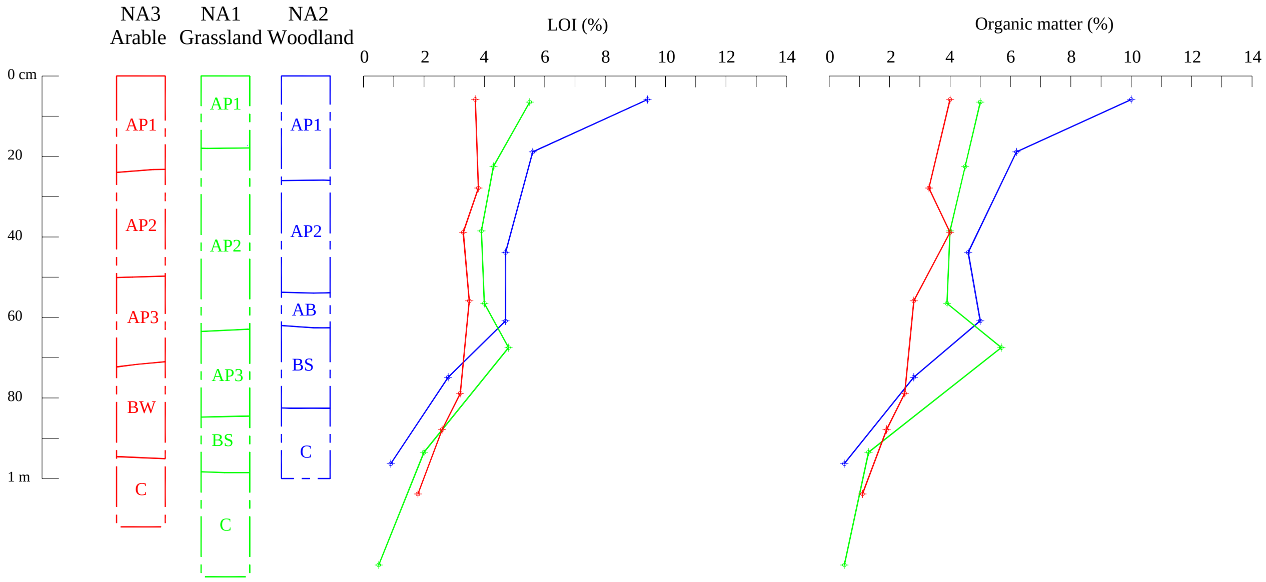
This may seem counterintuitive, given that these soils were partly created through the application of huge amounts of rich organic material. However, although it is undoubtedly the case that modern agriculture is responsible for soil organic matter depletion (see below) there are a variety of explanations for low organic matter values in an anthropogenic soil which belie either the assumption that high organic matter content is characteristic of an ‘undisturbed’ deep anthropogenic soil, or that low organic matter values indicate modern land management or land cover influence. Despite the huge input of organic material associated with plaggen-style manuring systems, it has been suggested that once this input ceases, soil organic matter levels may return to an equilibrium level dictated by climate (Simpson 1985: 74). The particular nature of the organic materials added through intensive manuring systems has also been highlighted: manure contains high levels of nitrogen, which promotes rapid microbial breakdown. Consequently, manure-derived organic matter is not very persistent in the soil environment and it is suggested that elevated levels of organic matter will disappear in a relatively short period of time (Entwhistle *et al*. 2000: 185).

Despite these observations, it is likely that the main agent of change for levels of organic matter in deep anthropogenic soils is continuing cultivation. Soil tillage increases the rate of organic decomposition by breaking up organic residues and soil aggregates and bringing them into contact with soil organisms, sometimes accelerating soil erosion and thus further loss of organic matter. Improvements in drainage increase aeration and therefore oxidation and decomposition of organic matter, and cropping involves the removal of large amounts of organic matter in the shape of plant materials, little of which is returned to the soil, especially under modern intensive cultivation methods (Simpson 1985: 74; Sandor *et al*. 1986a: 177; Entwhistle *et al*. 2000: 185; French 2003: 161). All of these effects, however, could as easily be caused by ancient as by modern cultivation, which raises the dilemma outlined in Section 6.1.1: it is theoretically possible that in a deep anthropogenic topsoil, successive cropping patterns throughout the use-life of the soil have depleted organic matter content in the horizons immediately below, a model which has been suggested for the organic-matter poor deep anthropogenic topsoils of Orkney (Simpson 1985: 459).

6.3.2 Soil organic matter content: results and discussion

The measurement of soil organic matter was undertaken by both loss-on-ignition (LOI) and wet oxidation (WO) following the methodologies given in Appendix 7. The results of both studies are tabulated in full in Appendix 6. Figures 6.7, 6.8 and 6.9 provide a site-by-site illustration of the down-profile variations in soil organic matter content.

Figure 6.7 Nairn: soil organic matter results for arable, woodland and grassland profiles

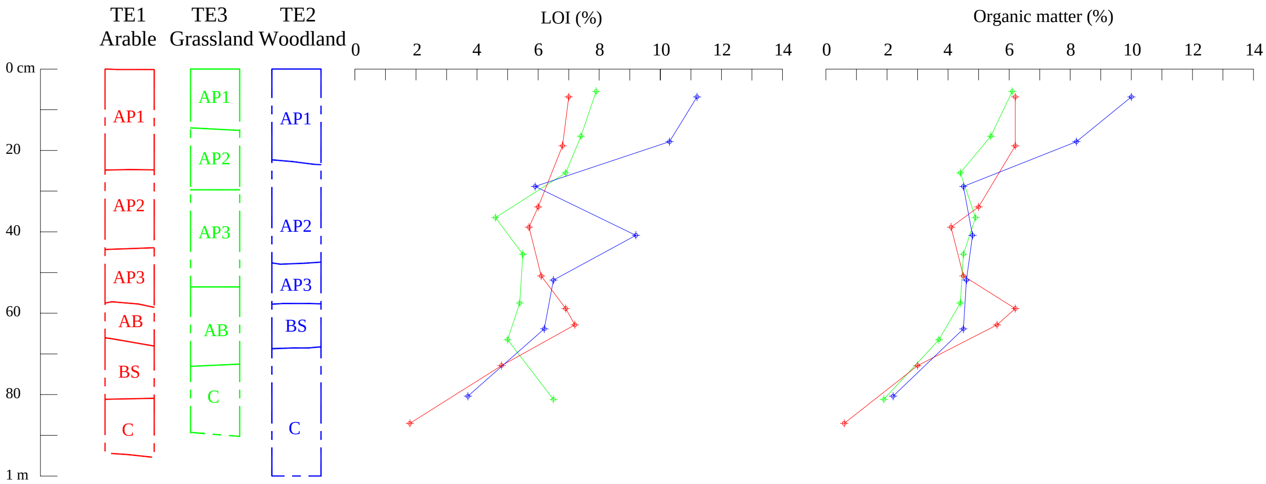


The results from both the loss-on-ignition (LO1) and wet oxidation (WO) from the Nairn sample profiles are strikingly similar, which is unsurprising, given the sandy nature of these soils. The two datasets indicate a contrast between the A horizons, in which relative concentrations of organic matter differ markedly between profiles, and the B and C horizons, where much lower concentrations of organic matter overlap and indicate few differentiating characteristics at this level of the soil profile. The A-horizons, however, are strongly differentiated. Throughout these, the woodland profile shows the highest concentration of organic matter, followed by the grassland profile, with the arable profile showing the lowest concentration. There is thus a clear separation by land cover and management type. The high levels of organic matter in the woodland profile can be attributed to the effect of leaf litter and vegetation, a conclusion supported by the clear ‘spike’ at the top of the profile, at the level of the leaf litter cover itself. At the other end of the scale, the far lower levels of organic matter in the arable profile can in all probability be attributed to the effects of cultivation, in particular the removal of the crop shortly before the sampling of this profile.

Between the two lies the grassland profile: subject to organic matter input from vegetation cover, but at a lower level than that seen in the woodland profile.

The gradual decomposition of organic matter through the soil profile is clearly indicated: all profiles show a decrease down-profile. An interesting point, however, is the rapidity of this decrease below the topmost part of the soil profile: despite the hugely augmented organic matter content of the woodland profile, this is quickly reduced in the Ap2 horizon to levels more in accord with those seen in the other two profiles. Below this point, organic matter levels overlap to completely mask a signature for this originally increased input, indicating that, as suggested in Section 6.3.1, natural environmental processes may have as significant an effect on organic matter content in anthropogenic soils as the influence of later cultivation.

Figure 6.8: Tealing: soil organic matter results for arable, woodland and grassland profiles

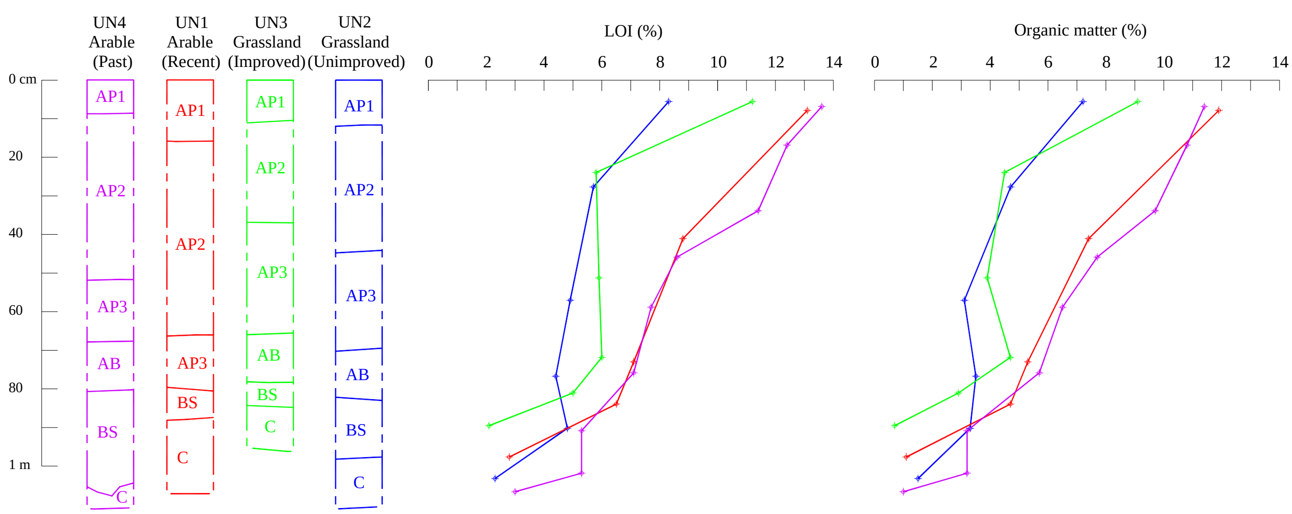


A more complex picture emerges from the Tealing sample profiles. Here, some differences are observed in the results from the LOI and WO analyses, notably a 'spike' in LOI in the Ap2 section of the woodland profile. This is not unexpected for this more clayey soil, and may be caused by water loss from ferrous compounds present in these horizons. The more reliable picture of organic matter content is likely to be seen in the WO graphic.

Once again, there is a contrast between the upper and lower parts of the soil profiles, with a clearer separation between organic matter concentrations emerging from the upper horizons. However, in contrast to Nairn, this distinction is lost far higher up the profile, and, overall, the organic matter content remains higher in the lower parts of the profile. It is possible that this is partly due to the reduced drainage capacity and therefore presumably lower oxidation and decomposition rates in these imperfectly drained soils.

Despite these differences, overall the three Tealing profiles show a similar pattern to that seen at Nairn. The woodland profile has a significantly higher organic matter concentration at the top of the profile which quickly decreases to match the other two profiles. The grassland and arable values are lower, and more similar to each other in organic matter content. A significant inter-site difference here, however, is that there is a reversal of the relative concentrations of organic matter at the top of the profile in the grassland and arable sample sets (although this is minimal). This is potentially explained by the presence of a crop on the arable profile during sampling. However, observed vegetation cover on the grassland profile was far in excess of that seen on the in-crop field. Secondly, organic matter content increases in the arable profile, as it decreases in the grassland profile, in the Ap2 immediately below this topmost profile point. Clearly, vegetation cover cannot fully explain this pattern, which suggests that an additional factor is present. Is it possible that the TE1 profile is displaying an organic matter signature traceable to the relict deep anthropogenic soil? This is discussed further in Section 6.4.2.

Figure 6.9: Unst: soil organic matter results for arable and grassland profiles



The sample sets from the two Unst deep topsoil polygons present a more complex and potentially more interesting picture, which is replicated fairly closely in the two methods used. Overall trends follow those seen for the other profiles, in that organic matter content decreases down-profile. At Unst, this is a noticeably smoother progression, which can be attributed to the absence of a woodland profile and a comparable current vegetation cover for all profiles. There is also a trend towards separation at the top of the profile and convergence towards the B/C horizons.

Considered separately, the two deep topsoil polygons at Unst show relatively little variation in their representative pairs of profiles. The two plough profiles from the relict infield deep topsoil polygon at North House/ New House crofts are remarkably similar, with only a minimal – and unexplained – inconsistency between the LOI and WO results at the very top of the more recently ploughed profile UN1. The two grassland profiles from the second deep topsoil polygon associated with the settlement remains at Underhoull show greater divergence, with the improved grassland profile showing a greater concentration of organic matter in both the topmost A and the AB/Bs horizons. It is possible that the higher concentration at the top of this improved profile is related to increased vegetation cover as a result of sward improvement, but a more convincing explanation is that grazing, and thus the input of dung, on the improved grassland area is responsible for this difference.

A more interesting scenario is presented when the two deep topsoil polygons are compared to one another. Unlike pH, the organic matter content bears no relationship to parent material, allowing greater scope for the Unst sample set to be considered as a whole. Despite this, the organic matter results from the four sample profiles are seen to separate clearly by deep topsoil polygon, with the profiles from the relict infield deep topsoil polygon at North House/ New House crofts showing consistently higher organic matter concentrations. Both polygons show comparable levels of current vegetation cover, and no polygon has been subject to crop removal or other cultivation activity for at least the last 10 years. According to the factors cited in Section 6.3.1 as influencing organic matter status, all four polygons should be closely comparable for this property with, if anything, the more recently cultivated crofting profiles displaying a reduced organic matter concentration as a result of relatively modern cropping and ploughing activity. This therefore raises the possibility that the profiles from the UN1/UN4 polygon depict a relict organic matter signature deriving from intensive infield cultivation and soil augmentation associated with the two abandoned crofts which, unlike the profiles associated with the presumably earlier cultivation at the Underhoull polygon, have not been depleted in organic matter as a result of the environmental processes suggested in Section 6.3.1 or, significantly, the more recent cropping and cultivation activities known to have been in action on the crofting profile. This is explored further through the inter-site and chronological comparisons illustrated in Figure 6.12 and discussed below.

Inter-site comparisons of the relative concentrations of organic matter content for woodland (Figure 6.10) and grassland (Figure 6.11) profiles provide very little material for discussion. The pattern of woodland down-profile organic matter content has already been discussed, and the presence of generally higher organic matter concentrations at Tealing compared to Nairn is unlikely to be significant. The four grassland profiles present a confusing picture, with repeated overlaps between profiles at all levels and therefore no significant trends emerging from this inter-site comparison save that organic matter decreases down-profile at all of these sites.

Figure 6.10: Soil organic matter content for all woodland profiles

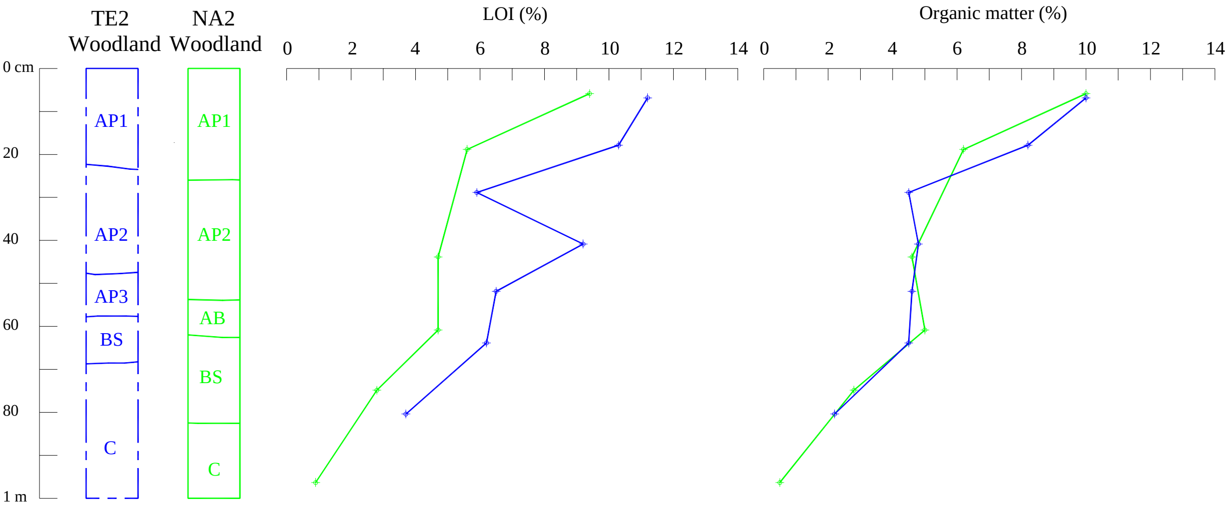


Figure 6.11: Soil organic matter content for all grassland profiles

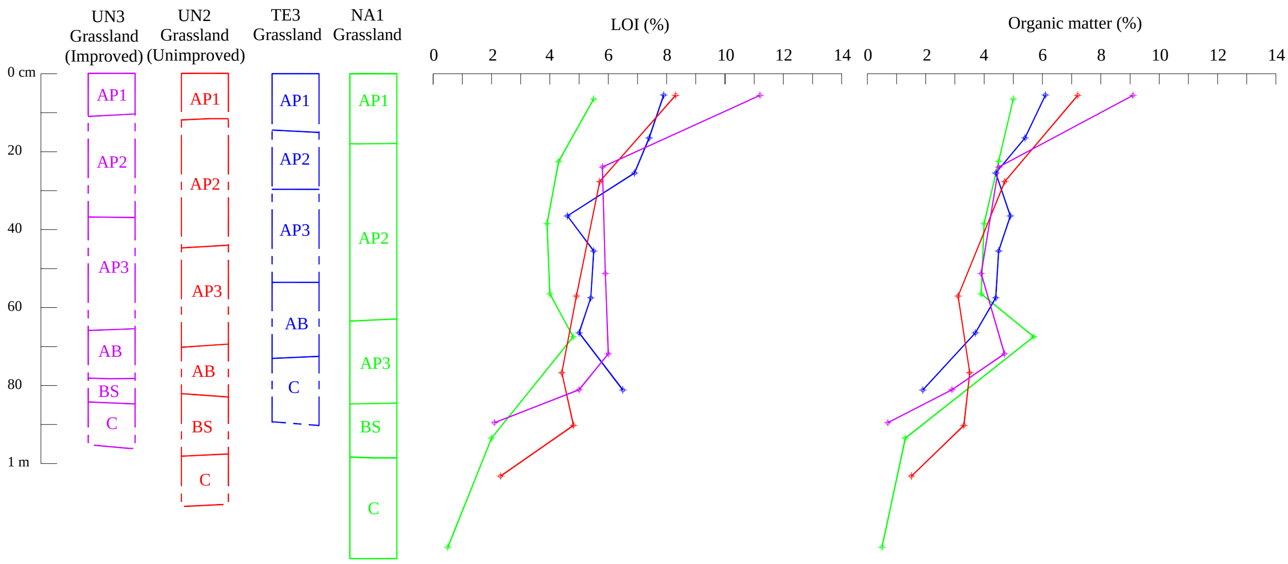
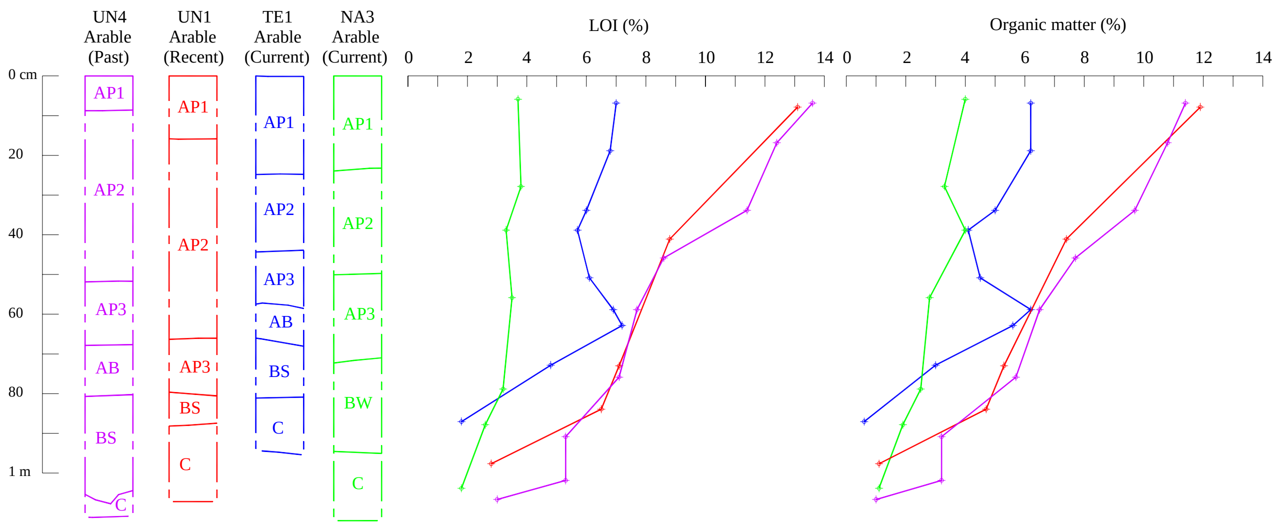


Figure 6.12: Soil organic matter content for all arable profiles



The inter-site and chronological comparisons between the arable profiles, however, are more interesting (Figure 6.12). It can be seen that the two Unst profiles, taken from the deep topsoil polygon associated with the infield areas of North House and New House crofts, show consistently higher organic matter concentrations than either of the arable profiles from Nairn or Tealing, although all of these profiles show a degree of convergence down-profile.

There are two possible interpretations for this. The first is that at both Nairn and Tealing, current cultivation activity has acted to deplete organic matter through cropping and plough disturbance, whereas at Unst, a cessation in cropping and a permanent sward of vegetation has allowed organic matter content to increase within the A horizons. This is generally supported by a comparison of the Nairn and Tealing profiles, which show significantly higher organic matter concentrations at Tealing, sampled while under crop, than at Nairn, sampled just after crop removal.

A second interpretation, however, is that the increased organic matter concentration seen in the two Unst profiles is a relict signature representative of the organic augmentation of this deep topsoil as part of an intensive manuring system, an augmentation which historical and contemporary sources indicate was in action far more recently than that at Nairn or Tealing (Chapter 5) and is thus less likely to have been depleted through natural environmental processes. This is strongly supported by the organic matter results from the other two Unst profiles which, although under a comparable continuous sward of vegetation, show organic matter concentrations more in line with those seen at Nairn and Tealing for the majority of the A horizon (Figure 6.9).

There is a flaw in this second interpretation which, although valid, potentially raises another interesting point for this analysis. Although the two Unst arable profiles are not under current cultivation, they are known to have been subject to cultivation and cropping during the 'use-life' of the deep topsoil polygon up into the relatively recent past. Why, then, have the known effects of ploughing and cropping not acted to reduce soil organic matter in these profiles through the same processes assumed to affect the currently cultivated profiles? The only known variable here is the mode of cropping. Historical sources and personal communication record that the deep topsoil polygon at Unst was spade-cultivated, as opposed to the intensive plough cultivation known to be in operation at Nairn and Tealing. Perhaps more importantly, the more traditional fertilisation methods employed during the lifetime of even the more recent cultivation at Unst are known to have relied upon organic fertilisers such as dung, rather than artificial fertiliser applications (A. Smith pers. comm.). It is therefore suggested that modern utilisation of these traditional modes of cultivation may be associated with a less marked degradation in organic matter content, and therefore potentially the survival of a relict archaeological manuring signature.

6.4 The analysis of soil total phosphorus content

6.4.1 Soil phosphorus content and geoarchaeological study

Phosphorus (P) is a key macronutrient element, a basic component of vital cellular compounds such as adenosine triphosphate, DNA and RNA. It is therefore vital to all plant and animal life (Brady and Weil 1999: 540-541). In natural systems, phosphorus is cycled by being released through microbial action from the decomposing systems of plant and animal residues and then taken up by plants, as is the case with other macronutrients such as nitrogen and potassium. However, unlike these elements, the chemical processes of the phosphorus cycle (Section 6.4.1.1) are such that the vast majority of phosphorus released from organic residues into the soil system becomes chemically fixed, making it unavailable for plant uptake and further cycling. Unlike other macronutrients, additions of which are recycled through the soil at an equilibrium which leaves no long-term indicator of their presence, phosphorus additions to the soil in the form of organic wastes are theoretically measurable through the study of this chemically fixed soil phosphorus reserve. It is estimated that in locations where substantial inputs of such organic waste have been made, soil phosphorus enhancement may be detectable even over $10^2 – 10^3$ years (Crowther 1997: 93).

Studies of soil phosphorus were first undertaken by agronomists as a tool for management of this essential yet potentially low-availability agricultural resource, and through this it was noted as early as 1911 that human occupation acted to increase soil phosphorus concentration (Bethell and Mate 1989: 1). It has been estimated that a community of 100 people in an area of 1 hectare will add 125 kg of phosphorus to the soil annually - an annual increase of 0.5 to 1% of P in the uppermost parts of the soil which will largely remain fixed in the soil system. Moreover, due to the rapidity of this chemical fixation, measurements of relative phosphorus concentration can be used as an on-site spatial indicator for archaeological activity (Herz and Garrison 1998: 182). This, and the ubiquity of this element in organic materials, has resulted in phosphorus being perhaps the most widely-studied chemical indicator in archaeological and geoarchaeological research, with numerous reviews published tracing the development of phosphorus study in archaeology and evaluating the many and varied techniques of analysis used (Provan 1971; Proudfoot 1976; Sjoberg 1976; Eidt 1977; Bakkevig 1980; Hamond 1983; Bethell and Mate 1989; Crowther 1997). The majority of archaeological phosphorus studies have concentrated on its use as a simple prospection tool for locating archaeological settlement, with countless landscape-scale and inter-site studies into patterns of phosphorus anomaly (Dauncey 1952; Dietz 1957; Schwarz 1967; Eidt 1973; Lippi 1988; Nunez 1990; Chaya 1996; Lima da Costa 1999). In the Netherlands especially, phosphorus analysis has long been a standard survey technique (Bethell and Mate 1989: 4). Intra-site studies have, however, contributed to a wide range of research areas. As a principal mineral of bone, phosphorus has long been used to identify burial contexts (McCawley and Kerrell 1972; Keeley *et al*. 1977). There is also a significant literature on the use of phosphorus to identify intra-site features and structures, and even to investigate the use of space within them (van der Merwe and Stein 1972; Provan 1973; Conway 1983; Entwhistle *et al*. 2000). Soil phosphorus analysis has also contributed to the study of non-structural 'activity areas', notably those connected with animal husbandry (Herz and Garrison 1998; Sanchez Vizcaino and Canabate 1999). More sophisticated studies have applied the technique at varying stratigraphic levels, thus using phosphorus analysis as a method for three-dimensional site reconstruction (Craddock *et al*. 1985). Phosphorus concentration through combustion activity (Miller and Gleason 1994: 33) has facilitated studies into hearth location within sites (e.g. Moore and Denton 1988; Dormaar and Beaudoin 1991). Differential concentrations of phosphorus in refuse derived from animal bone and plant materials has seen P analysis of archaeological contexts proposed as a means of studying diet (Sjoberg 1976: 452). More recently, the chemical fixation processes associated with phosphorus have been recorded as facilitating preservation through the 'phosphatisation' of fragile seeds and roots (McCobb 2003). Phosphorus determination has also begun to be incorporated into more complex techniques of multi-element analysis (Entwhistle *et al*. 1998; Entwhistle *et al*. 2000).

Despite this widespread utility, there has been a commonly held view among archaeologists that, although useful in identifying human occupation on a larger scale, phosphorus analysis has proven to be of limited use in detailed, intra-site investigations, with some notable exceptions cited above (see Bethell and Mate 1989). This has some legitimate basis; however, much of the criticism levelled at phosphorus analysis can be traced to the limited accuracy of the quicker and therefore more affordable methods of phosphorus determination often used in archaeological survey and analysis. This is discussed further in Section 6.4.1.2.

As the faeces and urine of humans and animals is a major source of phosphorus, phosphorus analysis is a hugely important indicator for anthropogenic soils, which are largely created through the application of these materials as fertiliser (Provan 1971: 39). Low phosphorus levels have even been used to rule out anthropogenic influence as an explanation for the presence of deep, dark and otherwise apparently man-made soils (Pettry and Bense 1989). Almost all studies into the distribution and character of deep anthropogenic topsoils have made use of phosphorus analysis. Many key studies among these are mentioned below, as the ubiquity of phosphorus study in geoarchaeological soil research has meant that many of the advances in our understanding of the complex expression of this element in the soil profile, and thus advances in techniques of analysis, have come from anthropogenic soil research.

6.4.1.1 Phosphorus in the soil profile: forms and fixation processes

In order to understand the various analytical methods applied to the extraction of phosphorus from the soil, and to evaluate the conclusions of the studies based upon them, it is necessary to understand the chemical processes which not only fix phosphorus (P) in the soil, but also convert it into a range of forms of *varying* availability.

When organic residues decompose, soluble P enters the soil and normally combines with four oxygen atoms to form the phosphate ion, $(PO_4)^{3-}$. In soil solution, this phosphate is present in the form of the two orthophosphate ions, $H_2PO_4^-$ (dominant in acid soils) and HPO_4^{-2} (dominant in alkaline soils). The very low solubility of these ions means that although they are subject to uptake by plants in the immediate vicinity of roots or mycorrhizal hyphae (Brady and Weil 1999: 551), the vast majority of phosphate ions quickly react with dissolved iron, aluminium and manganese ions (in acid soils) and calcium ions (in alkaline soils) and are taken out of the soil solution. This phosphorus becomes fixed, first onto the surface of these minerals as *labile* P (or ‘available’ P) (see

Proudfoot 1976: 100; Eidt 1977: 1328), but gradually transforming over time into increasingly insoluble, *occluded* (or ‘unavailable’) P forms (Rowell 1994: 201; Brady and Weil 1999: 559, 562). These mineralised P forms are termed the *inorganic* phosphorus fraction, which is generally resistant to desorption back into the soil solution.

However, soil phosphorus is not only present in solution and its inorganic forms. The third and largest reservoir of soil phosphorus is present in variety of *organic* forms, such as nucleic acids and phospholipids. Although organic phosphorus forms are far more stable than phosphates in both acid and alkaline conditions, they too are gradually released into the soil solution through microbial degradation, where they are subsequently mineralised to inorganic P forms (or taken up again by plants). The organic phosphorus fraction represents about 50% of the total P in soils, and typically varies between 15 and 80% in most soils (Havlin *et al*. 1999: 160).

The relative concentrations of all of these fractions are not fixed. A variety of environmental and often human-induced variables act to alter both the ratio of phosphorus fractions in the soil and the rate at which phosphorus is likely to be removed by plant uptake or leaching, and an understanding of these is important in evaluating the reliability of the various methods for extracting soil phosphorus outlined in the following section.

The capacity of a soil to fix P into its inorganic forms is principally dependant on its mineralogy and texture, with soils rich in iron, aluminium, manganese and calcium having a high capacity for phosphorus fixation (Herz and Garrison 1998: 182). Fine grained soils with a high clay content are extremely efficient at fixing phosphorus (Walker and Syers 1976: 11; Hamond 1983: 49; Brady and Weil 1999: 559). The role of these soil properties in phosphorus fixation therefore means that processes of erosion, weathering and sedimentation (either through human-induced or natural causes) will affect the ratio and relative concentrations of phosphorus forms present in different levels of the soil profile (Hamond 1983: 51). A further variable is land cover, with soils under vegetation and tree cover, especially those with an effective root penetration, subject to not only greater surface phosphorus uptake, but upward translocation of P even from the subsoil through root action (Williams and Saunders 1956: 93).

The role of pH in phosphorus movement means that changes in soil properties that affect pH, such as temperature and soil moisture content, will also have an effect on the phosphorus signature (Smith 1994: 11). In neutral soils, the ratio of the different forms of phosphate ions results in slightly more phosphorus being available in solution and thus lost to the soil through plant uptake (Hamond 1983: 49). Soil moisture content, in its influence on the volume of soil solution and thus amount of soil solution P, is one of the most important variables affecting the ratio of P fractions in the soil, governing as it does the complex chemical processes which act to maintain an equilibrium between the amount of P in the soil solution and that held as available, or *labile*, P on soil minerals. This 'buffering' through the labile P reserve is the most complex aspect of phosphorus movement in the soil, and involves the release of inorganic P from mineral surfaces when soil solution P is low (Brady and Weil 1999: 562). From thence, this inorganic P may eventually be taken into the organic P fraction (Havlin *et al*. 1999: 168-69).

It can be seen that, despite the understandable perception of phosphorus within archaeological study as a strongly constant, quantifiable indicator of additions to the soil, a truer view is that of a system of 'phosphorus dynamics', controlled by a huge range of both chemical and physical variables affecting the relative concentrations of organic, inorganic and solution P, creating a situation where phosphorus forms in the soil are, to some extent, in a constant state of flux (Smeck 1985: 187). The history of archaeological and (especially) geoarchaeological study into soil P measurement has been, to a large extent, dedicated to, and compromised by, the understanding and quantifying of these processes.

6.4.1.2 Methods of phosphorus analysis

The agronomist Arrhenius first applied soil phosphorus study to archaeology in 1929 (Herz and Garrison 1998: 181) and, since then, it has been observed that there appears to have been 'as many methods for extracting phosphorus from the soil as there have been workers in this field' (Macphail *et al*. 2000: 71). However, these can be broadly categorised into three essential types: those that extract and measure the available or labile P in the soil; those that use more complex chemical methods to convert organic to inorganic P which is then extracted, giving a 'total P' determination; and those that extract the inorganic and organic fractions separately, allowing relative concentrations of each fraction to be compared as a basis for archaeological interpretation (Bethell and Mate 1989: 10-13).

The oldest, and simplest, of these methods is the determination of available phosphorus. Developing out of agricultural research, this method has been much criticised as an archaeological tool, firstly as the amount of available P in a soil is dependant on many variables which relate to current, not relict, soil conditions; and secondly because the available P generally represents so little of the total P retained by the soil: as little as 2% (Herz and Garrison 182-184). Essentially, this method could be seen as a measurement of soil fertility rather than past anthropogenic influence.

Despite this, the determination of available phosphorus even now remains relatively well established (e.g. Sanchez *et al*. 1996; Macphail *et al*. 2000: 72), especially in survey-based studies, largely as the ease and therefore cheapness of the technique facilitates the analysis of the large datasets which are essential for landscape-scale research. Users of this technique posit that by taking a measurement of 'background' P from an area outside of that under survey, the level of soil fertility represented by available P is established from which anthropogenic enhancement may then be calculated even from just the available P signature (Provan 1971: 40; Bethell and Mate 1989: 12). A further advantage of this mode of analysis has been that it can be carried out entirely in the field, through the use of the various 'spot tests' developed from the 1960s onwards (notably Eidt 1973; 1977, and see Bethell and Mate 1989: 12).

A large number of studies support the basic utility of the spot test for available phosphorus in survey (Craddock *et al*. 1985; Prosch-Danielsen and Simonsen 1988; Nunez 1990), and have attempted statistical (e.g. Bjelajac *et al*. 1996) as well as comparative (Nunez and Vinberg 1990; Terry *et al*. 2000; Parnell *et al*. 2002) validation of this. However, on-site determination methods have also been strongly criticised for their imprecision and irreproducibility (see Hamond 1985: 55-61 for an extended discussion of this), problems recognised as partly due to the variability of the available P fraction depending on the physical and chemical characteristics of individual soil profiles (Bakkevig 1980: 85-86), and partly due to the limitations of on-site laboratories, where the necessity of lower temperatures and weaker reagents mean that only a fraction of the available phosphorus achieved in more detailed studies (e.g. Provan 1971) can be extracted. However, more recent comparative studies into the distribution of various P-fractions conclude that although there may indeed be less phosphorus identified through such analyses, given the complexity of phosphorus dynamics in the soil, this need not result in an overall loss of information (Sanchez *et al*. 1996: 154). This scepticism as to the potential of such variable and complex chemical processes to provide anything more than a generalised anthropogenic indicator is ingrained in archaeological science (Bethell and Mate 1989: 17) and may be partly responsible for archaeology's somewhat apathetic, continued acceptance of the available-P spot test.

By contrast, the determination of total phosphorus content (total P), although superior to all methods of available P analysis in terms of the accuracy, reproducibility and – most crucially – archaeological validity of its results, has received far less coverage in archaeology. This is unsurprising, as analysis for total P is a much slower, more complex, and therefore effectively more expensive analysis, especially difficult to achieve for the large number of samples generated by a large landscape survey. Nevertheless, total P determination has been used in archaeology from a comparatively early date, repeatedly producing superior analyses, for example Davidson's investigation into tell formation and erosion and intensities of occupation (Davidson 1973; 1976), following on from Cook and Heizer 1965 (in Bethell and Mate 1989). Other significant analyses using total P extraction include Conway's analysis of hut circles (1983), Sandor's larger scale studies into ancient terraced soils (Sandor *et al*. 1986a; 1986b) and Chaya's surveys on midden location (1996). Total P is the method of analysis which has been selected for this study.

Several methods for extracting soil total P have been used in archaeological and geoarchaeological study, but all are representatives of the same basic procedure, firstly; a conversion of the organic P fraction into an inorganic form, and secondly; the use of various reagents to bring this inorganic (which is now presumed to represent the *total*) P into solution, in which state it can be measured through colorimetry (Hamond 1985: 62-64; Bethell and Mate 1989: 12-13). The method selected for this study follows that described by Smith and Bain (1982), and involves the decomposition of the soil through fusion with sodium hydroxide, followed by a standard procedure for colorimetric determination of phosphorus concentration through comparison with a prepared calibration curve (Appendix 7). This method was selected for several reasons.

Firstly, it is significantly safer in terms of the acids used for phosphorus form conversion than other commonly used methods, notably those involving hydrofluoric acid (Bethell and Mate 1989: 11) and especially perchloric acid (Conway 1983; Sandor *et al*. 1986b; comment Bethell and Mate 1989: 13). Secondly, whereas the other 'safe' sodium carbonate fusion methodology (Syers 1968; Walker and Syers 1976) requires the use of platinum crucibles, which are expensive to buy and refurbish after use, the sodium hydroxide fusion method requires only the more user-friendly provision of nickel crucibles, and therefore provides a more affordable analytical method which it can be assumed will increasingly prove popular in future research (Smith and Bain 1982: 185). Thirdly, the efficacy of the sodium hydroxide fusion method, devised at the Macaulay Institute in Aberdeen, has been tested through comparison with XRF analysis on a range of Scottish soils, with excellent results (*ibid*.: 188). Above all, the widespread use of this technique in comparable studies into phosphorus content in deep anthropogenic topsoils (e.g. Davidson and Carter 1998; Simpson *et al*. 1998a; Simpson *et al*. 1998b) makes this an appropriate and reliable method for this study.

The numerous reasons for the enhanced archaeological interpretation made possible by the determination of total phosphorus have been touched upon in Section 6.4.1.1, which describes the many chemical and physical variables which control P- distribution in its various forms throughout the soil profile. All of these variables may, to a greater or lesser extent, represent anthropogenic influence, and it is these influences that are masked through the analysis of available phosphorus alone. The most significant of these is the addition of organic matter to the soil profile through anthropogenic influence, the potentially slow microbial decomposition of which can result in the retention of significant amounts of anthropogenic P in the organic fraction beyond the reach of available-P determination methods (Ottaway 1984). The ability of total-P measurement to provide an indication of P enhancement irrespective of the degree of mineralization achieved by the soil P-dynamic is also an important factor in overcoming the effects of down-profile alteration. Textural variation, leaching, and mixing by both human and natural processes all alter P-signatures (as described above), and while total P measurement cannot completely overcome the limitations on interpretation posed by these distortions to the anthropogenic signature (see, for example, Crowther 2002 on the differential leaching of P according to soil pH), it at least allows for a baseline P reading to be achieved from which these effects may be *recognised*, and thus incorporated into archaeological interpretation (Crowther 1997: 99-102).

A more detailed method of investigating these distortions and changes to the anthropogenic P signature caused by soil chemical and physical processes is that of phosphorus fractionation which, as this method has not been employed in this study, is not described in detail here. Here, the different soil P fractions are separately quantified through a sequential fractionation procedure, with a variety of methods advocated for this (Eidt 1977; Woods 1977; Bethell and Mate 1989: 13). The determination of, in particular, organic phosphorus concentrations through this method has proven useful in archaeological studies (Schlezinger and Howes 2000), as well as the identification of different archaeological sources for P-concentrations, such as bone versus manure deposition (Macphail *et al*. 2000: 73-74). Although used with success in a variety of archaeological studies (Mattingly and Williams 1962; Moore and Denton 1988; Lillios 1992), fractionation of phosphorus from deep anthropogenic topsoils has proven less useful. It would seem that, despite the potential for relative concentrations of organic to inorganic phosphorus to indicate, for example, specific fertiliser materials, the potential for other elements of the soil chemical system to control the rate of P-mineralization may mask these details in soils with a significant depth of A-horizon (Guttmann 2000: 184; 204), and that thin section micromorphology is a more informative method for the definition of manuring materials and fertiliser strategies (Simpson *et al*. 1998b). Consequently, P-fractionation has not been employed in this study.

6.4.1.3 Phosphorus content and deep anthropogenic topsoils

As previously stated, a high phosphorus content, resulting from intensive levels of organic fertiliser application, is universally recognised as a key indicator for deep anthropogenic topsoils (Pape 1970: 243; Conry 1974: 323; Van de Westeringh 1988: 14; Blume 1998: 4; Macphail *et al*. 2000: 74). However, a wide range of total P values have been recorded from deep anthropogenic topsoil profiles both in the Continental plaggen soil areas and within the British Isles. While a total P of ‘almost always more than 100mg per 100g soil’ is quoted for plaggen soils from the Netherlands, and analytical results considerably higher than this also recorded (Pape 1970: 235, 243), some Irish deep anthropogenic topsoils have by comparison relatively low total P concentrations (Conry 1971: 413; Conry and MacNaeidhe 1999: 88). By contrast, Scottish deep anthropogenic topsoils typically show extremely high total P concentrations, with a mean of 304mgP_2O_5/100g recorded from the Orkney Toft's Ness deep anthropogenic soils (Simpson *et al*. 1998a: 733), the Orkney Marwick soils showing a mean of 537mg and a maximum of 1148mg P_2O_5/100g P (Simpson 1985: 53), and the Shetland Scatness Iron Age soils showing a maximum of 1224mg/100g (Simpson *et al*. 1998b: 121).

6.4.1.4 The effect of cultivation on soil phosphorus content

Numerous studies indicate that anthropogenically enhanced phosphorus levels are likely to be affected by modern agricultural activity. The low natural availability of soil phosphorus typically results in a situation where large amounts of phosphorus are added as part of an artificial fertilisation regime to overcome any potential deficiency, which over time results in the saturation of the P-fixation capacity of a soil and a resulting build-up of even the available phosphorus, with potentially damaging environmental results (Brady and Weil 1999: 542-5). In an archaeological sense, this treatment is also damaging, potentially masking an archaeological P-signature at every fractional level. A second scenario, however, is the depletion of P-levels through cropping and removal of vegetation, and other physical disruptions related to ploughing activity, such as erosion and leaching (Hedley *et al*. 1982; Leonardi *et al*. 1999: 347), as described in Section 6.3.1. However, it has been suggested that, due to the nature of P-fixation processes within the soil profile, certain forms of physical disturbance may in fact act to *protect* the anthropogenic phosphorus signature of a soil. For example, slaking, resulting in the net downward movement of clay particles, will likewise result in a net downward movement of associated fixed P towards the lower portion of the soil horizon. At this lower level, the P is likely to be immune to plant uptake and will be protected from surface disturbances such as the removal of topsoil portions or redistribution through plough activity. Moreover, this P will theoretically remain distinct from more recent (perhaps intensive artificial) P additions to the top of the profile, apart from the gradual down-profile movement of fixed portions of these additions over time. In this scenario, sampling from the lower portions of the soil horizon should provide a more believable picture of anthropogenic P enhancement over an area (Hamond 1983: 51).

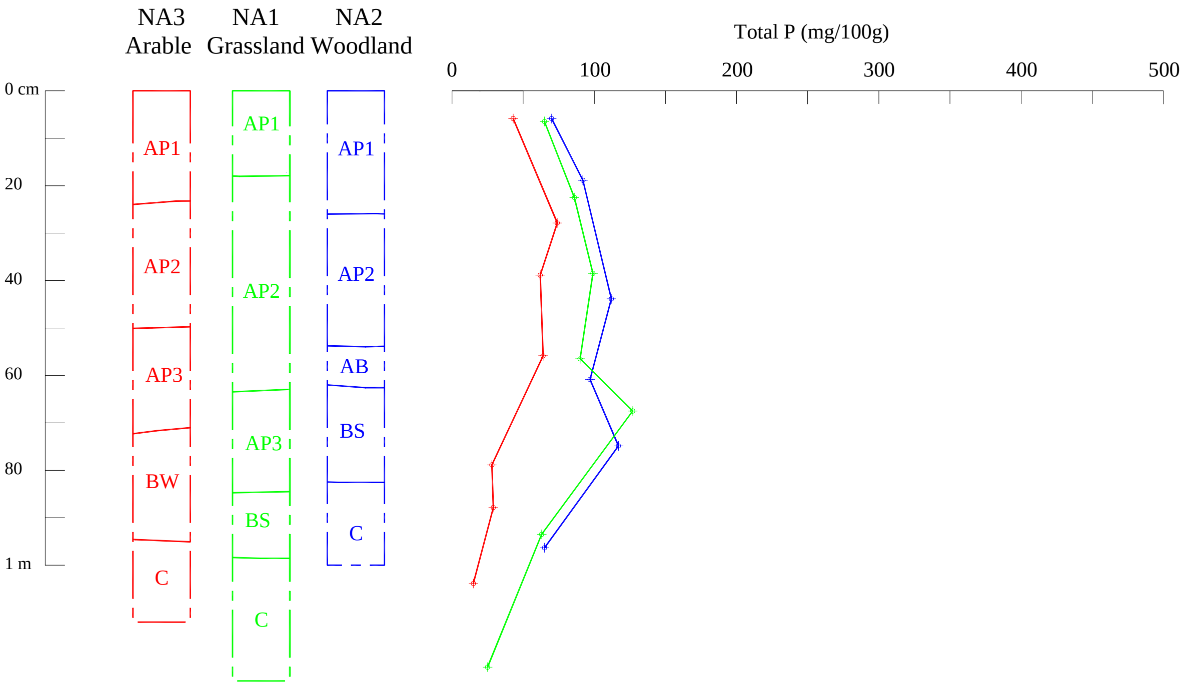
6.4.2 Soil total phosphorus content: results and discussion

The results of the soil total phosphorus content are tabulated in Appendix 6. Figures 6.13, 6.14 and 6.15 provide a site-by-site illustration of the down-profile variations in this.

The Nairn results (Figure 6.13) all show a similar down-profile pattern, all sample sets showing a gradual rise in P concentration from the top of the Ap1 horizon through the Ap2/Ap3, dropping in P concentration through the B and C horizons. Within this, some differences emerge: the arable profile peaks into the Ap2 horizon and is relatively steady before dropping into the B and C, while the woodland profile continues to rise steadily until the lower portion of the Ap2.

Compared to recorded total P in deep anthropogenic topsoils, these are relatively low concentrations, with a maximum of 127mg P_2O_5/100g soil recorded for Ap3 in grassland profile NA1. Despite this, the results show that overall the woodland profile records the consistently highest total P concentration, followed by the grassland, and then the arable profile.

Figure 6.13: Nairn: soil total P results for arable, woodland and grassland profiles



There is a correlation at Nairn between the relative concentrations of total P and of soil organic matter (Figure 6.7), which also show higher concentrations of soil organic matter seen in the woodland profile and correspondingly lower concentrations in the arable profile: a clear separation by land cover and/or land management type. This has been interpreted as a result of, on one hand, increased inputs of SOM through constant vegetation cover, on the other, loss of vegetation and corresponding SOM input through cropping. Theoretically, these by-cover separations could be interpreted similarly for this analysis: i.e. there is a greater top-profile P input from the woodland leaf litter cover than from the recently cropped-off arable profile. However, the total P picture appears to be more complex. The top of profile results for the organic matter content showed *marked* differences in SOM – notably in the woodland profile – which were clearly related to respective differences in profile vegetation. Here, there is actually only a small difference in total P concentration between all three profiles at the top; in fact, hardly any between the woodland and grassland profiles. Can these be as directly related to cover as the SOM results? If SOM is a reflection of the organic (and therefore a part of the total) P-concentration, why is there not a corresponding 'spike' in total P concentration to match that seen in the NA2 woodland profile SOM content? Furthermore, why does recently-cropped arable profile NA3 not show a far lower total P than seen at the top of the profile, considering that a portion of the available and organic P must recently have been removed with the crop?

The answer perhaps lies in the level of P-fixation in operation at the top of the arable profile. It is estimated that phosphorus fixation reactions in soils may allow only 10-15% of the phosphorus added through manures and fertilisers to be taken up by plants (and thus cropped off) in any one year of application (Brady and Weil 1999: 542). Consequently, a reasonable interpretation of these top-of-profile results is that because only a small amount of the added P has been removed with the crop, an enhanced arable profile total phosphorus signature *is* being shown, placing the arable profile P-concentration near to the un-cropped profiles enhanced in P by way of constant vegetation cover. Thus, it is possible to conclude that from the point of view of later P additions and their effect on a relict P-signature, a profile under modern cultivation may be no more at risk of 'swamping' of this relict signature than one under grassland or woodland cover.

Given this, what can be deduced from the relative concentrations of total P seen in the lower horizons? Do these represent the relict total P-signatures of the deep topsoil polygon? It can be seen that there is a clear variation between the patterns of concentration down-profile at all three locations. If this indicates later P addition, it would seem that these additions are greater from both the grassland and woodland profiles. Again, this is not what might be expected, given that the arable profile is known to have received regular applications of artificial fertiliser, the P-concentration of which must be above that added to the soil through decomposition in either the woodland or certainly the grassland profiles. Again, the mechanism of P-fixation and cycling may be responsible for this differential, and to explain this it is once again necessary to return to a consideration of the relative levels of soil organic matter shown in Figure 6.7. Although it has been established that, if removal of some P through cropping is taken into account, the levels of fixed P within the top horizon of each profile are likely to be similar, the mechanisms by which they are held within this section of the profile are not. In the grassland and especially woodland profiles, this modern P-input is largely present in the high soil organic matter fraction as organic P, and is therefore subject to microbial decomposition, gradual mineralization and, depending on soil conditions, mobilisation into the soil solution P. By contrast, a far greater proportion of the P-input which has survived cropping activity to remain within the arable profile will be present as inorganic, even occluded P, bound more tightly to mineral particles and potentially less likely to be mobilised and – eventually – proceed down-profile to mask the relict anthropogenic P-signature. The implication from the Nairn total P analysis is as follows: it is possible that constant vegetation cover, with its high, constantly renewed additions of soil organic matter, may be a more pernicious, *mobile* source of modern P than that provided through modern fertiliser additions.

The results from the Tealing site, while differing in some important respects, broadly support the interpretation suggested above. Here, the woodland and arable profiles show a fairly comparable pattern, with greater overall P concentrations in the woodland and grassland profiles compared with the arable profiles, and a general increase in soil total P below the topmost Ap1 sample point for both the woodland and arable profiles which then drops into the B and C horizons. A similar interpretation to that given above is therefore suggested for these profiles, which also strengthens its overall validity, in addition to perhaps answering the question posed in Section 6.3.2 – that the Tealing arable profile (among others) may indeed be displaying a relict anthropogenic signature for key soil properties. A marked difference, however, is seen in the Tealing grassland profile. Higher in total P than either the woodland or arable profiles throughout the A horizon, this profile also shows an increased total P at the very top of the profile, in contrast to all other profiles so far examined. There are two possible interpretations of this high top-profile concentration. Firstly, that the deep vegetation cover seen in the 'walled garden' from which the profile is taken is responsible for this increase. This is possible (especially considering that the woodland profile may be relatively low in SOM- added P, given the clearance activity seen within the woodland profile area – see Section 5.2.2.4 and Appendix 5). However, the relative levels of SOM recorded for the top of these profiles (see Figure 6.8) do not support this, showing a high SOM for the woodland profile comparable to that seen at Nairn, and a similarly less enhanced SOM for the top of the grassland profile. More likely, then, is the alternative explanation: that at some (perhaps relatively recent) point, there has been a modern fertiliser addition to the grassland profile, giving an increase in total P that has, crucially, not been cropped off, nor one that is present mainly as inorganic P. Although there is no evidence for this from the desktop study, given the previous known use of the area as a (possibly kitchen?) garden, this is a reasonable explanation. A final point to mention is that all of these profiles show considerably higher total P concentrations than those recorded for Nairn, to a maximum of 266mgP_2O_5/100g soil at the top of the grassland profile.

The results from the two deep topsoil polygons sampled at Unst, Shetland, present a more complex picture. The two grassland profiles vary hugely in their total P signatures throughout the A horizons, before converging in the AB horizon to show a similarly sharp, and expected (Simpson 1985: 53), reduction of total P concentration into the Bs and C horizons. At the top of the profile, however, the results are less explicable, with the unimproved grassland profile UN2 showing a far greater total P concentration (particularly high for any deep anthropogenic topsoil) compared with the improved grassland profile UN3. These results do not tally with the soil organic matter content for each of these profiles shown in Figure 6.9; furthermore, they differ in their expression down-profile, with the improved profile showing a gradual increase in total P down-

Figure 6.14: Tealing: soil total P results for arable, woodland and grassland profiles

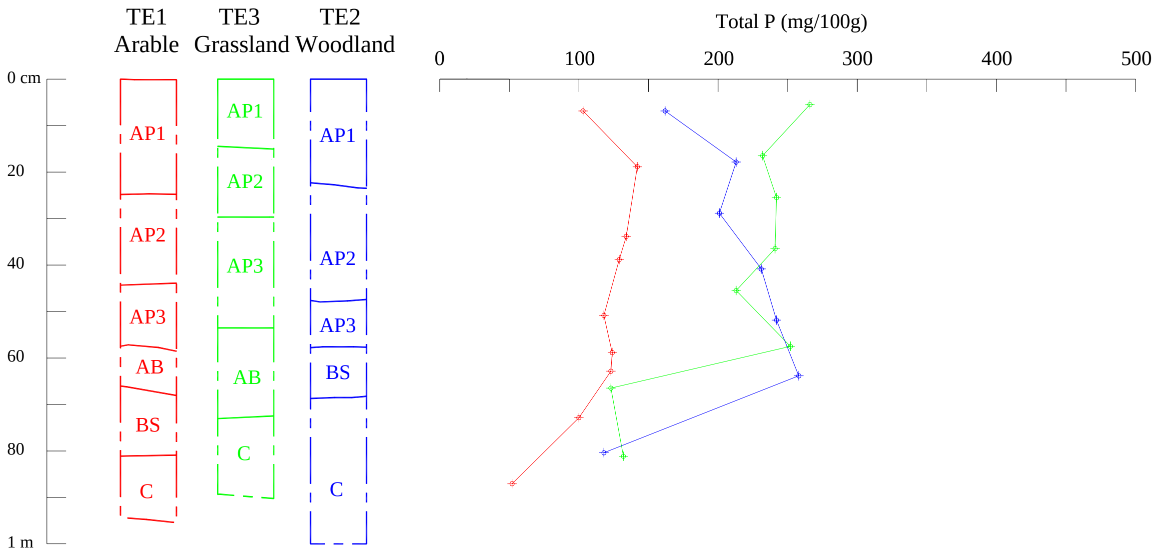
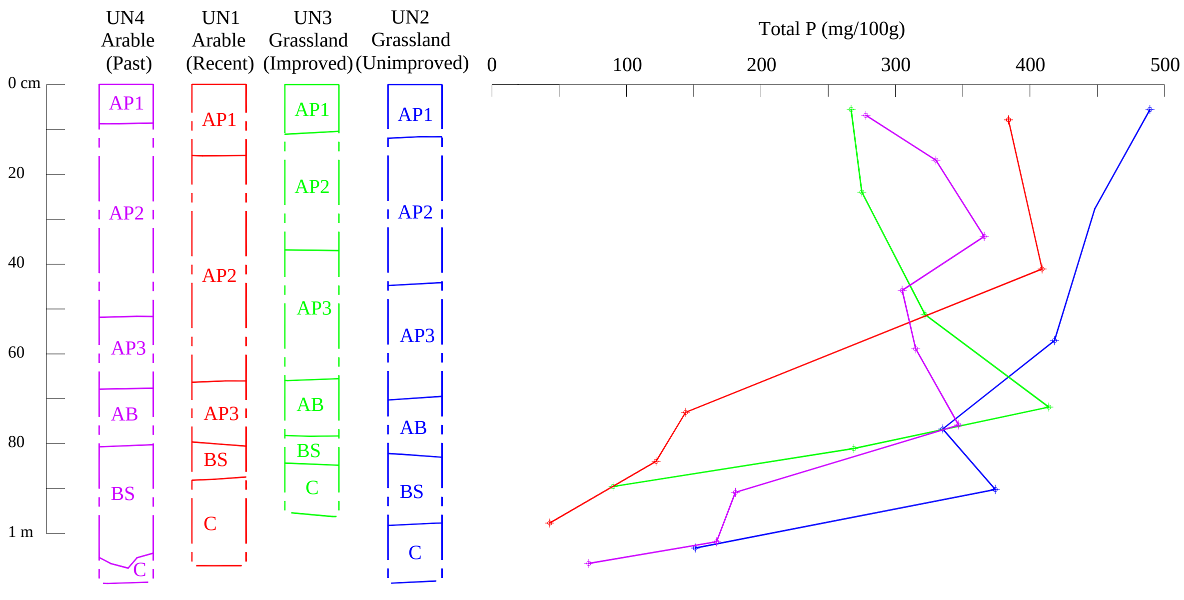


Figure 6.15: Unst: soil total P results for arable and grassland profiles

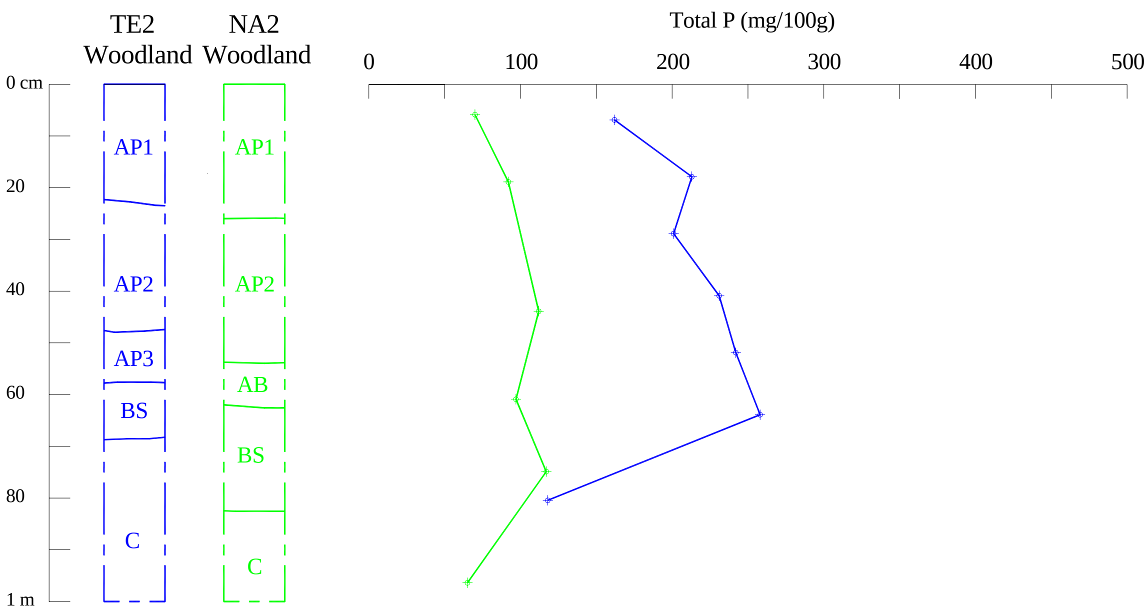


profile, compared with a decrease in the unimproved profile. There is no obvious explanation for this patterning, except for that connected with the archaeological context of the two profiles, the unimproved profile UN2 being situated closer to the Iron Age and Norse period activity represented by the broch and house site at Underhoull (Section 5.2.3.3). It is possible that the differences in total P content below the topmost horizons in these otherwise comparable profiles may represent a relict archaeological signature; however, this does not explain the heightened P-concentration at the top of the unimproved grassland profile, which might reasonably be expected to show a lower P concentration than the improved – i.e. fertilised, but *not* cropped – profile UN3.

The two arable profiles present a more explicable picture, and one broadly comparable to that seen in the arable profiles for both Nairn and Tealing (Figure 6.18). Total P is seen to rise from the top of the profile through the A horizon, before dropping (very sharply in more recently cultivated profile UN1) from the Ap2 horizon downwards. Once again, the implication is that, as discussed for Nairn, the profiles subject to cultivation and cropping activity appear to offer the potential for relict P signatures to survive below the plough layer of the soil profile. Once again, this supports the observations made for these profiles through the comparison of the soil organic matter content between deep topsoil polygons discussed in Section 6.3.2.

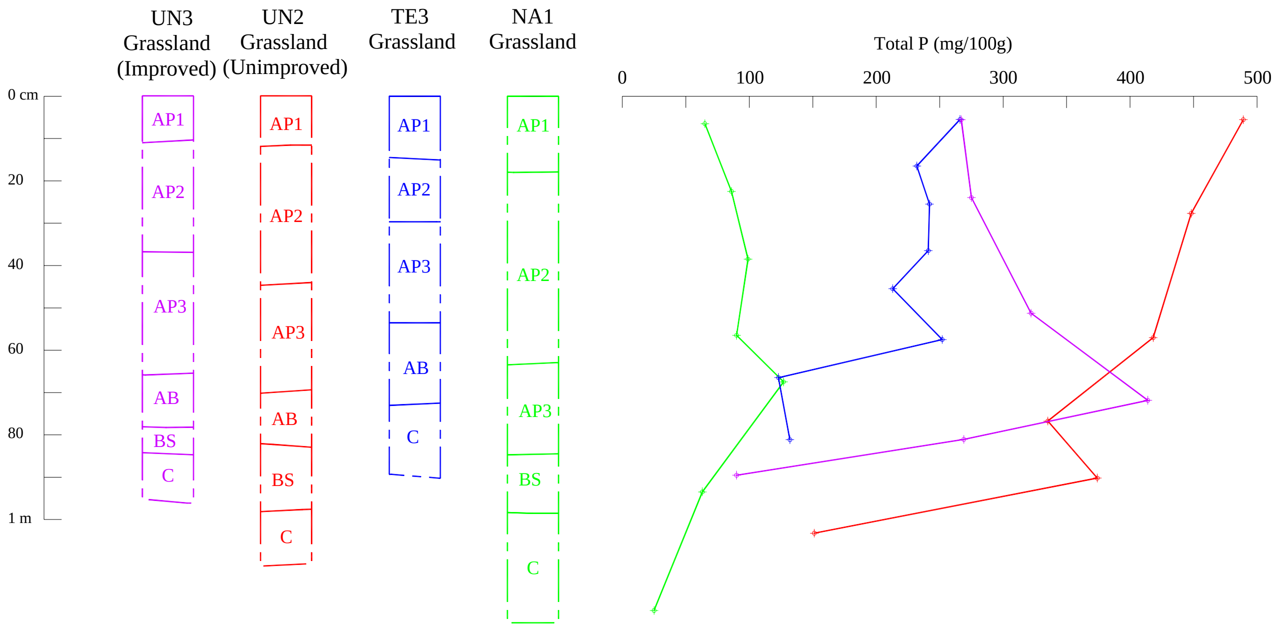
Inter-site comparisons of the relative concentrations of total phosphorus content for woodland (Figure 6.16) provide little additional material for discussion, save to underline the broadly comparable patterns of total P distribution down-profile for this land cover type, discussed in detail at the beginning of this section.

Figure 6.16: Soil total P content for all woodland profiles



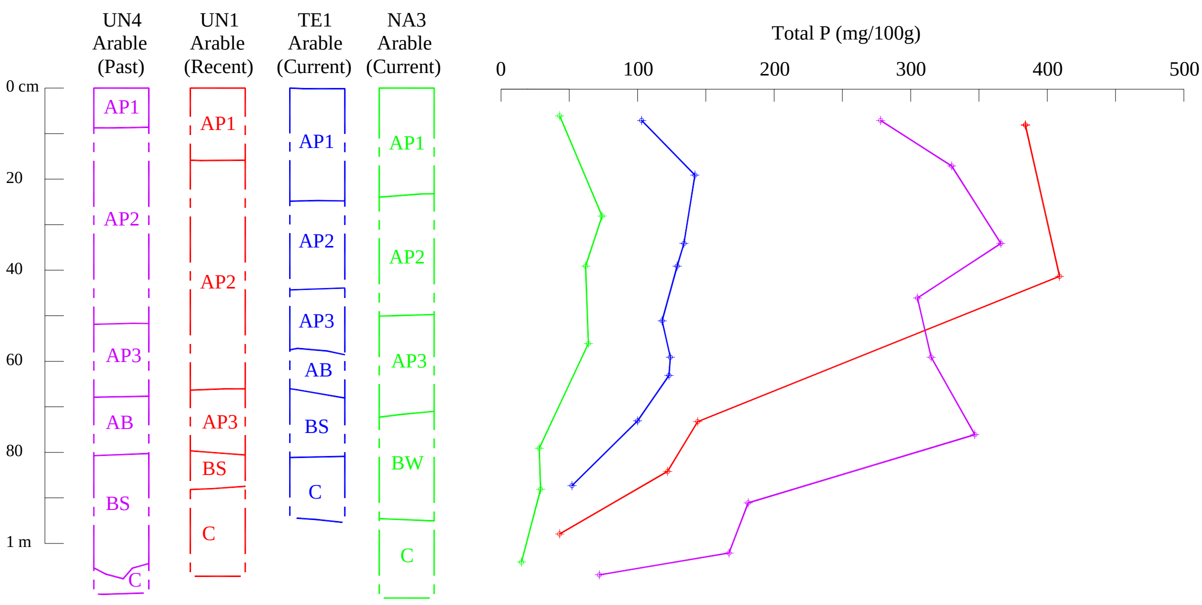
Likewise, the inter-site comparison of the four grassland profiles presented in Figure 6.17 illustrates the several largely unexplained differences in the overall patterning of P distribution throughout these profiles, but provides no further explanation other than those already offered. However, it is interesting to note that each of these unexplained differences occurs within the grassland profile – highlighting perhaps the greater *natural* variation in P-concentrations possible under this possibly more diverse category of land cover.

Figure 6.17: Soil total phosphorus content for all grassland profiles



The final inter-site comparison of the four arable profiles seen at Figure 6.18 is perhaps the most illustrative of the model identified through the analysis of, in particular, total phosphorus content in conjunction with organic matter quantification: that under the particular set of conditions created by cultivation activity, a relict anthropogenic soil chemical signature may survive. It would appear that, through the removal of available P by cropping and the limitation placed on the development of an organic soil P reservoir through ploughing and the removal of surface soil organic matter, only a relatively small down-profile addition of total soil P is allowed to move into the lower soil horizons where a relict anthropogenic soil P signature may survive. The implication of this model for conservation of relict cultural soil signatures is discussed further in Section 6.6.

Figure 6.18: Soil total phosphorus content for all arable profiles



6.5 Summary

6.5.1 Bulk soil analyses: evidence for cultural indicators

The results of the three bulk soil analyses undertaken for this study identify several trends within the data which can potentially be interpreted as chemical and physical indicators for retained cultural information in the three deep anthropogenic topsoils examined.

Of these, soil pH proves to be the least informative. Although the greater degree of variation seen between overall pH upon each site rather than upon each land cover type may be interpreted as pH reflecting the relict anthropogenically-induced character of each different deep topsoil polygon, it is far more likely that this between-site variation is a reflection of the different parent materials and drainage characteristics of each site.

Soil organic matter, with its link to organic manure input, is potentially a more interesting study. However, the results from all profiles indicate that overall, distinctive differences in organic matter content appear to reflect current land use conditions, particularly the effect of vegetation cover, with profiles under woodland showing a generally higher organic matter content in the upper anthropogenic horizons, followed by pasture and then arable (Section 6.6). An exception to this pattern is seen at Tealing, where a higher organic matter content in the arable than the grassland profile does not reflect the greater vegetation cover present on the latter. Although it is possible that this indicates a relict manuring signature, the minimal difference in organic matter between both arable and grassland profiles - and the significantly higher organic matter content seen in the nearby woodland profile which undoubtedly reflects modern leaf litter input - make this unlikely.

More convincing evidence of organic matter content indicating relict soil conditions is seen at Unst, where OM levels for the four profiles clearly separate by topsoil polygon. Here, profiles from the deep topsoil polygon located upon the infield area of the North House/New House crofts show a markedly higher organic matter content than those located upon the less recently manured Underhoull topsoil polygon, despite comparable current vegetation cover. That this may be a reflection of intensive organic additions to the croftland polygon is supported by the fact that these arable profiles also show significantly higher organic matter levels than those at both Nairn and Tealing. It is possible that these results are indicative of not only more intensive manuring upon the croft infield compared to the Underhoull area, but also the long-lasting effect of a reliance upon traditional, organic manures and less intensive cultivation methods in the Unst system up into the relatively recent past (Section 6.3.2) (Figure 6.12). It would appear possible that the continuation of these manuring systems may have acted to protect the organic matter signal from the degradation seen down-profile in the mainland arable profiles (Section 6.6).

Total phosphorus content in the upper horizons of all profiles appears to show a relationship with the patterning of organic matter content discussed above, interpreted in Section 6.4.2 as relating to modern organic input in the form of either vegetation cover or perhaps, in the case of the arable profile, artificial fertiliser additions. However, further down-profile, this pattern changes, and it is posited that as a result of the different P-forms and fixation processes involved in P-cycling under these different modern cover types, it is the arable profile that is more likely to retain a relict P-signature, unaffected by modern phosphorus moving down-profile, within these lower horizons (Section 6.6). While at Tealing and especially Nairn these P-concentrations are relatively low for a deep anthropogenic topsoil (Section 6.4.1.3), at Unst, it appears likely that a relict P-signature independent of organic matter content and land cover type *is* being expressed, with unimproved grassland profile UN2, adjacent to the Viking settlement at Underhoull, showing a strongly enhanced total phosphorus content throughout the depth of amended soil, and a phosphorus ‘spike’ in the lower amended horizon of nearby profile UN3 (Figure 6.15).

6.5.2 Bulk soil analyses: the effect of modern land cover

As is evident from the preceding section, the majority of information obtained from the three analyses undertaken for this study relates not to relict soil chemical indicators, but to the clearly powerful ability of current land cover types to affect and even overwrite them. Some of these observations confirm previous research in this area: for example, the raising of pH towards neutral as a result of arable activity (Section 6.2.2). In this study, this effect appears to result from improvement in general, with the improved grassland soil at Unst showing a higher pH than its unimproved counterpart (Figure 6.3).

Soil organic matter status is the property most clearly linked to current land cover and management activity, with organic inputs into the top of the profiles and their gradual decomposition down-profile providing the most plausible explanation for organic matter variation through the sample set. The most interesting observation from this otherwise expected set of results is the rapidity of this decomposition down-profile, and thus the potential for a relict soil signature to be present in profiles showing a less drastic organic matter reduction in their lower horizons, as discussed above.

Perhaps more surprising is the degree to which soil total phosphorus content, the chemical property most closely identified with and used to indicate relict anthropogenic activity, appears to be allied to organic matter status, and therefore similarly influenced by modern land cover and management. However, what these results also suggest is that the complex mechanisms governing phosphorus cycling through the soil may act to offer a certain degree of protection to relict phosphorus signatures under arable cover (Section 6.4.2). This is supported by the Chapter 7 analysis, wherein the relationship of organic matter decomposition, and thus a percentage of phosphorus cycling, to the faunal activity recognisable through thin section micromorphology is explored.

What are the implications of these results for approaches to the conservation of deep anthropogenic topsoils under modern land cover? The suggestion that the most effective means of preserving chemical indicators for cultural activity in these relict soils may be through a continuation of arable cropping is contrary to prevailing opinion. With plough disturbance recognised as a major cause of damage to structural archaeological remains (Section 1.1.1), current thinking on preservation strategies for the wider historic landscape have, so far, generally adopted the position that ploughing has a negative effect on the burial environment. While this is certainly true in terms of, for example, disturbance through deep ploughing turbation or alteration of drainage regimes, this study appears to show that continuation of the arable cropping systems under which deep anthropogenic topsoils were formed may also have a beneficial effect on the preservation of their chemical and physical cultural indicators, by either preventing or delaying the reversion of certainly organic matter and probably total phosphorus content to a 'wild' signature under both woodland and long-term pasture cover.

The relevance of these observations to the question of conservation of deep anthropogenic topsoil indicators in Scotland, however, should be considered with reference to both the historic and present-day landscape contexts within which these soils are likely to be found. These have been considered in earlier sections of this thesis. Paradoxically, the notion that arable cropping may be a constructive land management method for the preservation of deep anthropogenic topsoils is less positive news for the Scottish historic landscape, where the majority of land is designated as Less Favourable Area and where pastoral agriculture dominates (Section 1.1.2). However, research undertaken into the distribution of deep topsoils in Scotland - through both the historical review undertaken in Chapter 3 and the database evaluation and survey programme in Chapters 4 and 5 - indicates that it is precisely within these more limited present-day arable parcels that many Scottish deep topsoils may exist. This is partly a result of the tendency for these heavily fertilised soils to continue as foci for cultivation into the present day – as seen in the Continental plaggen regions – but may in Scotland also be connected to the noted bias towards deep topsoil formation in urban and semi-urban contexts, and thus potentially to areas more closely related to arable production. This is discussed further in the following chapter with reference to micromorphological indicators for cultural activity, and forms part of the concluding discussion in Chapter 8.

7. Micromorphological analysis and discussion

This chapter presents the analysis of the thin section samples taken from the three deep anthropogenic topsoil sites described in Chapter 5. It aims to investigate the effect that current land cover and/or modern land management techniques may have on the retention of micromorphological signatures of past anthropogenic activity, by assessing the status of the microscopic inclusions and suites of micromorphological soil features considered to be the most reliable indicators of this activity within the sample set. As such, this chapter provides a companion analysis to that of the physical and chemical soil properties presented in Chapter 6, and therefore the potential effects of the changes in these properties discussed therein on these micromorphological indicators, and thus on the retention of cultural information, is also considered.

This chapter is, however, more complex in both structure and range than that preceding it. The often detailed and specific nature of the evidence for anthropogenic influence provided by thin section micromorphology allows this chapter not only to explore the effects of land cover and land management activity upon soil features within deep anthropogenic topsoils, but also to provide a micromorphological characterisation of the three individual deep topsoils featured in this project. This chapter therefore revisits, and provides an important contribution to, the themes of deep topsoil definition and classification explored in preceding chapters. Specifically, this chapter illustrates that manure input variations, indicated by the historical record as existing between different locations, may be at least partly recognisable micromorphologically.

Micromorphological analysis of archaeological soils can reveal not only the effect of human activity on the soil record, but simultaneously the effect of natural pedogenetic and environmental processes upon the same, and likewise changes in, and even the creation of new, processes and effects as a result of the interaction of both these factors within the soil environment. The complexity of these interactions and the potential for equifinality in their visible expression makes archaeological interpretation and reconstruction through micromorphology a challenging task (French 2003: 251). Attempting to establish causal links between such processes (such as, for example, the retention of cultural information under changing land cover conditions) therefore returns us to the difficulties inherent in attempting to interpret features which are the product of a multivariate, dynamic soil environment - as discussed in Section 6.1.1 - difficulties that the wealth of information provided by micromorphology often serves to compound.

Such issues, and the extent to which micromorphology as a discipline has been able to address them, are of central importance to this study, validating the selection of micromorphological features upon which the analysis concentrates. The first section therefore discusses key problems of thin section interpretation and the approaches taken to mitigate them, first with reference to prior studies into the effects of land cover and land management on the micromorphological signature, and then through discussion of previous geoarchaeological work of similar relevance to this study. The section concludes with a review-based discussion of previous work concerning a selection of micromorphological features deemed the most reliable and appropriate potential indicators for change and/or degradation of the anthropogenic signature as a result of land cover or management change. It is on these features that the micromorphological analysis undertaken for this project concentrates.

The second section of the chapter provides a micromorphological characterisation of each individual soil profile taken from each land use type within the three deep topsoil sites. This provides a general micromorphological context for each profile, plus an examination of how variation in the micromorphological character of each deep topsoil unit is seen under different land cover types. This is undertaken with particular reference to those features identified in the previous section as having the greatest potential to inform upon the likely effect of land cover on the micromorphological record.

The chapter concludes with an assessment of how the range and relative concentration of micromorphological features at each of the study sites may provide anthropogenic characterisation of these soils, illustrating, in particular, the likely context of their manure input system. A comparative analysis discusses how this micromorphological character varies between sites, and thus how closely it may relate to the inter-site variations in geographical, environmental and especially archaeo-historical context identified and explored in preceding chapters. Finally, the contribution of this part of the study to the identification and interpretation of land cover effects on the retention of cultural information in these soils is assessed, a discussion that continues and expands upon that of Section 6.5.2.

7.1 Issues affecting the micromorphological analysis and interpretation of soils influenced by agriculture

7.1.1 Research into the effects of modern agricultural activity

The effect of cultivation and land management practices on the structure and functioning of soils is an area of soil science in which micromorphological analysis has made a significant contribution. Some of this research is of relevance to this study, with the impacts of forestry and ploughing, and changes in agricultural usage such as the turning of arable land over for pasture all having been investigated using this technique. However, although a number of soil processes expressed as micromorphological features have been identified as resulting from agricultural activity, this area of research remains complex, for two reasons. Firstly, particularly in modern western Europe, as soils absolutely unaffected by human activity are effectively absent, the assessment of 'control profiles' against which to quantify the effects of agricultural activity is not possible. The 'natural soil' does not exist: even the defining properties of a Soil Series can be modified according to vegetation cover and land use variations (Macphail *et al*. 1998: 636). But most importantly, as discussed in Section 6.1.1, the intricacy of biological-chemical-physical-interactions within the multivariate soil environment, here combined with human influence, create a complex system within which it is extremely difficult to attribute changes in soil properties to a single or even dominant cause. For the purposes of thin section analysis of agricultural activity, a three-step process can be envisaged:

Agricultural or land management activity → the soil process it initiates, intensifies or retards → the physical expression in the soil profile

Not only can many of these processes be traced to more than one agricultural activity and/or natural event, but they may also be expressed by more than one micromorphological feature.

Research in this area has therefore focused upon the identification of broad categories of soil processes, and their relationship to similarly wide-ranging groups of changes in soil structure and function. Jongerius (1970) used the term 'regrouping phenomena' to describe these soil processes, identifying three master categories of event to which sets of agricultural activities could be linked: *pedoturbations* (the mixing of soil components, excluding that caused by illuviation), *pedocompactions* (the increase in soil density as a result of pressure), and *concentrations* (the accumulation of specific soil components due to mobilisation or separation).

The most significant of these categories, and that most fundamental to the issue of changing land cover, is that of pedoturbation in its various forms (Jongerius 1970: 315). Within this category, of particular interest to this study is pedoturbation of organic matter: the processes by which this enters the soil (i.e. the prevailing vegetation cover), the mechanics of its processing by soil fauna, and the effects that these processes have on the soil structure (Jongerius and Schelling 1960: 138). The interplay of these factors defines the nature of humus formation: from the basic *mor* to the intermediate *moder* and acidic *mull* type (French 2003: 16). Organic matter processing thus links the effect of land cover and land management to soil structure and function: the moder humus form - in which successive 'food chain' processing of organic matter is undertaken by soil fauna until humification into a structureless mass is achieved - is characteristic of the topmost humus layer in soils under natural vegetation and, in the case of heavily manured soils with significant additions of organic matter, is essentially the conversion process by which such soils become entirely reworked to consist of a deep, homogenous soil horizon. The same process is observed to a lesser extent in both less intensively manured arable soils and pasture (*ibid*.: 139-140). Also significant is the *mull* humus form, which consists of a mix of organic and mineral particles bound with excretive matter produced by the larger soil fauna linked to this process (Kooistra 1987: 446), creating a 'mechanically inseparable mixture' of organic and mineral materials. The more porous mull structure is identified with soils under natural vegetation: woodland, grassland, or garden soils (Jongerius and Schelling 1960: 143), and is considered the ‘ideal’ structural type (Kooistra 1987: 446). However, mull decays if brought into arable cultivation, as the biological activity associated with its formation generally declines with tillage (Jongerius and Schelling 1960: 143).

Much of the research into the effect of land cover and land use upon the soil has concentrated upon overall structural properties of this nature, and generally concludes that cultivation essentially acts to degrade and mix the soil structure in comparison to both forested and grassland soils (Jongerius 1983: 112), with the action of tillage itself creating ‘artificial aggregates’ within the soil (Kooistra 1987: 446). Specific studies underline the central role of organic matter transformation, and thus soil fauna, in determining soil structural properties. A study into the relationship between soil structure and tree species (Nys *et al*. 1987) found that a change from broad-leaved to coniferous species altered a porous acid mull, associated with high faunal activity to a denser, less biologically active moder. Studies into the effect of manure additions show that, not surprisingly, the addition of organic matter as fertiliser promotes the formation of mull-type structures, but also that different composts may result in different humification rates, with a compost of stable manure and soil compost (i.e. a plaggen-type manure) significantly slower to see reworking of the soil structure than one also containing a superphosphate (Jongerius 1983: 121). Addition of organic matter as manure also improves soil structure by boosting aggregate stability (Fortun *et al*. 1989). The complexity of this area, with its multiplicity of interrelating and variable factors, has proven central to archaeological studies into identification of ancient cultivation, raising not only the issue of equifinality but also, with its clear emphasis on processes of reworking, that of the erasure of relict agricultural structural soil signatures through later activity.

A second and perhaps more easily quantifiable body of research into agricultural soil properties has focused upon the effect of mechanical activities: mainly ploughing, but also other forms of physical disturbance. Here, soil moisture content is of vital importance. Machinery and cultivation implements on wet soil result in ‘puddling’, a process where pressure causes clay domains to slip and swell, distorting the internal arrangement of intergranular spaces and creating a hard, compacted soil structure (Jongerius 1983: 113). The ‘knock-on’ effects of this can initiate and/or intensify other soil processes, impeding downward water flow and promoting internal slaking (see below), or hampering root development and thus affecting the crop-organic matter balance by retarding crop development altogether. Experimental work has linked ploughing, harrowing, vehicle movement (not only vehicle weight, but also the vibration caused by movement over the soil and the resulting destruction of void space) and even cattle trampling to compaction effects (*ibid*.: 115). The deleterious effects of certain crops on soil structure have been traced to harvesting methods; i.e. to mechanical soil disturbance (Jongerius 1983: 116). A decrease in ploughing depth has been shown to cause compaction in the abandoned furrow (*ibid.*: 122). Work in this area has focused on ameliorating the adverse effects of mechanical disturbance: for example, finding tillage techniques to reduce compaction (e.g. Kooistra 1987), or to minimise soil loss (Norton and Schroeder 1987). It can be seen that even in studies of contemporary effects, with clear and quantifiable parameters, the complex interplay of soil processes – here, of both pedoturbation and pedocompaction – again illustrates the challenge facing archaeological studies into interpreting past activity of this kind.

However, the most distinctive of the physical soil features indicative of agriculture are those of concentration: the result of mobilisation and accumulation of soil components, chiefly clays and sometimes organic matter (Jongerius 1970: 319). Concentration features can be the result of entirely natural soil-environment interactions (e.g. illuviation), human activity, or a mixture of the two, but the specific characteristics of certain concentration features have made these not only some of the most useful features for examining the effect of modern agriculture upon the soil, but also one of the most widely accepted as diagnostic of ancient agriculture.

Two key concentration processes commonly occur in agric horizons, especially those with weak or moderate water-stability. *Surface slaking* is the destruction of surface aggregates by raindrop impact and the subsequent washing and sedimentation of the resulting fine particles into a ‘crust’ which impedes soil permeability and crop germination (Jongerius 1983: 118). This process is strongly linked to tillage type and/or surface vegetation. *Internal slaking* is the structural collapse of a cultivated layer (or its lower portion) through water saturation. This is an issue for low water-stable soils, but can also arise as a result of agriculturally-induced drainage problems such as the formation of a plough-pan below the cultivated layer (*ibid*.: 119).

The most distinctive feature of slaking processes, however, is that most directly attributable to cultivation activity itself. *Agricutans* are distinctive accumulations of clay and fine material within voids and against mineral particles, created through the separation of soil components and the resulting downward movement of clay particles due to mechanical disturbance (Jongerius 1970: 320). While clay accumulation of this kind is linked to all processes described above, agricutans can display internal structuring which is interpreted as specifically indicative of tillage (Section 7.1.2.1), often displaying laminated micro-layers of varying texture and/or composition which have been linked to successive disturbance episodes of varying strength, with layers of silt or even sand-sized inclusions indicative of stronger disturbance. Small 'punctuations' of organic matter, interpreted as originating from the cultivated horizon, are sometimes observed within the clay matrix of these features (Bullock *et al.* 1985: 82). The high stability of agricutans in the soil, in addition to their diagnostic value, makes these features a key component of both experimental and site-based studies into indicators for past agricultural activity.

Modern studies into the effect of agriculture upon the micromorphological signature therefore identify several key issues central to the discussion below: notably, the role of soil fauna in creating and altering characteristic soil structures, and (especially significant for studies of manuring) the importance of organic matter cycling to the same, as well as several clear physical indicators that can be traced with some certainty to cultivation. Above all, such studies show that micromorphological signatures linked to agricultural activity are best understood as the expression of the interaction of a range of soil processes, both natural and human-induced, and that these processes exist within a dynamic system which, in responding both to continuing environmental change as well as anthropogenic activity, are likely to alter or erase micromorphological signatures over time. The implications of this for the validity of archaeological investigations into past agricultural activity are discussed below.

7.1.2 Geoarchaeological research into the effects of ancient agricultural activity

While studies into the effect of modern agriculture on soils typically investigate phenomena at a general scale, geoarchaeological research has a more challenging objective: to identify definitive soil features for a more detailed, often site-specific interpretation of past agricultural activity, such as the preparation of ground for cultivation, the pasturing of livestock, manuring choices or the existence of functional areas relating to agricultural activity (Wilson 2000: 13-18).

The use of micromorphology to investigate such events poses a further challenge, for, as a technique developed as a method of understanding soil properties and processes, micromorphology is undoubtedly a procedure adapted to, rather than designed for, archaeological investigation. A reflection of this is the relatively recent growth in thin section analysis of site formation processes and anthropogenic deposits: traditionally, micromorphology has focused upon palaeoenvironmental study, mainly through the buried soil contexts more suited to the concepts and terminology of thin section description (Davidson *et al*. 1992: 57). Discussion on the most effective means of utilising this descriptive system to complement archaeological methods of analysis and interpretation continues (Kemp 1998: 138; French 2003: 47-48). These issues, along with the difficulties inherent in interpreting cause and effect through physical soil characteristics – ongoing pedogenesis and anthropogenic activity, the interaction of the two, the issue of equifinality – have made identifying relict agricultural practices through micromorphology a complex and vigorously debated area of study (Carter and Davidson 1998; Macphail 1998; Carter and Davidson 2000).

Ongoing research seeks to understand and mitigate the effects of these factors through a variety of approaches, and the large body of field and experimental data produced from the last two decades of geoarchaeological study in this area has increased confidence in the ability of micromorphology to interpret indicators for ancient agriculture, albeit with some caution. Recent works provide summaries detailing the wide range of activities – clearance, cultivation, abandonment, the presence of livestock, manuring practices – examined through thin section analysis, such as Wilson (2000), French (2003), Holliday (2004) and Goldberg and Macphail (2006).

Specific areas of this research have informed the strategy adopted by this study: the holistic approach to understanding the effect of agricultural activity on the development of the soil profile, the use of experimental research techniques to isolate indicators for past cultivation, and the particular focus upon the key process of faunal activity in affecting evidence for ancient agriculture in the soil profile.

7.1.2.1 Holistic approaches to the interpretation of relict agricultural soils

A positive consequence of the complex effect of pedogenetic processes upon the archaeological soil profile is that such processes have seen considerable study, both within micromorphology and geoarchaeological research as a whole. The understanding that even the buried soil is not a static environment (Wattez 1992: 291) has led to a recognition that ancient agricultural activity should be examined as one aspect of overall soil development, and therefore that indicators for agricultural activity inevitably carry some ambiguity. Micromorphological studies into evidence for early agriculture have thus attempted to consider the parent materials and structural characteristics of as near to ‘natural’ soil profiles as is possible alongside those from archaeological contexts (Macphail *et al*. 1990: 62), on the understanding that these factors strongly influence the structural and textural features resulting from cultivation. This has also assisted in differentiating indicators of ancient cultivation from those of both later anthropogenic activity and post-burial pedogenetic processes (*ibid*.: 65) as well as investigating the potential for superimposition of such features (*ibid*.: 53; Romans and Robinson 1983). Such comparative studies have identified more general indicators for agricultural activity, such as lowering of faunal activity, presumably due to decreasing organic matter following cultivation (Macphail *et al*. 1987: 652).

Holistic studies into agricultural soils using micromorphology have also improved understanding of postburial processes such as cryoturbation, argilliturbation, soil creep, solifluction and structural deformation of archaeological contexts (Courty *et al*. 1989: 138ff; Leigh 2001; Goldberg and Macphail 2006: 42ff). Such mechanical disturbance can alter the position and relative concentration of both archaeological artefacts and micromorphological soil indicators, as well as destroying pedogenetic horizonation. Examination of these within the context of pedogenetic interactions has enabled specific soil textural features to be more surely identified with cultivation, for example agricutans. Despite the long association of these clay movement features with cultivation activity (Jongerius 1970: 320), the potential for clay translocation processes to indicate a variety of natural and anthropogenic soil processes (Kemp 1998: 139) has raised the issue of equifinality with regard to the interpretation of these features. However, studies of agricutans within a stratigraphic archaeological context largely confirm that textural variation within these features is likely to be indicative of cultivation activity of varying strength. At a series of prehistoric sites in the south of England, the superimposition of clear, or ‘limpid’ clay translocation features by notably less pure, ‘dusty’ agricutans containing larger material inclusions is linked with the onset of Mesolithic clearance and cultivation activity (Macphail *et al*. 1987: 651). Notable concentrations of agricutans at varying soil depths below a Scottish henge and mound site were interpreted as signifying shallower hoe versus deeper ard cultivation (Romans and Robinson 1983: 63). Despite such studies, debate still continues on the true diagnostic value of these features: thin section study into ploughed and non-ploughed pre-Roman buried contexts at Hadrian’s Wall recorded a greater concentration of agricutan features in those contexts *unaffected* by agriculture, and seemed to show a stronger link between agricutan formation and soil structure than agricultural activity (Usai 2001).

7.1.2.2 Experimental studies into ancient agriculture

Agriculture has proven an ideal subject for experimental archaeological research, and thin section analysis of experimental cultivated soils has provided comparative datasets for a diverse range of activities. The most informative of these have arisen from large-scale, interdisciplinary projects such as the Experimental Earthwork at Overton Down (Bell *et al*. 1996), which has provided valuable analogue data for the effects of processes such as compaction and faunal reworking on the micromorphological signature (Cruise and Macphail 2000: 183). Specific studies have looked at cultivation-related issues such as the nature of stabling deposits (Courty *et al*. 1991; Cruise and Macphail 2000: 185) and the identification of individual (building, but also potentially cultivation-related) materials such as turf in the soil profile (Cruise and Macphail 2000: 184). However, the most extensive body of experimental research into micromorphological signatures for cultivation has concentrated on the potential for survival and identification of tillage features, especially those diagnostic of specific tools, in relict agricultural soils (Gebhardt 1992; Gebhardt

1995; Lewis 1998). However, although changes in structure are detectable in experimentally-ploughed soils, these typically provide only general markers of limited value in identifying cultivation implements. While suites of 'organisational pedofeatures' (French 2003: 50) have been observed, such as fine material laminae related to (occasionally visible) ard marks and compaction features related to plough zones, survival of diagnostic features of this nature in even mildly reworked soils appears unlikely (*ibid.*: 53). There is also a potential problem in attempting to create soil 'analogues' for the effects of agricultural activity when, as previously discussed, the expression of such features is partly dependent on the structural characteristics of the soil type in question.

7.1.2.3 The effects of faunal activity on relict agricultural indicators

The role of soil fauna in processes of soil structural change, and their effect on both the stratigraphic integrity of archaeological contexts and the survival of soil indicators for agricultural activity, is a vitally important area of micromorphological study.

Earthworms act to mix and destroy stratigraphic layers by ingesting soil and casting it on the surface, or (less damagingly) within the soil (Canti 2003a), and create structural features such as channels which compact surrounding soil, and channel linings of finer excremental material. Highly biologically active soils can be completely reworked by these processes, creating a 'total biological fabric' consisting of densely packed aggregates of excreted material separated by a network of channels (Courty *et al*. 1989: 142), a process which can destroy even complex urban stratigraphy (Macphail 1994). Smaller soil fauna such as enchytraeids and microarthropods can only survive in organic-rich layers, and, as they do not move vertically through the soil profile, do less to modify stratigraphic relationships. However, within these horizons, such fauna are responsible for the majority of alteration and decomposition of organic matter and the alteration of soil structure that this causes (Fisher and Macphail 1985: 96). Therefore, within soil environments most suited to, or created by, cultivation, soil structural indicators arising from this are among the micromorphological features most at risk from faunal activity. Studies have indicated that complete soil reworking and a total loss of micromorphological features can be achieved within as little as 40, and certainly by 200 years (Davidson and Carter 1998; Davidson 2002).

While burial, either of archaeological layers or relict agricultural soils, does not immediately stop these processes - buried soil fauna may survive for a time after burial and cause postburial mixing (Bell *et al*. 1996: 115) – research into structural indicators for cultivation shows that their survival is largely dependent on the speed and effectiveness of burial after the last plough episode (Davidson 2002: 1253; French 2003: 53). But if a cultivated soil is abandoned to pasture or herbaceous cover, continued faunal reworking can completely destroy micromorphological indicators of this kind (Macphail *et al*. 1990: 65).

In soils under ongoing cultivation, the continued addition of organic matter to the soil as fertiliser or through crop growth encourages increased faunal activity so that a cycle of structural alteration through tillage, followed by faunal reworking, is created (Davidson 2002: 1252). Therefore, the effect of faunal reworking on structural indicators within cultivated soils subjected to large additions of organic manure, such as deep anthropogenic topsoils, is likely to be vast.

However, as a result of this relationship between organic matter content and increased biological activity the excremental, reworked soil fabric has itself become an indicator for agricultural practice, specifically addition of organic material. Excremental soil fabrics, particularly when seen in conjunction with features such as amorphous organic material, bone fragments or phytoliths, have been interpreted as providing evidence for manuring and soil amendment (Simpson *et al*. 1998c: 1189). Excremental features are thus an important pedofeature group. However, despite morphological studies into identification of soil fauna species from excrements (Courty *et al*. 1989: Stoops 2003: 123), ultimately, these features provide little more than evidence for soil reworking, possibly as a consequence of organic matter addition. It is difficult to imagine that in agricultural soils this process of reworking has not destroyed more information than these observations can provide.

7.1.3 Study rationale

It is now accepted that past agricultural activity can be identified micromorphologically, largely as a result of the gradual accumulation of a significant body of both field and experimental data in this area (French 2003: 50). However, the preservation of soil features indicative of agriculture is most likely in rapidly buried soils where the effects of faunal reworking are minimised, and their interpretation potentially most valuable in contexts where supporting archaeological (site-based) and pedological data can provide both anthropogenic and environmental context for the interpretation of such features.

As the aim of this study is to identify the effects of ongoing cultivation, as well as other land cover and management types, on cultural indicators within deep anthropogenic topsoils, the picture is complicated further. It is likely that all profiles from the deep anthropogenic topsoils studied herein have already seen both their anthropogenic and environmentally-induced microstructural characteristics substantially reworked through a *continuous process* operating throughout both their periods of development and cultivation and later, under not only the plough but also grassland and woodland cover. To draw conclusions from the soil structural features resulting from this continuum, either on the characteristics of individual deep topsoils or on the effects of modern land cover, would be unsound, and previous work supports this. Test studies on deep topsoils on Papa Stour, Shetland, for which ethnographic data confirmed tillage activity within the preceding 30 years, failed to detect tillage-related micromorphological features, a fact attributed to the high biological activity of the soils (Davidson and Carter 1998: 837). Likewise, although buried deep anthropogenic soils are known in the Northern Isles (Simpson 1998; Simpson *et al*. 1998b) these show considerable bioturbation (Guttmann *et al*. 2006: 83).

Previous thin section studies into deep anthropogenic topsoils, while evaluating microstructural characteristics and textural pedofeatures, have therefore focused primarily upon those anthropogenic features – generally additions – which are *not* subject to destruction and alteration of this kind. These have included analysis of coarse mineral makeup to identify sources of bulk mineral manures used in deep topsoil creation (e.g. Davidson and Carter 1998), but have mainly concentrated upon additions to the profile which, particularly in the form of carbonised materials such as charred or burnt remnants of peat and turf, charcoal, and bone, are notably unaffected by faunal activity (Canti 2003a: 139). Similarly robust materials, such as phytoliths, diatoms and ceramic materials, have also proven valuable for analysis. This study takes this approach, focusing primarily on the wide range of *anthropogenic additions* present in the study soils both to characterise each soil and examine the effect of modern land cover.

This methodology, though expedient, is also a productive approach to the particular questions posed by this thesis. Although foci of past tillage activity, the archaeological and historical significance of these soils arises chiefly from their unusual physical characteristics, notably depth. We are therefore interested in the materials and methods used to construct these soils, and the social and economic factors influencing this, more than, for example, the type of cultivation implement used to work them. By focusing on features which are both generally well preserved and also most informative for key aspects of deep topsoil formation and context, this analysis aims at a practical approach to the question of conservation of deep topsoils under modern land cover – how best to protect the cultural indicators most useful to geoarchaeological study whilst recognising the reality of ongoing modification of these soils.

7.2 Key micromorphological indicators in deep anthropogenic topsoils

A range of both man-made and natural introduced materials are known from deep anthropogenic topsoils. While deliberate additions provide evidence for fertiliser use and the soil amendment strategies used to create these soils, additional inclusions may also enter deep topsoils as a result of secondary anthropogenic activity related to cultivation, such as the disposal of domestic waste as fertiliser. Finally, deep topsoils, like other anthropogenic deposits, typically contain a wealth of materials providing general information on their historical and archaeological context. Structural indicators for cultivation activity may also occasionally be present as textural pedofeatures. The following introduces the series of micromorphological features which are significant to deep anthropogenic topsoils and upon which this study concentrates.

7.2.1 Carbonised materials and fuel residues

Charcoal and carbonised materials are among the most common anthropogenic inclusions recorded from deep anthropogenic topsoils. While in archaeological site contexts carbonised materials are commonly indicative of primary burning sites – hearths, ovens, episodes of destruction (Courty *et al*. 1989: 110) – in deep anthropogenic topsoils these inclusions are almost always secondary, dumped after burning elsewhere. They are thus important indicators for materials and methods of soil amendment, and seemingly particularly so for the deep topsoils so far studied in Scotland. Whereas research into Continental plaggen soil formation has focused upon the use of unburnt organic manures alongside bulk mineral material to deepen the soil, in the Northern Isles deep anthropogenic soils, micromorphology has shown that fuel residues were a major part of soil amendment strategies.

Much of the research in this area has been facilitated by the ability to distinguish different types of organic materials from the micromorphology of their carbonised remains. Well preserved wood charcoal may retain a cell structure visible in thin section, which although only rarely permits precise identification (Courty *et al*. 1989: 106), allows a woody input to be interpreted. More useful, however, has been the identification of morphological features within what are generally described in thin section as 'black (i.e. carbonised) amorphous organic materials' as indicative of peat and turf fuel sources. Studies of prehistoric settlement contexts from the Northern Isles demonstrate that carbonised peat can be identified in thin section by its structure – particularly fibrous peat, with its distinctive 'stringy' appearance – and characterised further by the inclusions (mineral grains, diatoms, fungal spores) that survive within larger fragments (Carter 1998). Micromorphological analysis of deep anthropogenic soils in Papa Stour, Shetland, for which historical and ethnographic source data cite the use of peat and peaty turf as manures, confirm the presence of both unburnt amorphous organic matter (Section 7.3.2) and carbonised fragments, with a mineralogically similar though denser coarse mineral fraction (Davidson and Carter 1998: 835). This increased density of mineral material relative to organic matter is attributed to the shrinkage of the latter as a result of combustion (*ibid.*: 836). Experimental reference samples of the organic fertilising materials described in the Papa Stour source data - dried peat, peat ash, cattle dung and straw bedding – have also been compared to thin section samples from deep anthropogenic topsoils in other Northern Isles locations (Guttmann 2001: 56; and see Section 7.3.2), and similar reference material collated for studies into the deep anthropogenic topsoils of Marwick, Orkney (Simpson 1997: 368).

The purely mineral remains of fuel residues - 'ashed' materials – are also an important indicator for soil amendment. Ashes are produced by fuel combustion under oxidising conditions, as opposed to the reducing conditions required for charcoal formation (Carter 1998: 100), and therefore comprise the majority of fuel waste under normal conditions. However, both the nature of ash and the soil conditions typical of deep topsoils minimise the likelihood of ash being recognised in thin section. As the bulk of ashed remains are generally comprised of minerals ubiquitous in thin section, e.g. quartz, recognising their origin as an ash deposit is difficult (*ibid*.: 102). Even in generally base-rich dark earths, mechanical disturbance and soil reworking is such that ash – sometimes recognisable in less reworked soils as patches of grey, fused fine mineral - is rarely found (Courty *et al*. 1989: 111). In addition, the water soluble calcium carbonate druses that characterise plant ash deposits (Canti 2003b: 355) rarely survive in typically acidic, reworked deep topsoil profiles. A rare example of ash survival in the deep midden-type soils at Toft's Ness is attributed to their location well above the water table (Guttmann *et al*. 2006: 78).

Ash within anthropogenic soils can however be indicated by other micromorphological features. Plant ashes can be identified in thin section by the presence of silica bodies and glassy slags (Canti 2003b: 350; Section 7.3.4). Heated mineral grains are recognisable under oblique incident light by their rubified and highly reflective appearance (Carter 1998: 101) and the presence of these has been interpreted as evidence of ash input in a range of deep topsoils (e.g. Simpson *et al*. 1998b: 116; Simpson *et al*. 2005: 374). Crystallitic b-fabrics are also indicative of a heated mineral input to the groundmass (Simpson 1998: 96; Simpson *et al*. 2000: 760). Indirect evidence of this kind is a strong indicator for additions of ashed material, even if the deposit overall is not high in identifiable carbonised remains (Simpson *et al*. 1998a: 739). In addition, the *range* of colours visible in oblique incident light can indicate the heating temperature of burnt and ashed inputs. Low-temperature burning causes structural disruption of coarse and fine mineral material and segregation of iron oxides, resulting in a reddish, rubified fine mineral fraction, whereas at high temperatures, organic material is completely combusted and the fine material fraction is generally yellow (Simpson *et al*. 2003: 1408). Samples of peaty turf obtained from Northern Isles locations and historically referenced as a fuel and manure source for deep anthropogenic topsoils, when burned at 400^{O}C, showed dominantly brown to orange-red colours under oblique incident light, while similar samples burned at 800^{O}C became bright orange-red to white (Guttmann *et al*. 2006: 72). Experimental investigation into ash residues from specific fuels, such as woods and dungs, have also identified specific colour and morphological characteristics: however, these are, again, unlikely to survive in the deep topsoil environment (Simpson *et al*. 2003: 1410).

The identification of specific fuel residues has enabled micromorphology to make a major contribution to the study of deep anthropogenic topsoil development in the Northern Isles, illustrating in particular the close relationship between manuring strategies and changing patterns of on-site waste and resource management, and thus demonstrating that evidence gleaned from anthropogenic soils can be vital to the understanding of settlement economics and development. Such indicators have provided the foundation evidence for the recognised change in manuring strategy - from the use of mainly domestic waste to the reliance on the composts of animal manures and bulk material more typical of the plaggen manuring system – seen in the Iron Age in the Northern Isles (Section 2.4.2.1) and understood as a reflection of both increasing organisation within the agricultural system and increased livestock input (Simpson *et al*. 1998b: 123). Thin sections of Bronze to early Iron Age Northern Isles deep topsoils at Toft's Ness and Scatness are characterised by a preponderance of domestic, 'midden-type' anthropogenic inclusions dominated by burnt materials – charred and carbonised peat, burnt seaweed, burnt wood and leaves (Dockrill and Simpson 1994: 86; Simpson *et al*. 1998b: 116; 121; Guttmann *et al*. 2006: 78). Later soils associated with Viking to Medieval period activity at Marwick and Quoygrew, Orkney, show closer parallels with the Continental system of plaggen soil formation, with micromorphological evidence emphasising the composting of unburnt peat and turf with animal manures (Simpson 1997: 373; Simpson *et al*. 2005: 374; Section 7.3.2). The clearest evidence for this development in manuring strategy is seen at Scatness, where successive Iron Age samples show an increasing frequency of finely fragmented amorphous organic material indicative of the addition of composted animal manures (Simpson *et al*. 1998b: 121; Section 7.2.2). Associated within-site thin section analysis indicates deliberate selection of these materials at this period, with domestic waste deposited in middens (Guttmann *et al*. 2003: 28).

Micromorphological indicators for fuel residues are of potentially similar value in interpreting later manuring strategies in pre-Improvement Scotland. As discussed in Chapters 3 and 4, the widespread discouragement of the use of bulk manures such as turf and peat is likely to have forced Scottish farmers to rely on the recycling of fuel residue materials in order to direct mineral bulk into the manuring system (Dodgshon 1993a: 423), in a manner similar to that adopted by their Bronze Age predecessors. Consideration of these materials in the deep topsoils studied for this project may therefore shed light on the nature of these more recent manuring strategies in mainland Scottish locations.

7.2.2 Organic additions: turf, peat and amorphous organic materials

Unburnt inclusions of organic material survive well in deep anthropogenic topsoils, and, as indicators for bulk manure materials such as peat and turf, their identification has proven an integral part of research into deep topsoil manuring strategies in the Northern Isles, as discussed above. As with carbonised materials, historical and ethnographic evidence and the study of reference samples have facilitated identification of a range of materials of this kind. Records from Papa Stour indicate that peat and turves were channelled into the manure supply through several pathways: from byre bedding, fuel, and the recycling of turf-built roofs and dykes (Davidson and Carter 1998: 828). Both composted and uncomposted peaty materials might therefore be expected in the micromorphological record for these soils. Reference thin sections of uncomposted dried peat from a Shetland source produced a reddish, convoluted mass consisting of roughly parallel layers of reddish, fibrous organic material (Guttmann *et al*. 2006: 71), great quantities of which can be identified in the Papa Stour deep topsoils (Davidson and Carter 1998: 836). Similar features are seen in the Scatness Iron Age soils, in which peat fragments can be identified despite significant biological reworking (Guttmann *et al*. 2006: 83).

Deep anthropogenic topsoils have provided the opportunity to observe the effects of faunal activity on organic manure additions, and thus various indicators for the presence of decomposed peat and turf-based manures can also be recognised. Dispersed areas of yellow, brown and reddish-brown fine amorphous organic material which typically create a ‘spongy’ microstructure are seen throughout thin sections from both early and late organically manured and reworked deep topsoils, such as Toft's Ness (Simpson *et al*. 1998a: 740) and Quoygrew (Simpson *et al*. 2005: 373). Parallels with this are noted from midden-type contexts with a high organic input (e.g. Simpson and Barrett 1996: 549; Simpson *et al*. 2000: 759), and also with experimental studies into the visibility of uncomposted grassy turf when used for construction in archaeological structures (Macphail *et al*. 1998; Cruise and Macphail 2000).

In the absence of the destruction caused by burning, related features in organic remnants allow additional interpretation. The colour of unburned organic fragments in thin section can indicate their terrestrial source: yellow-brown indicating grassy turves, and darker, redder-brown indicating peat (Simpson and Barrett 1996: 549). Phytoliths in organic fragments indicate a grassy turf origin, while diatoms are indicative of material from wetter contexts (Simpson and Barrett 1996: 549; Simpson *et al*. 2000: 759; Section 7.2.4). Peat and turf inputs can also be differentiated by the relative frequency of mineral inclusions within unburned organic fragments, with a limited mineral component indicating peat, particularly when in conjunction with diatoms, and more frequent mineral inclusions indicating turf, especially when seen alongside phytolith evidence (Simpson *et al*. 2005: 372). The excremental pedofeatures created by faunal activity, when seen in conjunction with fragmented organic materials such as this, are also indicative of significant organic inputs (Cruise and Macphail 2000: 185; Simpson *et al*. 1998a: 740).

7.2.3 Indicators for animal-sourced inputs: dung, bone and derivative products

Structurally fragile, highly porous and a rich food source for soil fauna, dung is rarely preserved in the soil environment (English Heritage 2004c: 11), and the identification of animal dungs is usually associated with preserved mineralised excreta, or coprolites (Courty *et al*. 1989: 113) or occasionally waterlogged deposits (Akeret and Rentzel 2001). However, dung inputs into anthropogenic soils can be posited, and even securely identified in thin section by both characteristic soil microfabrics and/or the presence of specific indicators. Although quick to decompose, dung inputs may persist in soils as areas of highly humified organic matter (Macphail 1994: 39), or become partially mineral-replaced due to iron and manganese movement, creating a recognisably different microfabric (Macphail *et al*. 1998: 638). Such differences have allowed burnt dung residues to be identified in thin section, even (in experimental contexts) to species (Simpson *et al*. 2003: 1410). Concentrations of fungal spores (Simpson 1997: 373) and fragmented lignified tissue (Simpson *et al*. 2000: 760) have also been used to indicate dung and associated stable wastes within deep topsoil and midden deposits.

However, the most frequent and durable – though ultimately indirect - indicators for herbivore dung inputs to anthropogenic soils are phytoliths, and less commonly, diatoms (Simpson *et al*. 2005: 372). These can be present in large numbers in herbivore dung due to the high proportion of grasses in the diet – particularly in grazing stock (Courty *et al*. 1989: 114), and survive in the soil environment after the organic component has decayed. They are typically fragmented in this context.

More specific indicators for herbivore dung input are calcitic spherulites. These are distinctive spheres of radially crystallised calcium carbonate, which are deposited in the gut of most herbivores grazing on calcareous pastures (Canti 1997; Canti 1999). Calcitic spherulites survive well in soils of neutral to high pH, and have provided thin section evidence for livestock stabling and manuring in varied archaeological contexts (Brochier *et al*. 1992; Simpson *et al*. 1998c). Although the generally low pH of deep anthropogenic topsoils does not favour spherulite preservation, these features are seen associated with fragmented phytoliths in the Late Bronze/Early Iron Age soils at Toft's Ness (Dockrill and Simpson 1994: 88; Guttmann *et al*. 2006: 78). However, in the deep topsoils of the Northern Isles, dung has more usually been identified through chemical analyses, particularly lipid biomarkers, which have successfully identified herbivore, pig and even human inputs (Simpson *et al*. 1998a: 744; Simpson *et al*. 1999). In experimental analyses conducted on the deep topsoils of Papa Stour, no dung was identified in thin section despite a known input (Davidson and Carter 1998: 835).

Bone, although also subject to rapid decomposition in acid soils, is a far more durable indicator, providing a wealth of information on deep topsoil manuring strategies. Frequent bone indicates domestic waste application as fertiliser (Simpson *et al*. 1998a: 739; Simpson *et al*. 1998b: 116), and a drop in bone content but not in phosphate levels in the Iron Age deep topsoils at

Scatness has been interpreted as indicative of increased animal manure input, and thus the development of a plaggen-style manuring system (Guttmann *et al*. 2006: 84; Section 7.2.1). Fish bone can be distinctive in thin section, providing detail on resource use (Simpson and Barrett 1996: 548; Simpson *et al*. 2005: 366) and has been identified as an input to deep anthropogenic soils (Simpson *et al*. 1998b: 121). Certain chemical decomposition products of bone are also identifiable in thin section, notably vivianite (Cruise and Macphail 2000: 188; Simpson *et al*. 2005: 372) and 'calcium-iron-phosphate' pedofeatures: yellow, anisotropic infills with a distinctive radial crystallisation pattern, formed through release of Ca and P from bone hydroxyapatite during decomposition (Gebhardt and Langohr 1999: 615; Simpson *et al*. 2000: 757). Ca-P-Fe features have been recorded in Bronze Age deep topsoil contexts from Scatness (Simpson *et al*. 1998b: 116).

7.2.4 Indicators for plant-derived inputs: diatoms, phytoliths and plant ash remains

The characteristic appearance and structural resilience of plant silica bodies such as diatoms and phytoliths make them a valuable, though indirect, indicator for the presence and/or origin of amorphous and degraded organic materials. However, although studies indicate that 'suites' of silica assemblages can provide more specific identifications – e.g. cattle from sheep dung - this is a complex area (Robinson and Straker 1991: 8) and rarely possible in thin section, as the shape and internal structure of silica bodies is often obscured by fine organic material (Macphail *et al*. 1998: 628). In addition, local variability in taphonomic processes can lead to differential preservation that can skew interpretations based on these features (Cruise and Macphail 2000: 183). Although sometimes present in specific contexts, such as in pottery fragments (Robinson and Straker 1991: 8), diatoms and phytoliths are therefore most useful as *general* indicators in thin section; e.g. for livestock presence (Macphail 1994: 32) or, especially, for a predominately dry (phytoliths) or wet (diatoms) environment. This latter association is particularly useful in amended soil studies, with increased numbers of phytoliths to diatoms indicating application of turf from dry, grassy sources, and the converse indicating application of wetter, peaty material (Simpson *et al*. 1998c: 1189), or even standing water (Macphail *et al*. 1998: 640).

Silica bodies are highly heat resistant - pure silica melts at 1713^{0}C - and thus their presence in numbers has been interpreted as a sign of clearance by burning (Simpson 1998: 94) or of fuel residues (Simpson *et al*. 1998b: 116). At higher temperatures, and depending on the soil environment, plant silica may melt and fuse to form small lumps of glassy, vesicular slag (Canti 2003b: 350). This poses a potential problem for micromorphological interpretation: while such formations have been identified as the result of intense heating events, such as grass fires (Thy *et al*. 1995), differentiating them from the by-products of industrial processes is difficult, with reference samples taken from deposits of half-burned coal and clinker showing a similarly vesicular structure (M. Canti pers. comm.).

7.2.5 Pottery, building materials and the coarse mineral fraction

Material culture remains are frequently present in anthropogenic soils, and many of these are identifiable in thin section. While not a key feature in the deep topsoils so far studied in Scotland, these are potentially significant features which, particularly in an urban context, can inform on the nature and intensity of soil amendment. Pottery is perhaps the most ubiquitous of these, with pottery scatters a recognised indicator for manuring (Wilkinson 1982). Pottery is easily recognisable in thin section, and is the subject of numerous, mainly petrographic, studies (Reedy 1994). More significant for this project, however, is the wide range of constructional materials which have been shown by micromorphology to not only be present in deep anthropogenic soils, but also to have contributed to their formation. Burned clay daub may survive as texturally discrete soil fragments showing charcoal inclusions and with planar voids, pseudomorphic of plant temper (Macphail 2003: 104, English Heritage 2004c: 11), and lime-based mortars and plasters containing a variety of mineral tempers are frequently recorded from urban contexts (Macphail 1994). Although the dissolution of such materials may be rapid in moist soil conditions, their relict mineral components themselves contribute to deep topsoil formation. Current thinking generally agrees that the ‘dark earth’ soil deposits within Roman and Medieval occupation layers in many large urban centres (Section 2.3) are largely formed from the weathering and biological reworking of building and occupation debris. In London, the sandy loams forming dark earth deposits are traceable to the Thames River sands used in mortar and plaster, and brickearth clay – a naturally occurring loess deposit – is commonly used for walls and floors (Macphail 1994: 97; Macphail and Cruise 2000: 10). There is evidence that such materials were also used in deliberate soil amendment, with building debris used as a growing medium in early Roman London (Macphail and Cruise 2000: 10). This use of soils and mineral matter makes it often difficult to differentiate natural from manufactured materials in these categories.

In rural deep anthropogenic topsoils, the coarse mineral fraction has also been a focus of study, here to identify sources of inorganic manure materials (Simpson 1997: 369; Davidson and Carter 1998) and, in some Northern Isles deep topsoils, identifying the episodes of blown sand which are a vital part of their formation processes (Guttmann *et al*. 2006: 69). Within-slide coarse mineral concentrations can also indicate the nature of inorganic amendment, for example the addition of peat or turf (Section 7.2.2) or even the presence of fuel residues, with, for example, dominantly silt-sized mineral grains taken as indicative of peat/turf ash (Simpson *et al*. 2006: 229).

7.2.6 Textural and excremental pedofeatures and other microstructural indicators

The deep anthropogenic topsoil environment - constantly reworked by faunal activity, and largely stabilised to slaking processes by the large volume of organic material typically contained within it (Dockrill and Simpson 1994: 91) - is not conducive to the development or survival of textural pedofeatures. As a result, their presence in these soils combined with an absence of the same from related agricultural soils has been taken as an indication of a decline in organic matter status, and possibly a cessation of manuring at this point in the sequence (Simpson 1997: 375; Simpson 1998: 94). This is however a complex area: with textural pedofeatures a key indicator of disturbance through cultivation activity, their presence has also been taken to indicate arable intensification (Guttmann *et al*. 2006: 84). However, the fact that reworking is likely to have destroyed many of these features makes estimating the intensity of past cultivation through textural pedofeatures a questionable strategy. Paradoxically, the features of this reworking are themselves considered pedofeatures for cultivation and soil amendment, with excremental material – especially in conjunction with degraded plant material - indicating organic manure applications and associated high levels of biological activity (Dockrill and Simpson 1994: 88).

Although deep anthropogenic topsoils are characteristically well-drained - commonly situated on sandy soils and created in part to combat the excessively free drainage they provide – some exist on imperfectly to poorly drained soils (Simpson 1998; Simpson *et al*. 2005) and can therefore display pedofeatures indicative of waterlogging. These are commonly signs of iron depletion in larger mineral grains, or amorphous, crypto-crystalline nodules and/or mottles of iron or manganese (e.g. Simpson 1998: 93). However, in amended soils, such features can of course be inherited – for example, as a result of sourcing inorganic manures from podzolic soils (Simpson *et al*. 1998b: 121). Finally, pedofeatures, as potential illustrations of the continuum of activity discussed in Section 7.1.3, should, like other microstructural characteristics, be interpreted with some care in a study of this nature.

7.3 Analysis

7.3.1 Methodology

Sequences of five to eight Kubiena tin samples were taken from each soil profile at each sample site (Appendix 6). A total of sixty-six undisturbed samples were taken, and thin section slides prepared from these at the University of Stirling.

Thin sections were described using an Olympus BX-50 petrological microscope and by following the standard procedures of the International Handbook for Thin Section Description (Bullock *et al.* 1985) and the most recent procedures of Stoops (2003). This facilitated a systematic description of soil microstructure, basic mineral components, basic organic components, groundmass and pedofeatures using a range of magnifications (x10-x400) and light sources (plane polarised, crossed polars and oblique incident). The descriptions are presented in a standard table format in Appendix 8. Digital images were captured using an Image Analysis system (AnalySIS Version 3.0) and are referenced in-text by number (e.g. ‘001’). These images are presented as Appendix 9, both digitally and as thumbnail hard-copy images, in the order referenced throughout this chapter.

The interpretation of the observed features is presented in the following sections. This is presented firstly on a site-by-site basis, and secondly as an inter-site comparative study, and concentrates chiefly on the series of anthropogenic additions to the soil profile discussed in the preceding section. The rationale behind this approach is discussed in Section 7.1.3. The range of land use contexts represented by the three sites, and their inter- and intra-site comparability, is discussed in Section 6.1.2.2.

Of the categories of feature assessed for each thin section, the most significant for this study are carbonised remains. These not only provide specific information on the input history of each deep topsoil but also, by remaining more generally identifiable than other anthropogenic indicators throughout the processes of breakdown and fragmentation, can inform upon the effect of modern land cover on the survival of micromorphological features. Carbonised remains - which in Appendix 8 are recorded under the categories of charcoal, amorphous black organic material, and amorphous organic material with inclusions – were therefore subject to additional, semi-quantitative analysis within this project. Following the morphological identifiers described in Section 7.3.1, the latter three general categories of amorphous material were subdivided into 'peat-like' material (stringy, fibrous in appearance), 'turf-like' material (containing mineral inclusions), and general amorphous carbonised material (fitting neither of these categories). Along with identifiable charcoal, fragments of these materials over 500 microns in size in any direction were recorded separately, and quantified in the following manner:

Carbonised fragment	Value
Maximum diameter 500 - 1000 microns	1
Maximum diameter 1000 – 2500 microns	2
Maximum diameter 2500 – 5000 microns	3
Maximum diameter over 5000 microns	4

For example, a slide showing two peat-like carbonised fragments measuring 750 x 200 microns, and one 4000 x 2000 microns, would have a value of 4 for this category of carbonised material.

This allowed the survival of carbonised material of specific types at a size at which identification is possible and useful to the micromorphologist to be assessed, and the information presented as a graphic. The histograms presented in this analysis are generated through the valuation system listed above. It should be remembered that carbonised fragments below 500 microns are a significant presence in many of the slides: any discrepancies in the tabulated frequencies of carbonised remains at Appendix 8 and the histograms presented herein result from this. Note also that, as the amounts of material recorded vary significantly between categories, applying a uniform scale to all histograms was not possible. Therefore, the histogram scales vary between material types, providing a direct comparison for histograms for each material category, rather than for various materials within each site with, for example, charcoal measured to a maximum value of 15, and peat-like material to a maximum of 120.

7.3.2 Study site 1: Nairn

Eighteen thin sections were taken from the three deep anthropogenic topsoil profiles at Nairn: six from long-term pasture profile NA1, five from woodland profile NA2, and six from arable profile NA3. Arable profile NA3 includes a thin section sample from the C horizon.

7.3.2.1 Mineralogy

The coarse mineralogy is similar in makeup throughout all three profiles, and confirms the field description of the Nairn deep topsoil. All thin sections are dominated by medium sand-sized, generally slightly weathered quartz, with slightly finer sand seen in arable profile NA3. Larger rock fragments are relatively rare in pasture profile NA1 and arable profile NA3 – the two profiles nearest one another – whereas larger inclusions of mainly rounded sandstones are frequent through woodland profile NA2. There is also a small degree of variation in less common minerals – particularly muscovite, hornblende and olivine – which may suggest a slight variation in the origin of mineral input into different areas of the topsoil polygon, though there is no between-profile or down-profile patterning to this.

7.3.2.2 Fine fraction and groundmass characteristics

The fine material fraction is also generally similar throughout the three profiles: a mid to dark and occasionally slightly reddish brown organo-mineral groundmass, commensurate with amendment by both mineral and organic material. The majority of slides show a high degree of biological reworking of this fine material groundmass, again commensurate with heavily manured and amended soils (001). This creates a generally intergrain microaggregate microstructure with occasional slides showing channels and vughs (002). The groundmass shows no signs of heating when viewed in oblique incident light.

The organic component of the groundmass is less dense in arable profile NA3, with slides from the top two horizons having an especially ‘open’ appearance. This is likely to be an effect of crop removal: both the loss-on-ignition and wet oxidation results from the upper portion of this profile show a lower organic matter content than either the woodland or pasture profiles (Section 6.3.2). However, while both pasture and woodland profiles show a marked decrease in organic material down-profile, with B horizon slides NA1Bs and NA2Bs strongly mineral dominated, B horizon slides NA3Bw1 and NA3Bw2 indicate that arable profile NA3 appears better able to maintain these albeit lower organic matter levels throughout its depth. Again, this concurs with the bulk analyses from these horizons. The microstructure of these slides thus supports the interpretation given in Section 6.3.2: that the effect of increased (probably through leaf and grass litter) or decreased (probably through crop removal) organic matter input is significant in the upper horizons, and lessens down-profile as organic matter levels in all three pits converge. The explanation for this given in Section 6.3.2 – the natural environmental processes of organic decomposition and recycling – are amply illustrated: both pasture profile NA1 and especially woodland profile NA2 show an almost entirely biologically reworked microstructure within which the fine fraction is largely present as small, rounded excrements, probably enchytraeid worm (D. Davidson pers. comm.). Arable profile NA3, from which a proportion of the organic input has been mechanically removed, is reworked to a far lesser extent. It appears that the high levels of organic matter introduced to both the pasture and woodland profiles through their vegetation cover result in a concomitant rise in biological activity, the effects of which, it is suggested, continue down-profile to result in lower levels of organic matter in the B horizon than seen in the less biologically active arable profile NA3.

How does this affect the study of past amendment of these soils? As discussed in Section 7.1.2.3, faunal activity, although destructive of structural indicators for cultivation, is also considered a good general indicator for organic amendment. Differences in both levels of organic matter and faunal activity in this deep topsoil as a result of modern land cover thus potentially affect interpretation. However, the Nairn analysis raises a further consideration. A feature of the groundmass in profiles NA1 and NA2 are occasional discrete patches of material, of similar coarse mineral makeup and of either a slightly lighter (e.g. NA1Ap1) or darker (e.g. NA1Ap3) colour than the surrounding groundmass. These are associated with frequent phytoliths, occasional parenchymatic tissue, and frequent red/brown and yellow/orange amorphous organic material, although not particularly with carbonised material. The patches average 5000 - 7000 microns diameter and are generally rounded to sub-rounded (003).

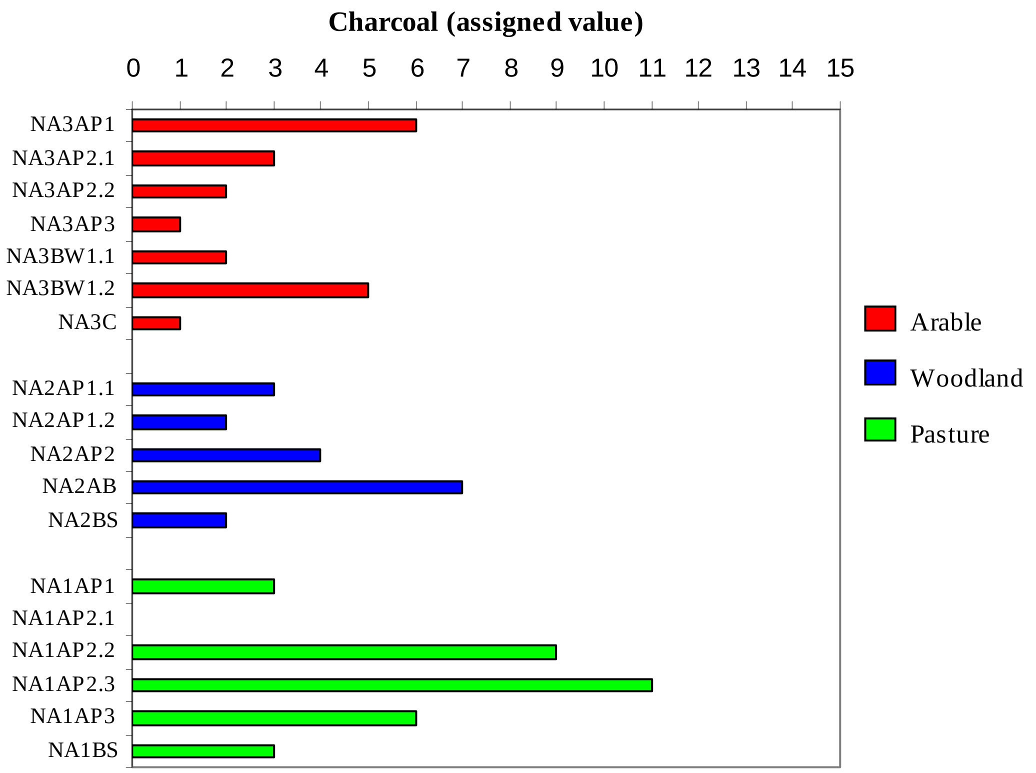
There is a general similarity between these features and key indicators for soil manuring and amendment, such as turf, or even surviving herbivore excrement (Stoops 2003: CD-ROM, Image 8:102). Only the similarity of the coarse material fraction of these patches to that seen throughout the groundmass indicates that these features are not inherited, but are more likely to be areas of groundmass which have not yet been reworked by soil fauna. By contrast, the less reworked arable profile displays several similarly discrete areas within the groundmass, again composed largely of amorphous organic matter with phytoliths, but in this case clearly introduced material (see Section 7.3.2.4).

Potentially, then, a highly reworked microstructure may, in addition to destroying features of amendment, may actually provide ‘false positives’ for the same. However, this is a potentially complex issue. Arguably, the most plausible explanation for the survival of these non-reworked areas in NA1 and NA2 is that they represent concentrations of plant material which have decayed to leave behind areas composed mainly of silica bodies, more resistant to faunal reworking. While such concentrations – particularly towards the top of these pasture and woodland profiles – probably originate from vegetation cover, they may also represent deliberate additions to the profile from local sources, indistinguishable by coarse mineral makeup from the rest of the horizon. Overall, it seems that the microstructure created by a combination of intense vegetative cover and the highly biologically active soil it creates is a potentially confusing medium within which to isolate true features of deep anthropogenic topsoil amendment.

7.3.2.3 Carbonised materials and fuel residues

A reasonable amount of charcoal – less than in the charcoal-rich Tealing samples, but generally more than at Unst – is present at Nairn (Figure 7.1). The highest incidence is seen in pasture profile NA1, particularly in the lower Ap2 horizon. However, charcoal levels for the remainder of the sample set vary considerably, with no clear difference between woodland profile NA2 and arable profile NA3, and the only sample showing no charcoal – NA1Ap2.1 – located immediately above the two showing the most.

Figure 7.1: Charcoal (over 500 microns) from the Nairn sample set



This would seem to indicate no appreciable difference in charcoal survival within profiles under different modern land cover, and that variation in charcoal within these pits is traceable to input, rather than degradation. This is supported by the appearance of the charcoal identified: overall, charcoal preservation in these samples is good. Large fragments with a clear cell structure are seen throughout pasture profile NA1 (004; 005; Plate 7.1), into the B horizon of woodland profile NA2, the most biologically active of the three profiles (006), and in both the plough horizon and lower B horizon of arable profile NA3 (007; 008). NA1 is noticeable for very small charcoal fragments (150-250 microns) which retain a cell structure despite high levels of soil faunal activity.

Plate 7.1: Well-preserved charcoal fragment in pasture profile NA3. Plane polarised light

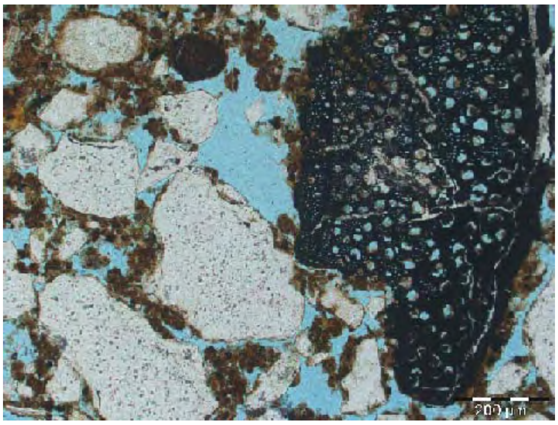
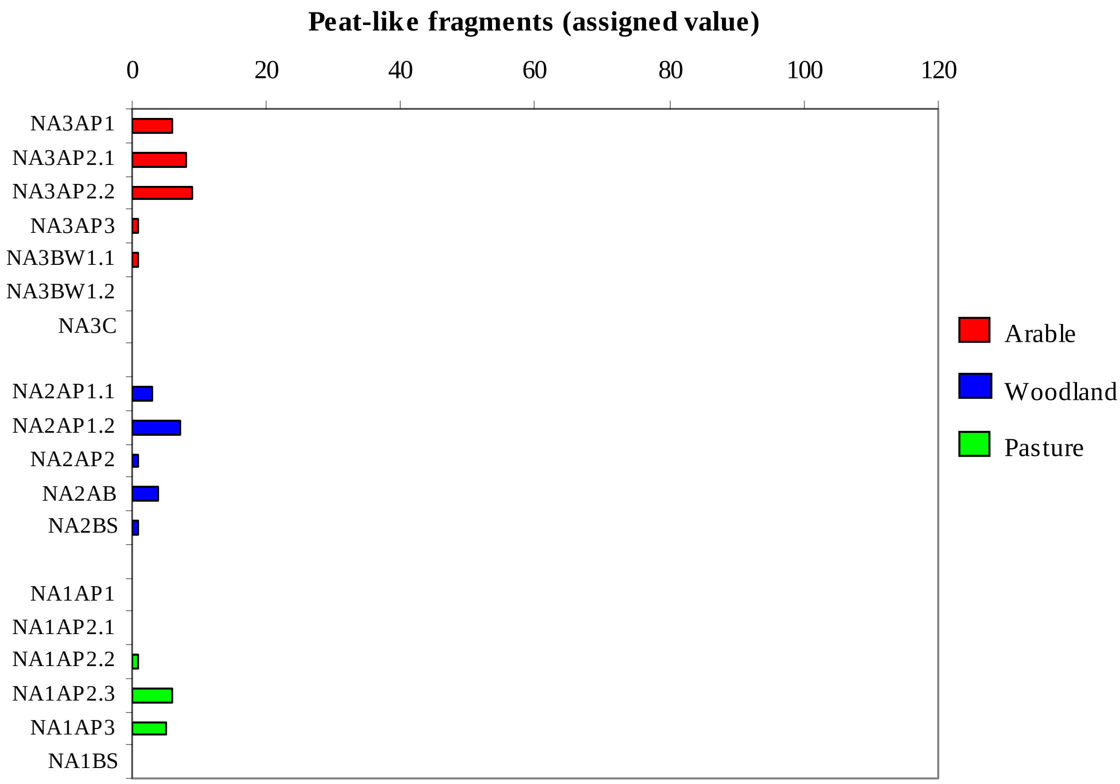


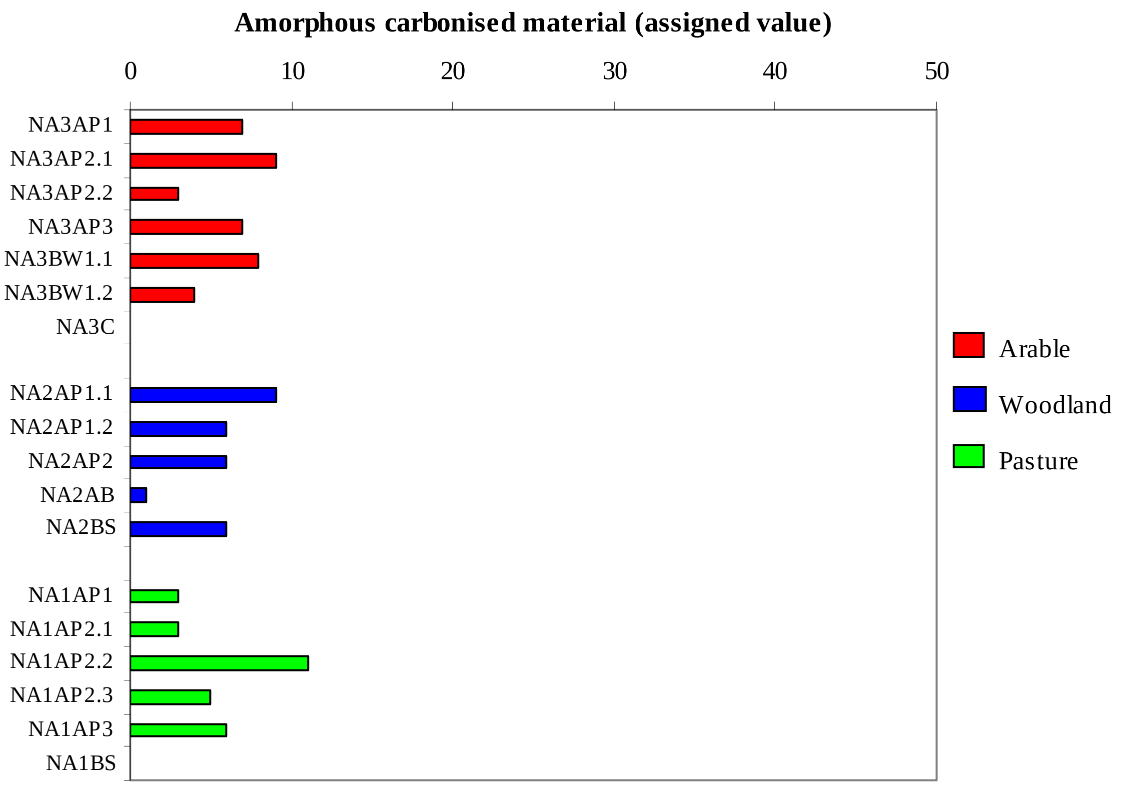
Figure 7.2: Peat-like carbonised material (over 500 microns) from the Nairn sample set



Carbonised material with a peaty morphology is present in slightly lower percentages than charcoal, with several horizons having no discernible fragments (Figure 7.2). There is again no appreciable difference in carbonised peat survival according to land cover, with a peat presence in all profiles. The largest and best-preserved fragments are seen in arable profile NA3 (009; 010), which has the highest incidence of fragments overall.

Turf-like carbonised fragments (showing mineral inclusions) are almost entirely absent from the Nairn samples, and are therefore not presented as a graphic. Amorphous carbonised material above 500 microns is, however, present in a similar frequency to charcoal (Figure 7.3). Only two of the lowest horizons show no fragments, and again there is no discernible difference in their presence according to land cover. In real terms, however, the frequency of this material is far higher than recorded at Figure 7.3, with by far the majority of carbonised fragments seen in all profiles being both amorphous and below 500 microns in size. This poses a potential problem: how can we know that this group of features does not represent a sizeable proportion of both charcoal, peat and turf fragments which have been subject to disaggregation and decay? Firstly, there is no

Figure 7.3: Amorphous carbonised material (over 500 microns) from the Nairn sample set



correlation between smaller fragments and the more biologically active horizons, and secondly, although disaggregation of carbonised material is certainly seen (011), structural survival in all carbonised fragments is generally good.

An additional set of fuel residue fragments, not discussed in either Section 7.2.1 or in the literature in general, are present in the Nairn samples. These can be identified as coal (012), and what, for the purposes of this study, are termed clinker-type fragments (013; 014).

With little micromorphological investigation carried out on the residues of coal burning, coal in the Nairn slides is identified through reference slides produced by M. Canti at the Ancient Monuments Laboratory at the English Heritage Centre for Archaeology, Portsmouth. Although similar to charcoal in general appearance, material identified as coal is characterised by the large, irregular voids which occupy most of the space within the material, in contrast to the regular cell patterning and relatively dense structure of charcoal (M. Canti pers. comm.). Charcoal and coal are therefore close in morphology, with one piece, identified as charcoal but with an irregular lower portion which looks coal-like, indicating the potential difficulty in separating the two (015).

Coal is present in sizeable quantities in the upper horizons of pasture profile NA1, in trace amounts in the top horizon of woodland profile NA2, and is absent from the rest of the sample set. The indication is that these are relatively recent additions to the profile, potentially intrusive rather than deliberately added. However, with urban manure inputs known to have been channelled into the Nairn topsoil polygon (Section 5.2.1.5), it is also possible that these coal fragments represent a valid, though small, part of the materials used for manuring and soil amendment, with coal ashes cited as a manure source in the First Statistical Account entry for Campsie, Stirling (FSA XVI: 328).

'Clinker-type' material is also identified by comparison with reference slides from modern contexts (M. Canti pers. comm.). Present in far larger quantities in the Tealing sample set and discussed in detail there (Section 7.3.3.3), only one – albeit large – piece of this material is present at Nairn, in the Ap2 of arable profile NA3. Again, although potentially intrusive, it is possible that this originates from the pre-1970 industrial waste used as fertiliser in this area of the deep topsoil polygon (Section 5.2.1.5).

A final point to be made is the potential overlap between all three of the categories of carbonised material isolated for this study. In addition to the similarities between coal and charcoal, several fragments show both charcoal- and peat-like characteristics (016), and a common occurrence are groups of fragments, clearly disaggregated parts of the same material, one of which shows charcoal or peat-like characteristics while the remainder appear as amorphous material (011). Cross-referencing the frequencies noted here with those of the recording table, where such features are recorded as one, is therefore vital.

7.3.2.4 Bulk material amendment – peat and turf-type features

In contrast to carbonised fragments, identifiable non-carbonised remains of materials likely to represent sources of bulk material amendment – peaty and turf-like fragments – are only occasionally seen in the Nairn sample set. This is to be expected: the levels of biological activity seen in all three profiles would be likely to hasten degradation of the organic fraction of these features. It follows that there is a relationship between the survival of these features and land cover type. Although fragments of brown and reddish-brown amorphous organic material both with and without mineral inclusions are seen in mainly the upper horizons of NA1 and NA2, by far the clearest examples of these are seen in the less biologically active arable profile NA3 where, although only just below the plough zone, identifiable peaty turf fragments are seen (017). These consist of yellow-orange to light brown almost wholly organic material with fine mineral inclusions, containing diatoms and occasionally phytoliths. Down-profile, as biological activity increases, several partially disaggregated comparable materials are seen (018). Similar examples of ongoing degradation are seen from other organic materials at this level (Section 7.3.2.6).

7.3.2.5 Animal-derived indicators

As expected from these relatively acid soils, very little bone is present in the Nairn sample set. However, it seems that bone did feature in the input system, with two very small fragments still extant as a result of heating (019; 020). Although these are both present in the upper horizons of arable profile NA3, this is too small a sample set to infer a relationship between survival and land cover type.

More interesting are the possible fragments of herbivore dung seen at the very top of pasture profile NA1 (021; 022). These consist of several small discrete patches of amorphous reddish brown organic material packed with fragmented phytoliths and diatoms. However, their position at the top of the pasture, upon which horses are known to have grazed several years prior to sampling, makes these features unlikely to be relict indicators of deliberate manuring. Rather, these are interesting as an indicator for the survival of excremental features in a highly biologically active soil. It is also possible that these silica concentrations are merely decayed plant material originating from the vegetation cover itself.

7.3.2.6 Plant-derived indicators

The high levels of organic matter entering both the pasture (grasses) and the woodland (leaf litter) profiles result in frequent parenchymatic material present throughout both, especially in the upper horizons. This has implications for the recognition of diatoms and phytoliths as indicators of relict features of soil amendment: how can these be distinguished from the numbers of (especially) phytoliths entering these profiles through vegetation cover? It appears likely from the appearance of these samples that diatoms and phytoliths may be of limited usefulness in soil profiles under heavy vegetative cover.

Lignified tissue, although also of limited usefulness as an indicator for amendment, is interesting for its strong presence in arable profile NA3 compared to the other two profiles (023; 024). This is unusual – a higher proportion of lignified tissue in the woodland profile would be a more likely scenario. However, as this material is unlikely to inform upon soil amendment strategies, it is of minimal importance to the discussion. Rather, the good survival of lignified tissue, especially in the plough zone, is another example of the better organic preservation associated with the slightly less biologically active arable profile.

7.3.2.7 Material culture inclusions

Anthropogenic inclusions, as fired material of varied size and morphology, are present in all Nairn profiles, with no clear difference between land cover types. This is unsurprising, as pottery is known to be fairly robust in the burial environment. What is more interesting is that the majority of fragments of fired material in the Nairn samples appear closer in makeup to mortar, seeming to have undergone only low-temperature firing, or to be formed from an unfired, possibly lime-based material containing more strongly fired inclusions of probably pottery. Weakly fired, and certainly lime-based mortar would be expected to quickly degrade in these acid soils – however, recent micromorphological investigations in Scottish Roman contexts have shown that this is not necessarily the case, and that mortar-type material can survive in acid and free-draining environments (McKenzie forthcoming).

There are similarities between these fired materials in all three profiles. Generally, the material is seen in both plane polarised light and under crossed polars to be a light grey to brown microcrystalline cement (025; 027; 029; 031), showing some similarity with photomicrographs of mortar and plasters taken from urban contexts (Macphail 2003: 96). In oblique incident light, small, generally rounded inclusions show as bright red areas, indicating their higher firing temperature (026; 028; 032). Occasionally, these inclusions appear to be themselves formed from composite materials fired to varying temperatures (030). Their presence into the B horizon of both the woodland and arable profiles indicates that these features are likely to have entered the profiles as part of the soil amendment strategy, which would not be unusual given the urban context of the inputs into the Nairn soil. Fired and mortar-type materials are also a feature of the Tealing sample set, and are discussed further in Section 7.3.3.7.

7.3.2.8 Pedofeatures

The most significant pedofeatures recorded in the Nairn samples are, of course, the excremental pedofeatures seen throughout the each of the profiles, the effect of which upon both the overall soil structure and survival of key micromorphological indicators has been discussed at various points above.

Textural pedofeatures are, however, in the minority. While organic coatings are seen in small concentrations throughout all profiles, most frequently in woodland profile NA2, these too appear to be closely correlated with areas of intensive biological activity. Rather than indicating down-profile movement of material, these coatings appear to represent organic material remaining in association with mineral grains in areas where the majority of such material has been reworked by soil fauna.

Textural pedofeatures indicative of illuviation processes and water movement are also occasionally seen. Iron movement is indicated by occasional depletion, particularly in larger sandstone fragments. A reddish cast to the groundmass in the lower horizons of woodland profile NA2 (in crossed polars) also possibly indicates iron movement through the profile. However, this is not significant.

7.3.2.9 Nairn: inputs and indicator survival

The complex mixture of urban and rural manures understood to have contributed to the Nairn deep topsoil (Section 5.2.1.3) are well illustrated in this sample set, with historical and contemporary evidence for the composition of these inputs strongly supported by the micromorphological evidence. While fuel residues such as charcoal and amorphous carbonised material are naturally ubiquitous, it is interesting that carbonised fragments with a peat-like morphology are equally frequent, while unburned peat is relatively rare even in the arable profile within which it appears to survive best. This accords with the historical evidence that peat was too valuable a fuel source in the Nairn area (Simpson 1956) to have been used for manure prior to burning, with ‘turf or sand’ (Donaldson 1794: 14) used instead. That said, evidence for turf – either burned or unburned – is minimal in the sample set.

Evidence for the probable urban context of much of the manures entering the Nairn deep topsoil is seen in the significant amounts of fired material, and some pottery, present in all profiles. The presence of burnt bone is indicative of domestic waste use. Oral testimony on manure input is also corroborated in thin section. The presence of coal in the upper horizons of the pasture and woodland profiles and ‘clinker-type’ material at a similar level in the arable profile confirms the report of burnt wastes from the local gasworks being used to manure the deep topsoil area until the 1970s (J. Forbes pers. comm.).

How have the survival of these indicators been compromised by the effects of the modern land cover types present on the topsoil polygon? A variety of observations can be made. Firstly, there do appear to be appreciable differences to the survival of different micromorphological indicators under different land covers. The cause of these appears to be the varying levels of biological activity in the different profiles, which are interpreted as resulting from the varying levels of organic matter inputted to the soil from each land cover type. Higher biological activity is seen in the pasture and especially the woodland profiles, and considerably lower biological activity in the arable profile, although this increases towards the B horizon. These observations concur with those of the bulk soil analyses of organic matter status, and therefore add weight to the interpretation of total P retention presented in Section 6.4.2.

Secondly, it appears that the destructive effect of high biological activity in the pasture and woodland profiles acts only upon certain categories of indicator. Unburnt organic materials are, unsurprisingly, the worst affected, with a noticeably low presence of features such as peaty turf and lignified tissue in all but the arable profile. By contrast, survival of carbonised material in recognisable forms does not seem compromised, nor do more robust indicators such as pottery or burnt bone.

Finally, it appears that this reworking of the soil structure through faunal activity, in addition to destroying certain indicators for soil amendment, may also create structural features which could be mistaken for deliberately introduced material. Likewise, enhanced numbers of phytoliths and diatoms in soils under these higher levels of organic input cannot be used as an indicator for relict amendment.

7.3.3 Study site 2: Tealing

Twenty thin sections were taken from the three deep anthropogenic topsoil pits at Tealing: seven from arable profile TE1, six from woodland profile TE2, and seven from long-term pasture profile TE3.

7.3.3.1 Mineralogy

The coarse mineral makeup of the Tealing deep topsoil is generally similar throughout all three profiles, confirming the field description of this soil as a silty clay to silty clay loam. As at Nairn, the coarse mineral fraction is dominated by quartz, here with only occasional signs of weathering. At Tealing this quartz-dominated fraction is both smaller – generally fine sand to silt size – and less prevalent throughout the groundmass, which is instead dominated by densely-packed organomineral material.

Larger rock fragments, although present in most slides, are not ubiquitous, and the three profiles generally present a poorly sorted groundmass with occasional large fragments of rounded to angular sandstone. As at Nairn, these are more prevalent in woodland profile TE2. However, in contrast to the Nairn samples, the presence of the less common minerals is fairly uniform throughout the three profiles.

The most interesting feature of the Tealing coarse mineral fraction is the frequent occurrence of calcium carbonate material, of varying size and shape, seen through all but the lower horizons of woodland profile TE2 and pasture profile TE3. Although many of these are in varying stages of dissolution, their survival in this relatively acidic, imperfectly drained soil is unexpected. Their presence may be related to the high incidence of 'clinker-type' materials in these soils, with which they share significant morphological features, and they may therefore represent heated and ashed material from a similar, possibly industrial source to that suggested for the clinker-type fragments (Section 7.3.3.3).

7.3.3.2 Fine fraction and groundmass characteristics

At Tealing, the fine material fraction dominates the groundmass, which is denser and more complex than that seen at Nairn, varying from light to mid, reddish and dark brown, with juxtaposed areas of light and dark material giving a mixed, turbated appearance to the samples (033). Seen most clearly in arable profile TE1, this turbated groundmass may represent an amended soil which has *not* undergone the extent of biological reworking seen at Nairn, as generally, the level of faunal activity in the Tealing samples appears to be much lower. However, in sections with a more excremental fabric, this turbated mixture of groundmass colours is replaced by a more uniform groundmass with occasional examples of the ‘patches’ of un-reworked material seen at Nairn (Section 7.4.2.2). This supports the interpretation of these features as an effect of faunal reworking rather than introduced material.

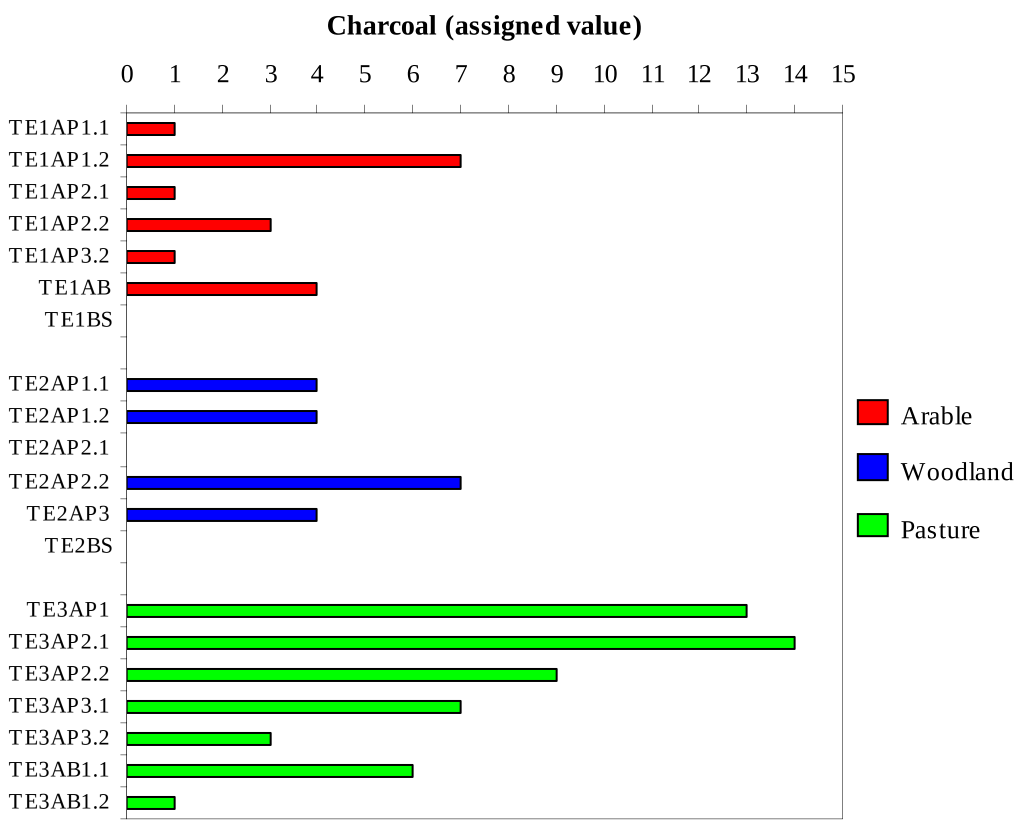
Although faunal activity is seen throughout all three Tealing profiles, not only is the overall level of reworking far lower than that seen at Nairn, but its down-profile patterning is more complex. Whereas the Nairn profiles tend to show an increase in faunal reworking down-profile, the extent of this through the Tealing profiles is more erratic, with variable levels of biological activity seen throughout, and only the woodland profile showing a steady rise in faunal reworking down-profile. As at Nairn, this pattern is reflected in the bulk organic matter analyses, which also show a more complex pattern of retention, and an overall higher organic matter content towards the base of the profiles (Section 6.3.2). It is suggested that this is a result of the reduced drainage capacity and lower oxidation and decomposition rates in this more clayey soil. To this, micromorphological analysis can add an additional and connected factor: the presence of earthworms, apparently largely in place of the enchytraeid activity ubiquitous at Nairn. Signs of reworking by larger soil fauna are seen at various intervals through the Tealing samples, with larger voids forming an occasionally vughy and channel microstructure, and large, rugose excrements present, for example in woodland profile TE2 and especially to the base of pasture profile TE3, where discrete, rounded areas of darker groundmass may represent material transported down-profile by worms (034).

Despite the frequent inclusions of fired and fuel residue material seen in these profiles (Section 7.3.3.3), the groundmass does not appear heated in oblique incident light. However, this is difficult to ascertain, as one of the most distinct features of this slide set is the high level of iron movement and accumulation seen throughout, creating a strongly red appearance to many of the slides in both crossed polars and oblique incident light. This is typical of poorly-drained soils: the clearest example is seen in the slide from the waterlogged B horizon of arable profile TE1, where highly Fe rich areas of groundmass are seen as discrete patches forming a lenticular platy pattern of Fe distribution.

7.3.3.3 Carbonised materials and fuel residues

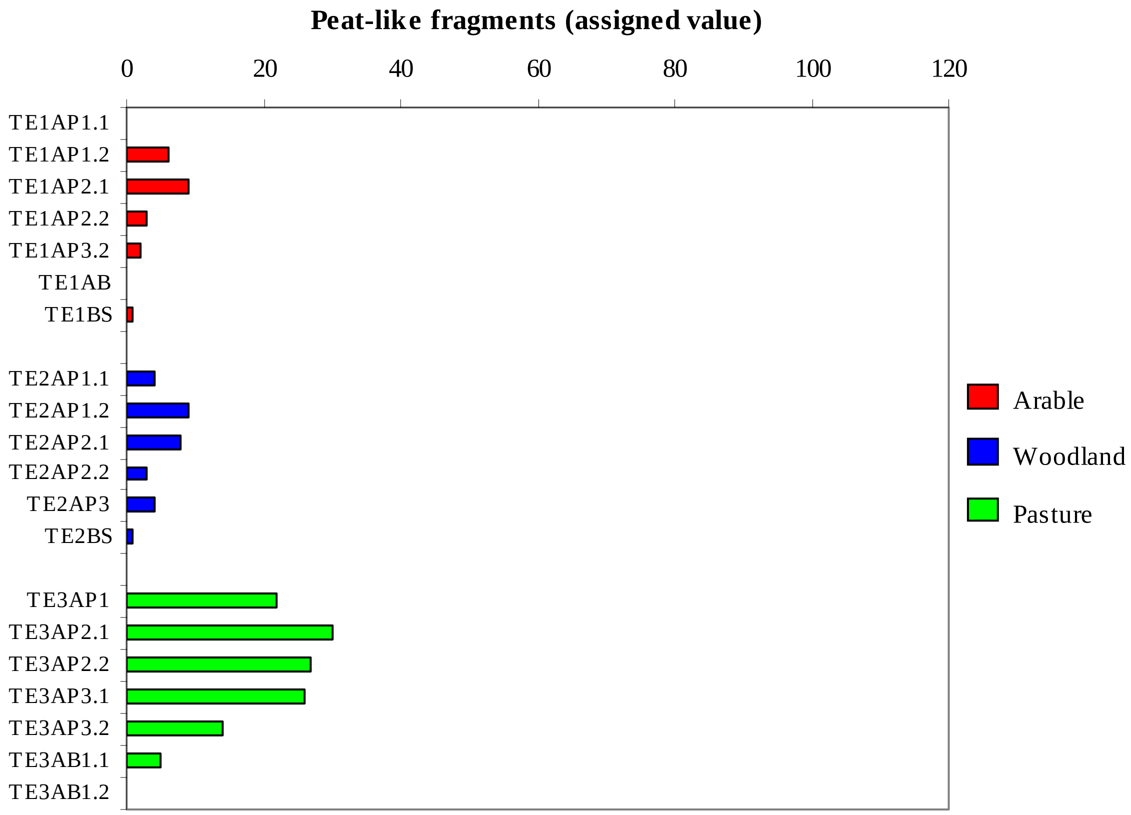
Fuel residue materials are well represented at Tealing, and are the largest and most complex series of features seen in the entire sample set. However, their distribution is somewhat erratic. Charcoal, although showing a higher maximum frequency than that recorded at Nairn (in the Ap2 horizon of pasture profile TE3), is entirely absent from several samples (Figure 7.4). Overall, however, the survival and distribution of charcoal through the Tealing profiles supports the observations of the Nairn study: most charcoal is seen in the pasture profile, while the arable and woodland profiles show broadly similar charcoal levels, and the general degree of structural survival under all three land cover types is good both at the top (035) and base of the profiles (036). Notable in this sample set is a structurally perfect carbonised root (037) and several charcoal fragments of less than 100 microns diameter surviving with a recognisable cell structure (038). As at Nairn, this would suggest that there is little difference in charcoal survival under different modern land cover types and that variation in charcoal levels in the three profiles is a reflection of input rather than of degradation.

Figure 7.4: Charcoal (over 500 microns) from the Tealing sample set



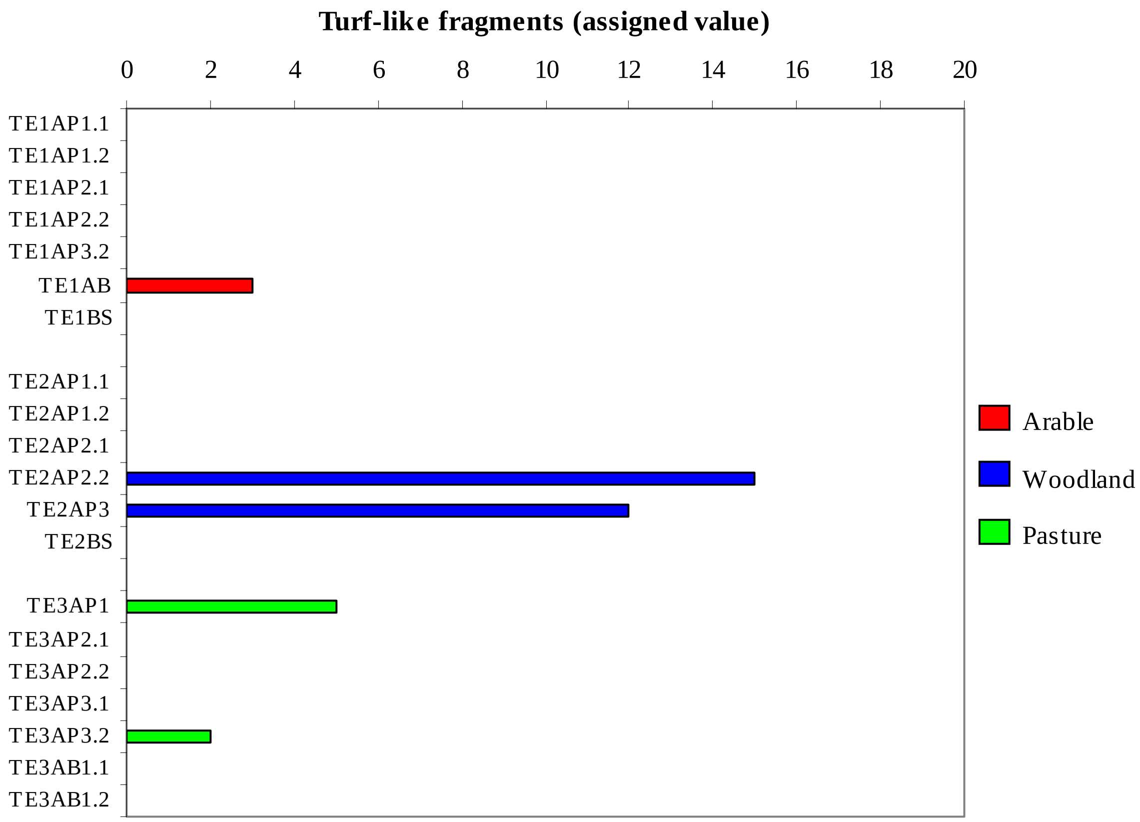
Peat-like carbonised material is more prevalent than at Nairn, and shows a clearer distribution, with the majority of fragments concentrated, like charcoal, in pasture profile TE3 (Figure 7.5). Although this distribution possibly reflects more intensive degradation of carbonised peaty material under woodland and arable profiles, this is considered unlikely. Firstly, this would not accord with the results from Nairn, whose (albeit small) sample of carbonised peat fragments is concentrated in the arable profile, and secondly, peat-like fragments in the Tealing samples do not appear more degraded in these two profiles than under pasture cover, with varied degrees of preservation of these fragments seen under all land cover types, from well-preserved to almost completely degraded (039; 040).

Figure 7.5: Peat-like carbonised material (over 500 microns) from the Tealing sample set



Carbonised fragments with a turf-like morphology are also more prevalent than at Nairn (Figure 7.6). However, although these are present in each profile, they are scarce, with fragments recorded from only isolated horizons in arable profile TE1 and pasture profile TE3. The majority of carbonised turf is present in woodland profile TE2. As at Nairn, it would seem that this material is either particularly prone to degradation or (more likely) was not a significant part of the manure input into the Tealing soils. An assessment of the effect of modern land cover on this indicator is therefore not possible; however, it is noted that unburned turf fragments are a feature of slide TE1AB (Section 7.3.3.4).

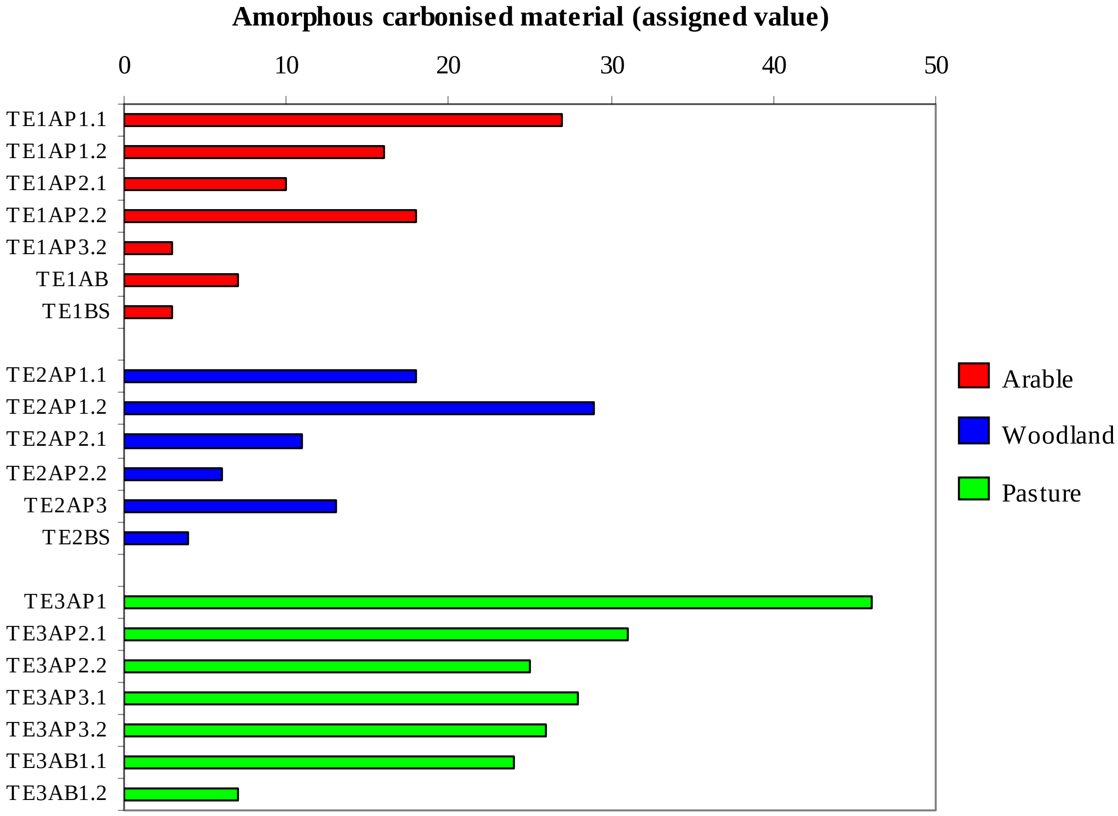
Figure 7.6: Turf-like carbonised material (over 500 microns) from the Tealing sample set



Amorphous carbonised material provides by far the largest set of carbonised fragments in the Tealing profiles, in contrast to Nairn, where charcoal was more frequent (Figure 7.7). All samples contain this material, and although pasture profile TE3 has the highest concentration, it is relatively frequent in all profiles. Varying levels of degradation are seen, with many fragments cracked or disaggregated (041). As at Nairn, this raises the possibility that some of this material may represent charcoal, peat or turf-like fragments which are decayed to the extent that they are no longer recognisable.

Coal is also present in the Tealing sample set, and in slightly higher frequencies than seen at Nairn, although the examples are both smaller and more fragmented (041; 042). This is almost entirely confined to the pasture profile, within the grounds of Tealing House and the nearest profile to the House itself (Section 7.3.3.9). One fragment is recorded from the Ap2 horizon of the woodland profile. Again, there is a potential overlap between this category and that of charcoal, but at Tealing, there is also a potential overlap between coal-like fragments and the most distinctive

Figure 7.7: Amorphous carbonised material (over 500 microns) from the Tealing sample set



category of fuel residues present in the sample set: clinker-type material. Represented at Nairn by one fragment and identified through reference samples, provided by M. Canti at English Heritage, the wide range of features of this nature in the Tealing slides allows this study to comment on the key characteristics of these materials, their survival in the soil environment, and their possible origin and anthropogenic context.

Clinker-type materials are seen frequently in the Tealing profiles: in the two uppermost horizons of arable profile TE1 and woodland profile TE2, and, most numerously, through the three Ap horizons of pasture profile TE3. Although varying in size, shape and colour, one or more of several distinctive characteristics are shared by all these features, making them easy to identify within the groundmass. These are as follows:

a. A vesicular, glassy structure to some or all of the fragment. This is generally a dirty green to brown in plane polarised light, generally isotropic in crossed polars and either isotropic or shows peripheral signs of heating in oblique incident light. This strongly resembles glass slag (Canti 2003b: 351).

b. Clusters of needle-shaped crystals inhabiting some or very occasionally all of the internal area of the fragment. These are colourless in plane polarised light and have some birefringence in crossed polars.

c. Areas of microcrystalline to crypto-crystalline material which resemble the frequent calcium carbonate fragments – probably ashed material – seen elsewhere through the sample set. These are brown to grey in plane polarised light and are anisotropic in crossed polars.

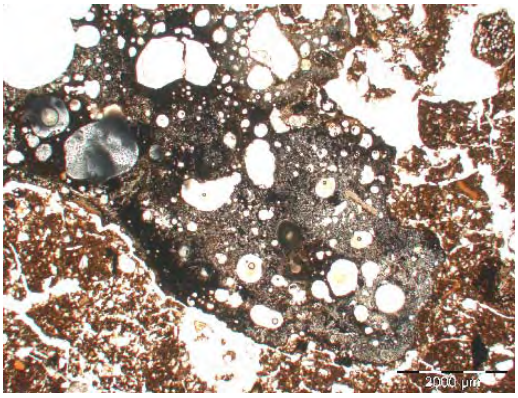
d. Signs of high temperature heating. Some or very occasionally the entire fragment appears bright orange to red, with some white areas, in oblique incident light.

Plates 7.2 and 7.3 show a typical example of a clinker piece from near the top of woodland profile TE2, and Plate 7.4 a sample of the needle-like crystal internal structure described at b. above. Plate 7.2 clearly shows the irregular vesicular structure throughout the fragment and the lighter, slightly cloudy bright grey areas showing a mixture of crypto-crystalline, calcite like material with small areas of needle-shaped crystals. These resemble those shown in the higher magnification image seen at Plate 7.4. It seems that the fragment contains inclusions of other material: towards the lower centre, a small, dark brown, roughly circular piece of possibly mineral material is seen. This is seen to be heated to white in oblique incident light in Plate 7.3. The edges of the fragment also appear heated to a high temperature.

A range of images from the Tealing samples illustrate the variability of these nevertheless coherent set of features. They contain a range of inclusions, such as degraded minerals and what appear to be small wood fragments (045; 046) and even amorphous organic material (047). They clearly show a range of heating temperatures, with colours in oblique incident light ranging from yellow-orange (048; 049) to white (050; 051). Specific fragments also illustrate the 'sliding scale' of identification between these features and other fuel residues, particularly calcite-based, probably ashed materials, with clear similarities between the crypto-crystalline, cloudy appearance of the more amorphous clinker-type pieces (052; 053) and the degraded ash-type material seen at intervals through the anthropogenic horizons (054; 055; 056). Fragments of clinker-type material which appear to partially surround or to be linked to recognisable charcoal and coal-type features are also seen (057; 058). The relatively frequent rubified, probably heated, small minerals through all three profiles also indicate some heated material input.

What do these materials represent? The reference slides used as a basis for identification of these features were made using waste material from modern episodes of relatively high-temperature burning, such as rake-out from ovens and furnaces (M. Canti pers. comm.). These features could therefore not only be created by industrial processes but also by domestic activity, albeit on a relatively intensive scale. The provenance of the material, adjacent to a large estate house, makes this latter explanation the most likely, and the probable source of the clinker features are the kitchens of Tealing House. This would explain the presence of small inclusions of materials such as wood and charcoal within and fused to the clinker pieces: what is recorded here is a mixture of the kind of domestic fuel residues familiar from countless anthropogenic contexts, but subject to the more intensive heating procedures associated with the more recent historic past. This is discussed further in Section 7.3.3.9.

Plate 7.2: Clinker fragment in woodland profile TE2. Plane polarised light



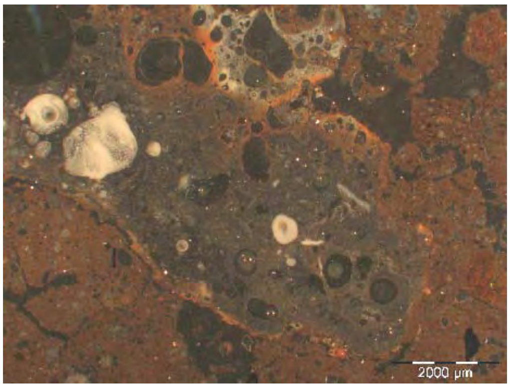
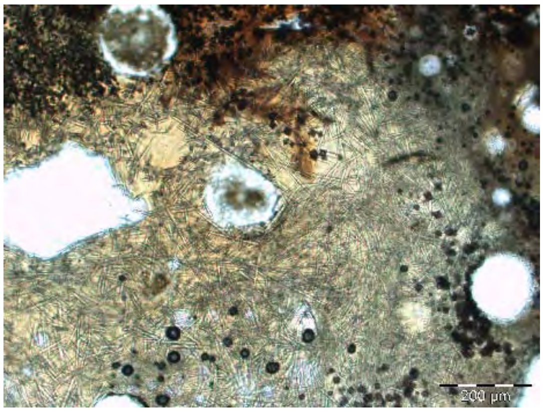


Plate 7.3: Clinker fragment in woodland profile TE2. Oblique incident light

Plate 7.4: Internal structure of clinker fragment in pasture profile TE3. Plane polarised light



7.3.3.4 Bulk material amendment – peat and turf-type features

As at Nairn, identifiable fragments of unburned organic and organo-mineral material which may represent bulk manure materials are relatively scarce. However, a range of materials can be identified. Unburnt peaty material is seen in minor amounts in arable profile TE1 and pasture profile TE3 (059; 060) and turf-like material is relatively frequent in especially the lower horizons of arable profile TE1 (061). One of these fragments is in association with small pieces of carbonised material, although the fragment itself is unburned, suggesting that this represents a deliberate addition of possibly manure material (062).

At Nairn, it is assumed that biological activity is responsible for the destruction of the majority of unburnt material of this kind: however, at Tealing, similarly low levels of this material are seen despite a far lower incidence of faunal reworking. This could of course be due to a low level of input of this material into the Tealing system – historical sources do indicate that large quantities of unburnt turf were unlikely to have been used for manuring (Section 5.2.2.3). However, evidence suggests that decomposition processes are more likely to be responsible for the intermittent presence of these features. Of the turf-like material recorded, a significant proportion does appear to have undergone significant disaggregation, often seen in association with fungal spores (063). As at Nairn, land cover is therefore implicated in the survival of unburned peat and turf fragments: woodland profile TE2, the most reworked of the Tealing profiles, shows the fewest examples of these materials.

7.3.3.5 Animal-derived indicators

Few indicators from this category are seen at Tealing, with no features indicating dung. Bone is however present in all samples, albeit in small quantities. The slightly higher pH of the these soils may be the reason for this apparently better preservation, although of course this may also be a function of manuring history, with the proximity of the profiles to Tealing House perhaps providing a higher input of domestic refuse to these soils. The fact that bone is most frequent in woodland profile TE2, despite this profile having a lower pH than the arable profile, supports this interpretation.

7.3.3.6 Plant-derived indicators

As seen at Nairn, parenchymatic tissue, cell residue, and frequent small patches of amorphous organic material are frequent in especially the upper horizons of the Tealing profiles, testifying to a level of organic material entering the profile as a result of land cover – especially in the woodland profile. Again, this has implications for the interpretation of diatom and phytolith evidence. At Tealing, however, preservation of these features appears particularly good. Perhaps as a result of the lower levels of biological activity seen in these profiles, parenchymatic tissue and cell residue survive into the B horizon of all profiles, and therefore some of this material may represent relict indicators for manuring inputs. However, the denser, less excremental fabric seen in the Tealing samples itself presents a problem for interpreting plant-based indicators. Although more of this relict material may survive, the dense organomineral groundmass seen in the majority of slides make features such as diatoms and phytoliths difficult to spot, with only large, whole features easy to see (064).

Lignified tissue is seen in small amounts throughout, and is most frequent not in the woodland but the pasture profile. Several pieces of what appear to be charred or partially burnt lignified tissue are also seen – again, possibly as a result of the addition of domestic fuel materials to the profiles (065).

7.3.3.7 Material culture inclusions

Along with clinker, fired materials of a variety of types are a distinguishing feature of the Tealing sample set. As at Nairn, there appears to be no correlation between land cover type and the survival of these robust materials, with all samples (save that from the lower Ap2 horizon of woodland profile TE2) showing fired material inclusions in some form.

While identifiable pottery fragments are present – particularly in pasture profile TE3 – by far the majority of fired material seen at Tealing, as at Nairn, appears to be mortar of varying composition. This is less unusual for these less acidic soils, and the range of materials seen in this category from this semi-urban context may indicate that the Nairn soils, with potentially an even greater urban character to their input system, may have lost a significant proportion of these features as a result of decomposition.

The defining characteristics of the mortar-type features seen in the Tealing samples are their relatively low firing temperature (in oblique incident light, these fragments appear to have a considerably less highly heated matrix than those identified as pottery), their generally large, coarse inclusions (although this varies – see below) and the amorphous, crypto-crystalline, slightly cloudy grey to brown appearance of the matrix, which at high magnification is similar to that of the calcitic features seen both extant within the groundmass and in several of the clinker features discussed in Section 7.3.3.3 (066).

The variety of inclusions seen in these mortar fragments indicates that they may represent different types of building material. Most prevalent are fragments with relatively large, square or angular inclusions of mineral material, the sharp boundaries of which indicate that they may be derived from material deliberately broken up for use as temper (067; 068; 069; Plate 7.5). In oblique incident light, these inclusions are generally not rubified, indicating the low firing

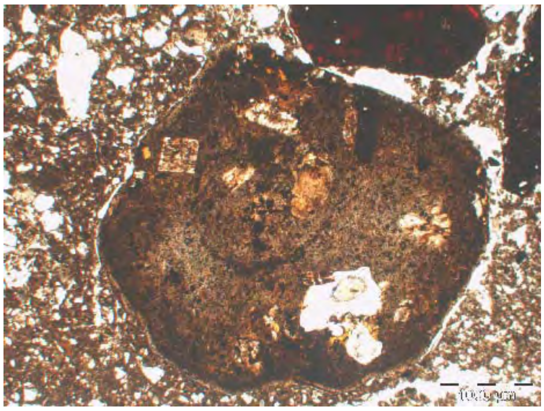


Plate 7.5: Image 9-67. Mortar fragment in arable profile TE1. Plane polarised light

temperature of the material as a whole (070; 071). Another, less frequent category of fragments show more irregular mineral inclusions, usually small pieces of weathered quartz, again generally non-rubified in oblique incident light. This use of apparently unprepared mineral temper may possibly indicate a distinctly different material type, possibly for use in a different medium (072; 073). Occasional fragments stand out as belonging to neither of these categories. A few appear clearly far finer in construction, containing very little mineral temper (074; 075), whereas some are extremely coarse, with temper consisting of larger rock fragments and even fragments of previously fired material (076; 077). This is seen at Nairn (Section 7.3.2.7). Most interesting is one large fragment from woodland profile TE2, which appears to contain a temper of angular fragments with a glassy internal structure which have clearly themselves been heated to a high temperature prior to incorporation in the mortar fragment (078; 079).

Identifiable pottery fragments are largely confined to pasture profile TE3, the nearest to Tealing House. These are fired at high temperature, and show a fine mineral temper consisting of small quartz grains (080; 081). Perhaps as a result of this relative fineness, they appear to have suffered greater disaggregation than mortar-type fragments seen in the same horizons (082, 083).

7.3.3.8 Pedofeatures

These are more frequent in the Tealing than the Nairn samples, and the majority reflect the processes of illuviation and particularly iron movement seen throughout all three of these imperfectly drained profiles. Weakly to moderately impregnated iron nodules are prevalent, especially in arable profile TE1, where they are also larger than those in the other two profiles, to a maximum of 4000 microns diameter. These tend to increase into the B horizons. Iron enriched mineral grains are also seen, and many larger rock fragments show signs of iron depletion, again particularly in arable profile TE1.

Clay coatings and infills indicative of illuviation processes are seen in all profiles; however, features of clay movement are largely confined to the B horizon of arable profile TE1. Here, a range of features are seen. Extensive, occasionally laminated channel coatings and infills of yellow to orange, clearly iron-rich limpid clay are seen at intervals through the horizon. These show frequent cracks and distortions, indicative of some physical disturbance (084; 085; 086). Non-laminated, amorphous infills of limpid to slightly dusty clay are also frequent (087). The structure and composition of these features indicate low-energy, down-profile movement of fine clays, probably as a result of water movement.

More interesting is the compound textural pedofeature seen in this horizon. This consists of a laminated coating of fine limpid clay, similar to those described above, superimposed over a relatively thick coating of silt-sized material (088; 089). The coarseness of the lower layer suggests that a more energetic phase of down-profile movement has preceded the illuvial clay deposition – certainly some kind of physical disturbance, possibly as a result of past agricultural activity. This is also possibly indicated by the relatively frequent organic void coatings and channel infills in this slide (090). These, along with several extensive organic coatings recorded further up the profile (091), stand out even within areas of dense groundmass. This is significant: while organic coatings are recorded from the majority of the Tealing samples, in most cases, they appear to represent a similar process to that seen at Nairn: most frequent in more biologically active areas, they are probably composed of the portion of organic material remaining in-situ after intensive reworking.

It is possible that the imperfectly drained soil at Tealing has provided an opportunity to assess the potential survival of textural pedofeatures in anthropogenic soils under different modern land cover types. Although showing similar signs of illuviation and iron movement in the form of iron nodules and depleted and enriched minerals, of the three profiles, only the less intensively reworked arable profile TE1 displays the more fragile structural indicators for these processes, namely clay coatings and infillings. Coincidentally, the equally fragile textural indicators for disturbance and cultivation also only survive convincingly in this profile. It is possible that, as noted for other indicators examined in this study, faunal reworking under woodland and pasture has acted to destroy these features more effectively. On the other hand, it is also possible that the particular drainage conditions of this profile have acted to create a series of features for which anthropogenic interpretation is possible. This is discussed further in Section 7.4.2.

7.3.3.9 Tealing: inputs and indicator survival

Although broadly similar to that seen at Nairn, the mixture of urban and rural manure inputs seen at Tealing appears more biased towards the urban, with an emphasis on the more ‘industrial’ carbonised materials of coal and clinker, construction materials such as mortar, and domestic refuse such as pottery and bone. Meanwhile, traditional ‘plaggen-type’ manures such as peat and turf are poorly represented.

This is in accord with historical accounts of the deep topsoil area. Although these make reference to ‘earth’ being used as a bulk manure material, turf is described as providing the main fuel resource for the area, making it unlikely that much of this material would have reached the dunghill without first having been used as fuel (Section 5.2.2.3). It is possible that the high proportion of ashed material seen in the Tealing samples is a reflection of this. Likewise, the variety of urban waste products seen in these samples accords with the description of this area in both county and parish-level accounts as receiving waste from urban centres such as Forfar and especially Dundee. However, the most significant factor in the manure input system seen in these samples is likely to have been the proximity of Tealing House, and the availability of the various waste products of the House economy, to the lands immediately around it.

As seen at Nairn, the effect of modern land cover on the survival of this range of indicator materials is variable. Generally, the survival of indicator materials identified at Tealing is good, apparently as a result of two factors: firstly, the less intensive biological reworking seen in the Tealing profiles, and secondly, the bias toward more robust inclusions such as carbonised and fired materials. However, individual observations support the conclusions reached at Nairn. Most striking is the complete absence of the more diagnostic textural pedofeatures such as clay and silt coatings in all except the arable profile which, as at Nairn, shows the fewest signs of faunal reworking. It would seem that despite a general absence of those features which seem most affected by land cover – peaty and turfy material fragments – the Tealing analysis supports the conclusion that the arable profile, with its less intensive disturbance, particularly at lower levels, is most conducive to indicator survival.

7.3.4 Study site 3: Unst

Thirty thin section samples were taken from four profiles at the Unst site: six from recently ploughed profile UN1, eight from relict ploughed profile UN4, and seven each from unimproved grassland profile UN2 and improved grassland profile UN3.

7.3.4.1 Mineralogy

The coarse mineral fraction of all four Unst profiles is similar, and distinctly different to that seen at both Nairn and Tealing. The coarse mineral fraction at Unst is less dominated by quartz and characterised by frequent large metamorphic rock fragments, chiefly mica schist, alongside a slightly weathered, fine to medium sand-sized quartz fraction. A slight difference is seen between the two grassland profiles UN2 and UN3, which appear to be more mineral dominated, and ploughed profiles UN1 and UN4, which, like the Tealing samples, show a denser fine organo-mineral groundmass.

7.3.4.2 Fine fraction and groundmass characteristics

The fine fraction and groundmass of the four Unst profiles show an immediate distinction between ploughed profiles UN1 and UN4, and grassland profiles UN2 and UN3. While ploughed profiles UN1 and UN4 show a dominantly dark to reddish brown, fairly dense organomineral groundmass, unimproved grassland profile UN2 and especially improved grassland profile UN3 show a mixed, turbated groundmass consisting of a range of brown to orange and light yellow organomineral material.

Despite this dense groundmass, ploughed profiles UN1 and UN4 also show higher faunal activity than UN2 and UN3, although this is a significant feature of all profiles. This is seen most clearly in more recently ploughed profile UN1, whose thick dark Ap horizons are seen at high magnification to be extensively reworked, consisting almost entirely of small, spheroidal faunal excrements.

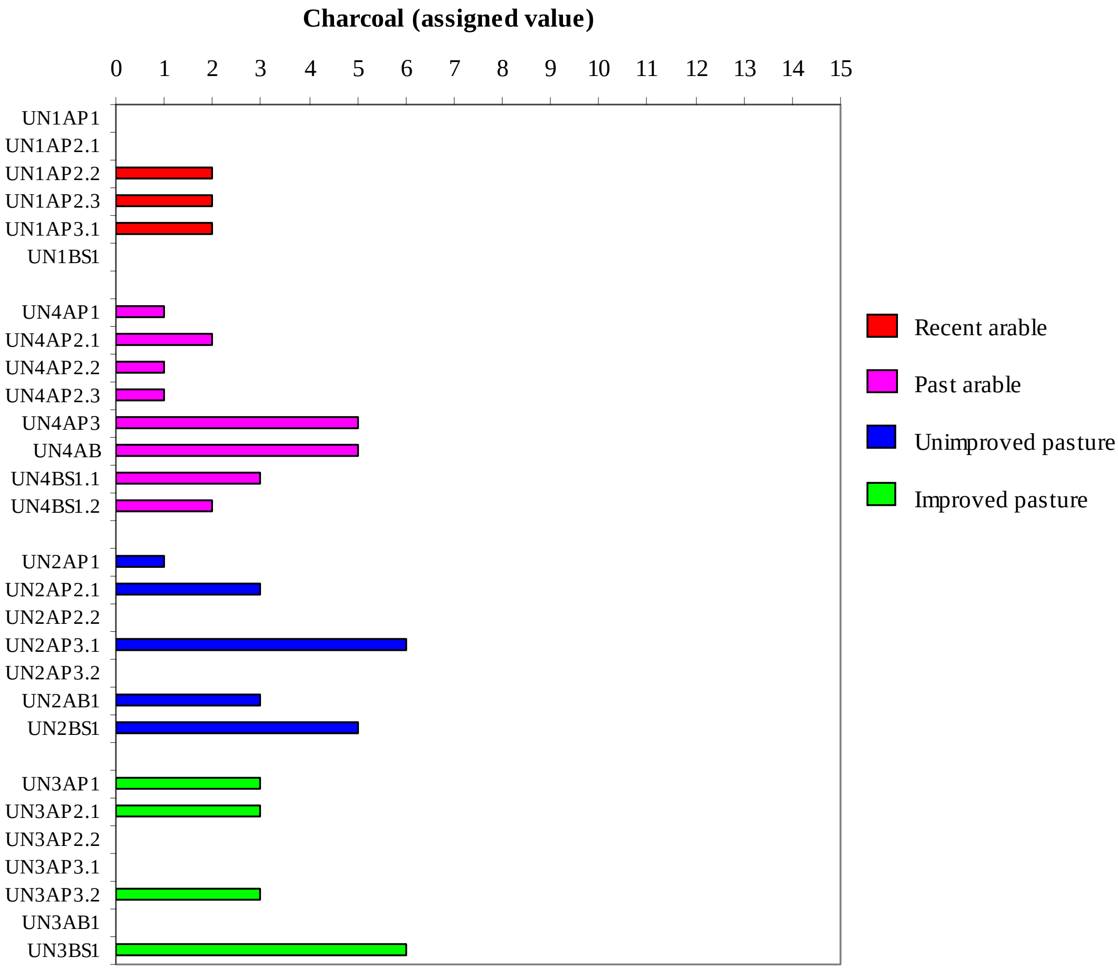
As seen at the other two sample sites, these varied intensities of faunal reworking correlate broadly with the levels of organic matter recorded from the bulk soil analyses, with ploughed profiles UN1 and UN4 showing a higher organic matter content than grassland profiles UN2 and UN3. As discussed in Section 6.3.2, as both profiles UN1 and UN4 are *relict* ploughsoils, and unlike arable profiles NA3 and TE1 have long been under constant grassland cover, that their organic matter status (and thus level of faunal reworking) are relatively high is to be expected. What is less explicable is the fact that these relict ploughsoils, especially in the upper horizons, show markedly *higher* levels of organic matter than grassland profiles UN2 and UN3, when past cropping may have been expected to slightly lower organic matter content. Section 6.3.2 posits that profiles UN1 and UN4 may therefore display a relict organic matter signature deriving from particularly intensive organic manuring of the infield area in which they are situated, and the darker, denser organomineral groundmass seen in both these profiles supports this view (as does the particularly high incidence of peat-like materials in these ploughed infield profiles – see Sections 7.3.4.3 and 7.3.4.4). However, this does not explain the fact that less recently ploughed (and therefore manured) profile UN4 shows a higher organic matter content than more recently ploughed profile UN1, which is also nearer to the North House croft (Figure 5.20).

Thin section analysis may explain this apparent contradiction. Although bulk soil analyses record a higher organic matter content for less recently ploughed profile UN4, it is profile UN1 which consistently shows higher levels of biological activity in thin section. It is therefore possible that more recently ploughed and more centrally located profile UN1 *does* represent the most intensively organically augmented profile, but that the correspondingly higher levels of faunal activity associated with this have affected this relict signature. That variations in the continuum of the cycle of amendment and cropping may affect relict signatures to different extents is not deducible from the sample set at either Tealing or Nairn, from which profiles showing the effect of a staggered cessation in cropping are not available, and where a simple, linear relationship between organic additions and faunal activity has been displayed.

7.3.4.3 Carbonised material and fuel residues

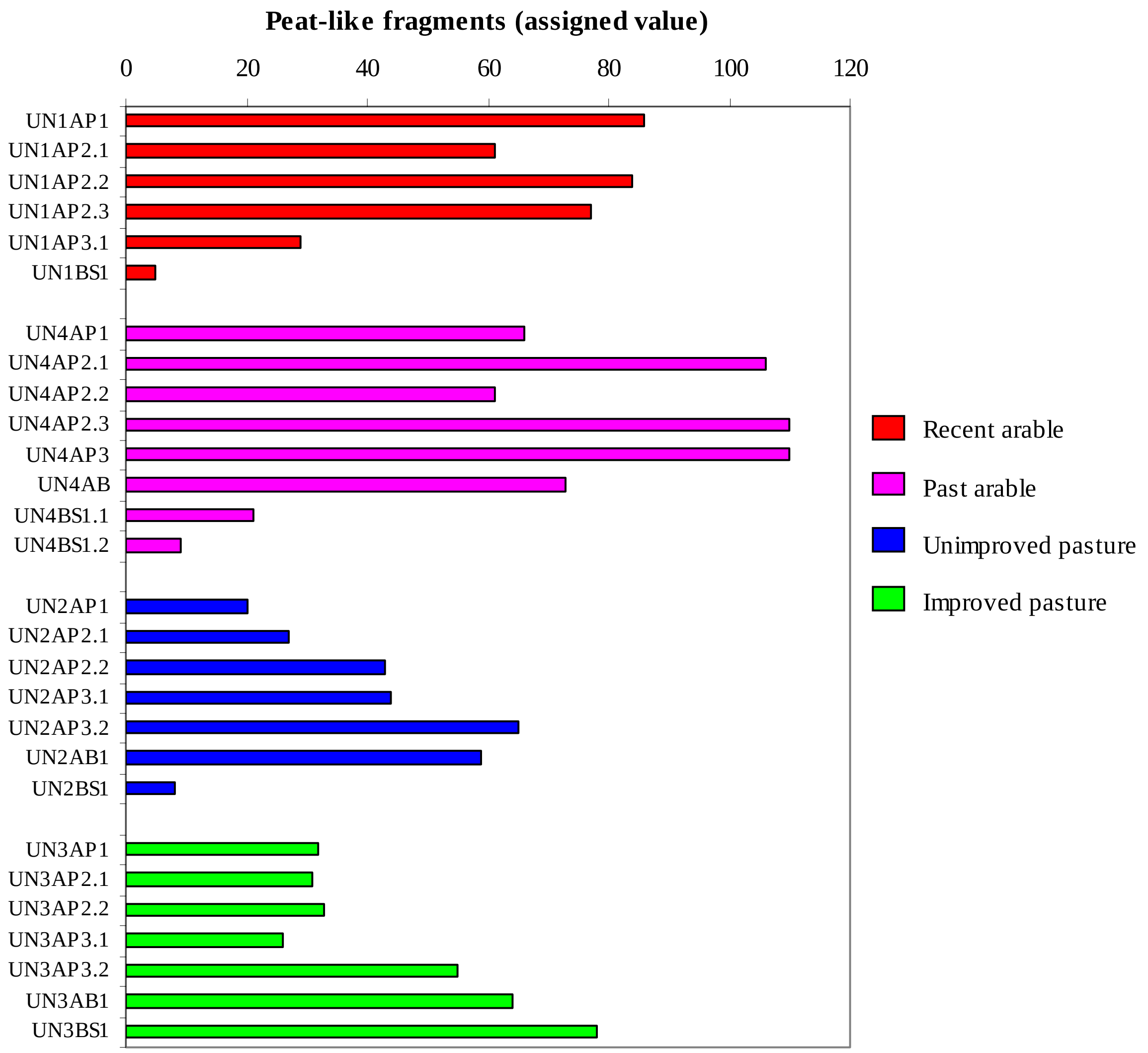
As seen at the other study sites, carbonised materials in their varied forms make up the largest and most diagnostic portion of the input indicators in the Unst sample set. Charcoal, however, is the least

Figure 7.8 Charcoal (over 500 microns) from the Unst sample set



frequent of these, with generally lower frequencies of identifiable charcoal over 500 microns in size recorded from Unst than from either Nairn or Tealing (Figure 7.8). There is also little patterning to the distribution of this, with variable amounts of charcoal seen in all four profiles. Neither is a relationship seen between charcoal presence and proximity to infield and croft-house: of the four profiles, the lowest charcoal amounts are seen in recently ploughed profile UN1. The relatively high frequency of charcoal in the lower Ap horizons and certainly the B horizon of unimproved grassland profile UN2 could, however, be related to the nearby Underhoull Viking House (Figure 5.20), although this is conjectural. Charcoal in all four Unst profiles is small and fairly fragmentary (092), with only occasional good survival (093). Little comment is therefore possible on either manure inputs or land cover effects using this indicator.

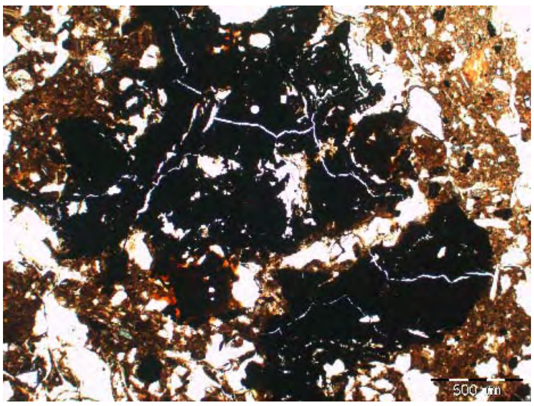
Figure 7.9: Peat-like carbonised material (over 500 microns) from the Unst sample set



Carbonised peat-like fragments, however, tell a different story. These, along with unburned peat fragments, are the most extensive category of indicator for manuring input seen in the Unst samples, and are present in every thin section (Figure 7.9). Here, a clear difference is seen between the ploughed profiles from the relict infield area and the grassland profiles, with consistently higher concentrations seen in the former, especially less recently ploughed profile UN4. However, the amounts of carbonised peat seen in all four of these profiles dwarf the amounts recorded from both Tealing and Nairn. They survive in a variety of sizes and shapes, from amorphous, loosely packed, often quite large pieces (occasionally over 1 cm in length) (094; 095; Plate 7.5) to smaller, rounded fragments with more closely packed fibres, possibly indicative of redeposition and/or disturbance (096; 097). Many fragments are clearly heated in oblique incident light (098; 099; 100; 101). Degrees of burning are also seen, with several amorphous brown peaty fragments (Section 7.3.4.4) showing burned and charred edges (102).

Varying degrees of degradation are seen within this category of fragments, with a large number of pieces seen partially disaggregated (103; 104). This creates a ‘sliding scale’ of identification, with evidence for small fragments of burnt peat, difficult to identify as discrete entities, seen throughout the organo-mineral groundmass (105). Interestingly, the majority of these more fragmented pieces of carbonised peat are seen in recently ploughed profile UN1, the most biologically active profile. It is therefore possible that this profile, the nearest to the croft and the most recently cultivated, may in fact have originally received the larger amount of peat-based manures, despite showing slightly lower concentrations than less recently ploughed profile UN4. In

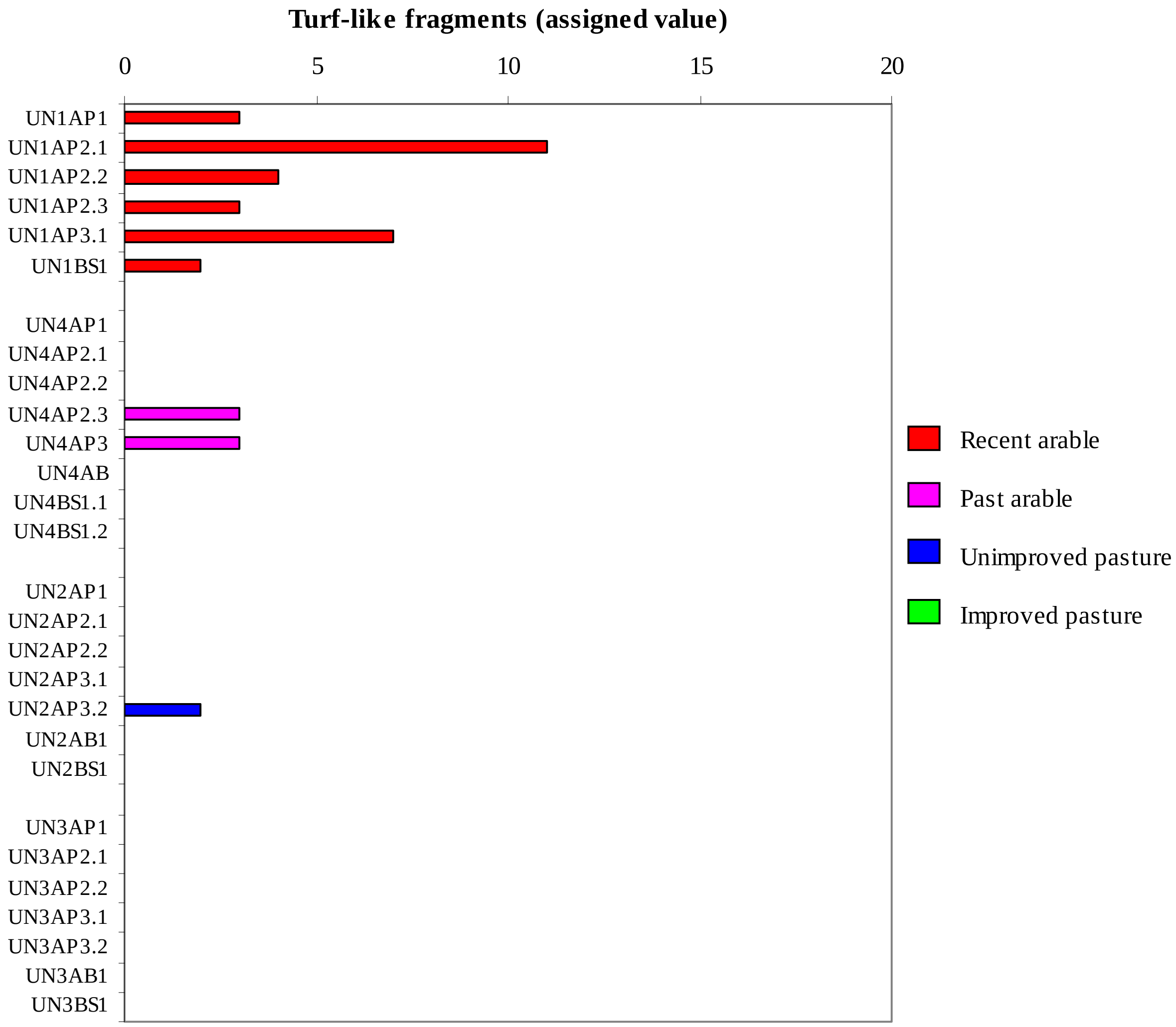
Plate 7.6: Burnt peat fragment in ploughed profile UN4. Plane polarised light



the grassland profiles, the down-profile distribution and frequency of carbonised peaty fragments is extremely similar, providing no distinction between the potential effect of unimproved or improved grassland on burnt peat survival, nor indicating any greater anthropogenic influence in, for example, profile UN2 nearer to Underhoull Viking House.

Carbonised fragments with a distinct mineral matrix and thus identifiable as turf are far less prevalent at Unst (Figure 7.10). Here, the distribution is almost entirely skewed towards recently ploughed profile UN1, with only isolated fragments seen in the lower Ap horizons of UN4 and UN2. Although this could be interpreted as a land cover influence, with a higher destruction rate for this indicator seen in the other three profiles, this is unlikely given the good survival of the structurally similar carbonised peat fraction, and the relatively good preservation of turf fragments seen in UN1 (106). It is more likely that this distribution illustrates a difference in manuring

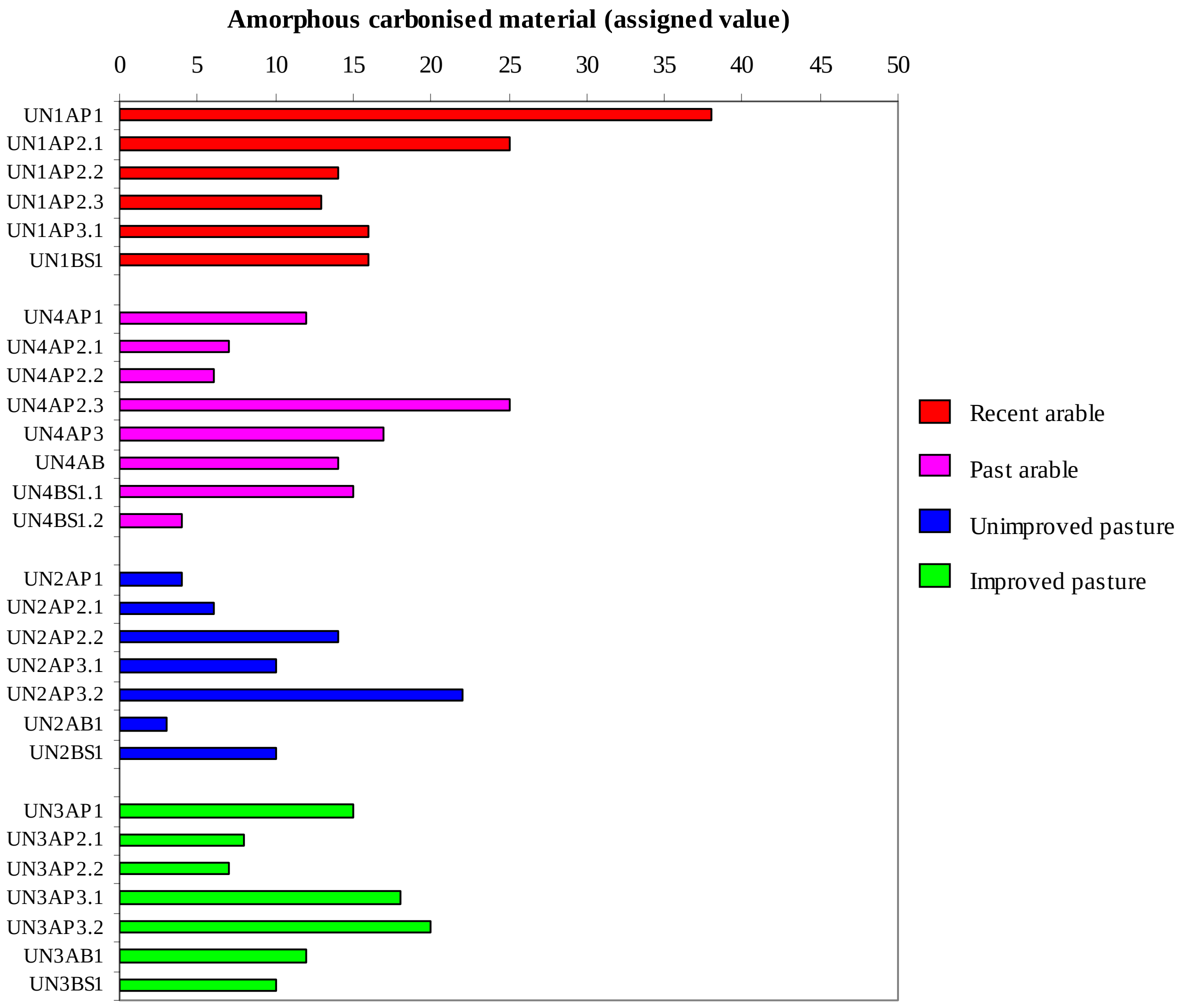
Figure 7.10: Turf-like carbonised material (over 500 microns) from the Unst sample set



strategy between areas, with turf manures used more intensively in the UN1 area. This is feasible: the proximity of profile UN1 to North House croft and its adjoining byre may mean that this profile has seen a more intensive input of the drier, more mineral-dominated turf material more suitable for use as stable litter than the peaty materials which appear to have made up the majority of bulk manures in the system. It seems that, even under the dual influences of long-term cultivation and current grass cover, the survival of these relict indicators is sufficient to inform upon specific strategies in the North House manuring system.

Amorphous carbonised material is, unsurprisingly, more frequent in the Unst sample set. Though less than that seen in the Tealing pasture profile, a reasonable amount is present in all samples. The topmost horizon of recently ploughed profile UN1 stands out here, with by far the greatest concentration of fragments. This perhaps lends weight to the earlier suggestion that this

Figure 7.11: Amorphous carbonised material (over 500 microns) from the Unst sample set



category of features (Section 7.3.2.3) is at least partly composed of disaggregated fragments of charcoal, peat and turf. The varied structure of the materials seen in this category in the Unst sample set supports this view, with many pieces having slight charcoal and especially peat-like features, though they cannot be securely identified as such (107; 108; 109). It appears likely that the large amount of amorphous carbonised material seen at the top of recently ploughed profile UN1 may reflect not only the more intensive faunal reworking seen in this profile, but perhaps also the destructive effect of the relatively recent ploughing episodes this profile has seen.

Unsurprisingly for this rural soil, coal and clinker-type features are absent from the sample set.

7.3.4.4 Bulk material amendment – peat and turf-type features

In contrast to the Nairn and Tealing sample sets, unburnt organic material indicative of bulk manure applications – peat and turf – is frequent in the Unst profiles. Although present in small amounts throughout grassland profiles UN2 and UN3 (110; 111), such indicators are significantly more frequent in ploughed profiles UN1 and UN4. Although less recently cultivated profile UN4 appears to show a slightly higher frequency of these materials than UN1, there is not a significant difference. It would seem that along with carbonised turf and peat, unburned additions of these materials were also a significant part of the manuring strategy at the North House croft.

However, using these materials to draw further conclusions as to the source of this organo-mineral bulk proves difficult. Few of the fragments seen in this category have either the density of mineral inclusions that would identify them as turf, or the distinctively fine, silt-sized mineral fraction which would identify them as peat, most falling somewhere in between. It would appear that without the increased density of mineral relative to organic material in turf as a result of shrinkage of the latter during combustion (Davidson and Carter 1998: 836), recognising unburnt peat from turf is difficult in these contexts. Rather, a large, variable category of ‘peaty turf’ is seen, characterised by a reddish-brown, fibrous structure and a generally small mineral fraction which nevertheless tends to contain isolated coarse minerals of medium to even coarse sand size (112; 113; 114; Plate 7.6). At higher magnification, however, the presence of frequent diatoms in these fragments indicates that the bulk of this material originates from a wetter context, and is thus probably closer to peat than turf (115; 116; 117; Plate 7.7).

Survival of these peaty turf pieces is relatively good at Unst, at least in the ploughed profiles. Although a proportion of the fragments clearly contain fungal sclerotia (119; Plate 7.8), there is little clear degradation seen. However, this is not to say that a comparative set of features in grassland profiles UN2 and UN3 have not undergone far greater decay. While this is possible, the lesser degree of faunal reworking seen in these grassland profiles, plus the apparently good survival within them of far more fragile indicator materials (Section 7.3.4.6), makes it more likely that this bias of peaty turf materials towards the ploughed profiles does indeed illustrate a localised manuring strategy.

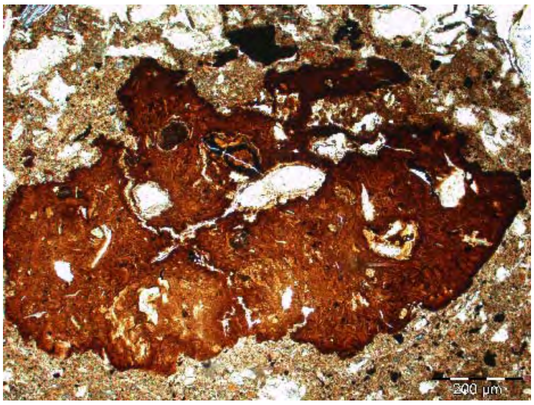


Plate 7.7: Peaty turf fragment in ploughed profile UN4. Plane polarised light

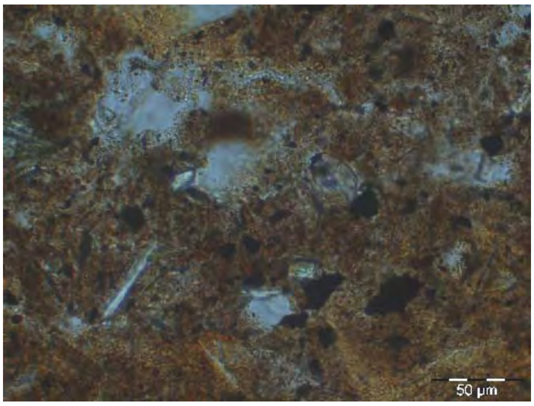
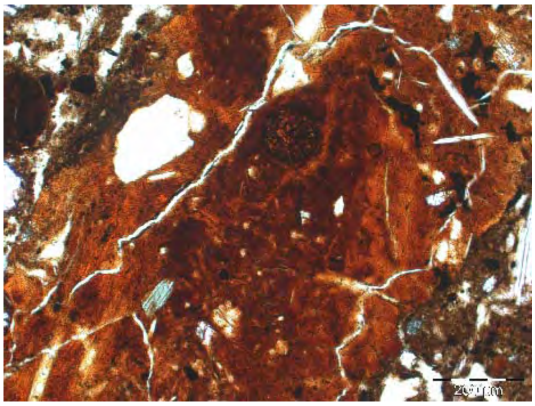


Plate 7.8: Peaty fragment showing diatoms in ploughed profile UN4. Plane polarised light

Plate 7.9: Peaty turf fragment containing fungal sclerotia in ploughed profile UN4. Plane polarised light



7.3.4.5 Animal derived indicators

This is a significant category within the Unst sample set. Bone is seen more frequently than at either Nairn or Tealing, despite the fact that the pH in the Unst soils is lower than either (Section 6.2.2). Although more frequent in the grassland profiles, there is no strong bias towards either of the two separate areas, with bone seen frequently throughout especially ploughed profile UN4. The majority of bone is either burnt (119; 120) or charred (121; 122; 123), which probably accounts for its good survival in these relatively acid soils. Rather, the bone degradation seen appears to be attributable to soil fauna (124).

More interesting are the several fragments, seen exclusively in improved grassland profile UN3, which have the characteristics of herbivore dung (Stoops 2003: Image 8-102). These are discrete areas consisting of a convoluted mix of light to dark brown organic fragments, which at high magnification are seen to be packed with phytoliths and diatoms and contain fungal sclerotia (125; 126). It is possible that these features are modern. The majority are seen at the top of improved grassland profile UN2, which at the time of sampling was used for grazing sheep (Section 5.2.3.5). However, similar features are also seen further down into the Ap2 horizon of the profile (127). The likelihood that relict features of this nature, recognised as particularly fragile in the soil environment (Section 7.3.3) may survive under the land use conditions seen in grassland profile UN2 is discussed further in the following section.

7.3.4.6 Plant-derived indicators

The variable distribution of plant-derived material – parenchymatic tissue, lignified tissue, cell residue - through the Unst profiles provide the clearest indicator for major differences in anthropogenic influence and possibly rates of accumulation existing between the two sets of soil profiles from this site.

For each of the categories of anthropogenic indicator discussed so far, the majority of material has been present in ploughed profiles UN1 and UN4. Thus, the characteristics of the two grassland profiles – unimproved grassland profile UN2 and improved grassland profile UN3 – have remained relatively undefined, as has their relationship to one another. This changes when the distribution and frequency of plant-based indicator materials is discussed. Profiles UN2 and especially UN3 are distinguished by the extremely high incidence of parenchymatic tissue, cell residue and amorphous organic material of similar origin distributed mainly throughout their upper horizons (128), while in ploughed profiles UN1 and UN4, these features are generally seen at a relatively low frequency.

This can be explained partly by their land cover type and recent use history. Both profiles are under constant vegetation cover and are intermittently used for grazing (Section 5.2.3.5). Although improved profile UN3 has in recent years seen some cropping activity, this has been in the form of hay removal, which necessarily leaves a much larger proportion of the cropped material behind as waste (D. Johnson pers. comm.) than is the case with the cereal cropping seen at Tealing and Nairn. These activities are likely to result in a large organic input into the profile in the form of both plant material and dung, and the rapid trampling and incorporation of this material into the soil profile, especially in profile UN3. Both profiles, but particularly UN3, appear to have upper Ap horizons consisting predominately of relatively recent, undecayed plant matter. The implication is that these uppermost horizons represent more recent processes of deposition and may not reflect a relict manuring signature.

This would appear to be supported by the distribution of indicator materials throughout the two profiles. While charcoal is relatively frequent in the upper horizons of improved grassland profile UN3, other carbonised material fragments - notably peat and amorphous material – show a steady increase in frequency down-profile through both of these pits. It would appear that overall, profiles UN2 and UN3 may only represent relict deep anthropogenic topsoils in their lower horizons. This is best illustrated at profile UN2 – adjacent to Underhoull Viking settlement, a considerable assemblage of anthropogenic indicators from this deep topsoil context might be expected. However, if a proportion of this deposition is more recent, the relative paucity of material seen in these horizons is explained.

Diatoms and phytoliths are present in most of the samples, though not frequently. The dense organomineral groundmass seen especially through ploughed profiles UN1 and UN4 make these features, as at Tealing, difficult to see. The majority of these features are therefore diatoms observed within lighter-coloured peaty material inclusions, and it is thus possible that the recorded frequencies for this category of feature are somewhat biased.

7.3.4.7 Material culture inclusions

Indicators in this category are rare in the Unst samples. No mortar or amorphous fired material is seen, and pottery is confined to a series of small, badly abraded fragments in the upper horizons of recently ploughed profile UN1 (129). These probably originate from the nearby North House croft.

An interesting feature of possibly anthropogenic origin is seen in the lower Ap horizon of unimproved grassland profile UN2, adjacent to Underhoull Viking House. This is an isotropic, crypto-crystalline material which has an internal structure characterised by large vesicles. Superficially similar to coal, it is a dull brown to grey in plane polarised light (130). This material is tentatively identified as pumice, which during the Viking period was used as an implement for rubbing and shaping materials (A. Forster pers. comm.).

7.3.4.8 Pedofeatures

Pedofeatures, with the exception of the excremental features previously discussed, are not a significant feature of the Unst samples. A degree of illuviation is seen throughout all profiles, and is represented mainly by iron nodules and occasional iron concentrations. This is seen most clearly in ploughed profile UN1 and UN4, where occasional iron-concreted roots and root pseudomorphs are seen (131; 132). A degree of clay movement is also seen, again indicative of illuviation processes. Small infills of limpid clay are seen throughout both grassland and ploughed profiles (133; 134), some of which infill peaty fragments and line groundmass channels (135; 136). Occasionally, these form more extensive, slightly laminated small coatings (137; 138). While small organic and occasionally silty coatings are seen, indicative of more energetic down-profile movement possibly resulting from cultivation disturbance, these are invariably small and fragmentary (139; 140). No variation in the survival of these features according to land cover type can be distinguished.

7.3.4.9 Unst: inputs and indicator survival

The range of indicators for manuring practice seen at Unst fully accord with what would be expected from a rural deep anthropogenic topsoil in this location, and echo those seen in similar contexts from elsewhere in the Northern Isles. Turf and especially peat, both burnt and unburnt, comprise the bulk of added materials to the soil, along with a small amount of domestic waste materials, chiefly bone. As expected, the Unst suite of manuring indicators is distinctly different from that seen in the more urban, mainland deep topsoil contexts examined at Nairn and Tealing.

The specific distribution of these features throughout the range of profiles sampled from the site also allows a more detailed interpretation of the local manuring system. The two profiles sampled from the infield area of the North House croft clearly indicate that peat-based material was the chief source of bulk manure, and thus soil augmentation, in the area. However, it would appear that inputs varied quite drastically even over this relatively small area (Figure 5.20), with profile UN1, adjacent to the croft house and byre, clearly receiving a substantial amount of drier, turf-based material almost entirely absent from the more distant UN4 profile. These findings support the historical evidence for manure production in Unst as described in the First Statistical Account (FSA V: 193).

Evidence from grassland profiles UN2 and UN3 further illustrate the very localised nature of this manuring system. Although very near to the North House infield, the range and frequency of manuring indicators seen in this separate deep topsoil polygon are distinctly different. With thin section evidence indicating that the uppermost horizons of this topsoil may be relatively recent, evidence from the desktop study presented in Section 5.2.3.2 – that this second deep topsoil polygon represents a much earlier period of cultivation, probably connected with either the Iron Age broch or Viking House at Underhoull - seems likely. If so, its manuring system appears to have had a different focus to that seen in the deep topsoils associated with the crofting settlement. However, with domestic refuse products such as bone slightly more prevalent in these grassland profiles, and far fewer identifiable burnt and unburnt peat and turf and fragments seen, the suite of manure indicators from these soils is closer to that seen in earlier, rather than later prehistoric anthropogenic soils from other areas of the Northern Isles (Section 2.4.2.1).

As seen at both Nairn and Tealing, indicators for the effect of modern land cover on the survival of manuring indicators in the Unst profiles are variable. Once again, overall survival of indicator materials is good, here even in the case of the more fragile organic unburnt turf and peat fragments, and likewise, where modern land cover appears to have influenced indicator survival, this is connected with faunal activity, traceable mainly to organic input from vegetation cover. At Unst, however, a more comprehensive series of relict soil contexts under the influence of constant vegetation cover allows a more sophisticated set of observations to be made. The extent of this likely detrimental faunal effect may, in the context of relict ploughsoils, be dependent not only on the levels of current vegetation cover, but also on the nature and intensity of previous organic additions to the profile, and even on the length of time since the cessation of cropping.

7.4 Micromorphology: evidence for cultural indicators

The generally good preservation of micromorphological features seen in all profiles from the three sample sites (Section 7.5) allows a comprehensive interpretation of the likely anthropogenic context of manure input at all three sites. From this, observations upon the outstanding micromorphological characteristics of Scottish deep anthropogenic topsoils can be made.

7.4.1 Anthropogenic characterisation

Although clear differences in the micromorphological character of each of the sites underlines the individuality of each of the topsoils studied (Section 7.4.3), in terms of anthropogenic context, the three sample sites separate clearly into two broad categories – those with a significant urban influence (Nairn and Tealing) and those of a predominately rural character (Unst).

Within both categories, the micromorphological indicators facilitating this characterisation arise not only from the (presumably) deliberate additions connected with soil amendment, but also – especially in the urban-influenced contexts – from the presence of those material culture indicators more usually associated with archaeological settlement, such as pottery and building materials.

At Unst, evidence for a manuring system familiar from deep anthropogenic topsoil contexts investigated elsewhere in the Northern Isles is seen, with the carbonised material fraction for both deep topsoil areas dominated by frequent carbonised peat-like and amorphous carbonised material additions. Further evidence for bulk manure addition of the kind described in detail in the historical source data (Section 5.2.3.3) is seen in the more recently (traditionally) cultivated 'crofting' deep topsoil area, with frequent burnt turf-like fragments seen in the profile closest to the croft-house byre. Bone and possibly even herbivore dung are seen, and pottery is limited to a few small, abraded fragments. No 'industrial' materials of the kind seen at Nairn and Tealing are recorded.

At the urban-influenced Nairn and Tealing, the picture is distinctly different. Fuel residues are frequent, and generally dominated by charcoal and amorphous carbonised material. At Nairn, a relatively high concentration of amorphous carbonised fragments under 500 microns in size is perhaps indicative of the likely urban context of much of this carbonised material: small-scale domestic waste transported out from the town. Meanwhile, both carbonised and unburnt material indicative of a peaty or turf-based origin is less frequent at both sites, indicating that neither turf or peat are likely to have been the primary mineral source for soil amendment at either Nairn or Tealing. Small inputs of burnt turf, particularly at Tealing, suggest however that when such materials *were* added, they tended to be as fuel residues.

More noticeable at both sites is the prevalence of material culture inclusions less typically associated with deliberate soil amendment strategies. Fired material inclusions of varying morphologies, representative of mortar-type materials, indicate that a range of building debris materials were added to these soils. Their presence into the B horizon at both sites may indicate that such additions were deliberate, perhaps as part of a strategy for soil amendment. Historical sources refer to the re-use of building material in this way (Section 3.3.7). More significant is the presence of 'industrial' waste materials. Seen most clearly at Tealing, this category mainly consists of the 'clinker-type' materials discussed in Section 7.4.3.3, but may - in the light of oral tradition concerning more recent industrial manure sources at Nairn – be broadened to include the coal fragments seen occasionally at both sites.

The micromorphological character of both the Nairn and Tealing samples strongly reflects the manuring information from both historical and oral accounts, and the interaction of these two sources of information allows the characterisation of these soils to go beyond merely 'urban' or 'semi-urban'. With historical sources for both areas suggesting that turf and peat were too valuable a fuel source to be used as manure prior to burning, the small but recognisable input of carbonised materials from these sources becomes explicable and, in light of this, the evident reliance of both input systems on a wider range of materials to add mineral bulk to the soils is logical. The question at both sites, then, may be: to what extent are these 'industrial' and 'domestic urban' inputs a reflection of pressure on more traditional bulk manure sources, or merely indicative of the nature of waste material available in these areas? With the deliberate incorporation of urban manures known to be a feature of the plaggen manuring system, the former suggests an interesting line of enquiry into the wider economic pressures governing the formation – and perhaps location of – deep anthropogenic topsoils in Scotland, and is discussed further in the following chapter. As regards the latter, it is interesting to note that, despite Nairn being considered the more 'urban' of the two sites throughout both desktop investigation and field survey, micromorphological study indicates that Tealing, probably as a result of its close association with the adjacent Tealing House, in fact has the greater input of 'industrial' materials (Section 7.4.3.9). As indicated through the research undertaken in the earlier sections of this thesis, the manuring systems governing the formation of deep topsoils in Scotland appear *strongly individualistic and localised* in nature, and are thus perhaps more representative of the availability of local waste for manure rather than of a recognisable, traditional 'system' of soil amendment. Even at Unst, where such a system is most clearly indicated, distinct differences in manure inputs into the two deep topsoil polygons appear traceable to the waste availability in their immediate vicinity.

7.4.2 Scottish deep anthropogenic topsoils: micromorphological characteristics

The study presented herein has, by examining the micromorphology of a series of Scottish deep topsoils in a range of locations and contexts, allowed the overall 'character' of these soils in Scotland to be explored. However, what has emerged is not a set of unifying characteristics, but a sense that what these soils have in common is their localised and thus very individualistic nature (Section 7.4.1), with micromorphological characteristics highly diagnostic of their local context of both fertiliser availability and choice of amendment strategy.

Micromorphological analysis has, however, highlighted an additional factor, identified by the historical research component of this thesis (Sections 3.3.3; 4.3.2.1): the potential role of fuel residue material in providing bulk mineral material for soil amendment. There is a strong indication in the historical source data that, with prohibitions existing in many Scottish regions on the cutting of both turf and peat for manure, fuel residue recycling may have played a vital role in channelling bulk material of this kind into the manure resource. In the study presented in this chapter, the most prominent and informative category of cultural indicators are those derived from carbonised materials. It would seem that if there is a unifying 'characteristic' of Scottish deep anthropogenic topsoils, comparable to the bulk composts so closely identified with the creation of plaggen manures on the Continent, then it may be this: that Scottish deep topsoils display a characteristically prominent fuel residue component which may at least partly be traceable to the wider economic situation during the immediately pre-Improvement period. However, that such a significant body of research into fuel residue materials already exists from previous studies into Scottish anthropogenic soils is indicative of the fact that such amendment is highly characteristic of not only the historic period, urban-influenced deep topsoils discussed herein, but also their prehistoric predecessors. Micromorphological analysis of these three very different deep topsoils therefore indicates that their cultural indicators may be indicative not only of the wider historic context of their formation, but also of a significant tradition of fuel resource recycling tracing to Scottish prehistory.

7.5 Micromorphology: the effect of modern land cover

Several indicators for the effect of modern land cover on cultural indicators in deep topsoils have emerged from this study. Already familiar from the archaeological literature (e.g. Millard 2001) is the effect of the more acidic of these contexts on bone preservation. With cultivation raising soil pH towards neutral, it can be argued that in typically acidic deep topsoils, the effect of cultivation may be beneficial for bone preservation. Although bone is present at all sites, this is mainly as small burnt fragments.

An issue more directly related to land cover is that of the interpretation of phytolith and diatom evidence in soils under current vegetation cover. It would appear that the provenance of these materials (Section 7.3.4) – may be compromised by the influx of modern equivalents, specifically phytoliths, into soils under (especially) current grassland cover.

However, the most significant effect of modern land cover on the soil cultural indicators in this sample set is one which appears closely linked to that identified in the bulk soil analyses: that of soil reworking through faunal activity, and the relationship of this with the decomposition of organic matter through the soil profile and thus, potentially, the validity of the relict soil phosphorus signature. All of the soil profiles examined in this study show the biological reworking typical of heavily manured soils, where repeated organic material additions have encouraged soil faunal activity (Section 7.2.2.3). However, organic matter status in the sample set overall appears to reflect not relict organic manure additions, but the influence of *modern* organic additions from current vegetation cover (Section 6.3.2). Given this, it follows that faunal activity – and the effect of this on relict cultural indicators - should be more intense in soils under current vegetation cover.

Towards the top of the soil profile, this has the potential to affect interpretation of deep anthropogenic topsoil contexts in two ways. As the excremental microstructure created through this cycle of organic amendment and biological reworking is itself considered a feature of manured soils, the augmentation of such activity through modern additions has the potential to affect geoarchaeological interpretation. On the other hand, the potential for such reworking to destroy other physical indicators for anthropogenic activity – such as fragments of peat or turf – may act to skew geoarchaeological study towards an under-estimation or misinterpretation of the extent and/or nature of anthropogenic influence.

Overall, this relationship between organic matter status and levels of faunal activity may mean that the excremental microfabric created by faunal activity makes the effect of modern organic matter addition on the relict phosphorus signature, discussed at Section 6.5.2, visible micromorphologically. Thus the *extent* of faunal reworking towards the top of a relict deep topsoil profile may have implications for the validity of soil chemical indicators throughout the profile.

The potential for this relationship to inform upon more detailed aspects of soil amendment is seen at Unst. At Unst, where all profiles are under current vegetation cover, more recently amended crofting profiles UN1 and UN4 show higher organic matter levels and faunal activity than less recently amended UN2 and UN3. The expression of a relict organic matter signature from the crofting profiles is suggested, and as this is also significantly higher than organic matter levels in the modern cropped profiles (Figure 6.12), the implication may be that at Unst, where traditional methods of organic manuring and spade cultivation persisted into the present day, a higher level of organic matter may have been maintained. But for closely related profiles, the complexity of organic matter decomposition and rates of faunal activity obscures this relationship. At Unst, UN1 shows lower organic matter levels than UN4, despite the former having more recent organic manure additions. In thin section, however, it is UN1 which shows the higher level of faunal activity, indicating that these more recent additions may have prompted increased biological activity and thus organic matter decomposition in the upper horizons of this profile. The extent to which organic matter status, and thus related chemical indicators for anthropogenic activity, may be reflected in the soil structure seen in thin section is a complex issue.

Despite these observations, it would seem that the overall effect of modern land cover on micromorphological indicators with the potential for informing on the character and context of deep anthropogenic topsoils (Section 7.4.1) is relatively small. Most significantly, this analysis identified no relationship between land cover type and the survival of the carbonised material indicators which, it is suggested, may prove the most informative and characteristic indicators for deep topsoils in Scotland. Material culture indicators such as pottery and building materials appear equally robust. The only casualties of these invariably biologically active soils are *non-carbonised* indicators for bulk manures, such as peat and turf fragments. A further issue for identification of such materials in reworked soils is their similarity to patches of un-reworked material within an excremental microfabric (Section 7.4.3.2). In summary, given the apparent significance of the carbonised material fraction to interpretation of the deep topsoils examined in this study (Section 7.4.1), the effect of modern land cover upon thin section indicators for relict cultural activity may not be a significant issue for Scottish deep topsoil research.

8. Conclusions

The research themes of historic contextualisation and geographical distribution applied in this thesis to the phenomenon of deep anthropogenic topsoils illustrate the degree to which the significant cultural resource held within these soils is linked to, and can inform upon, a wide range of issues relating to the development and change of the Scottish historic landscape. Recognition of the potential of this cultural resource to play a key role in the elucidation of this landscape cannot be claimed by this project. Indeed, it is the growing realisation of the potential significance of deep anthropogenic topsoils to both geoarchaeological and interdisciplinary landscape study that has provided the impetus for a project such as this to be undertaken: one attempting to embed the essentially passive aim of investigating the distribution and character of these soils in Scotland, and the effect of current land cover on the cultural properties of these soils, within a research project attempting to make active recommendation on a realistic conservation approach to this resource.

The complex research design through which these potentially conflicting retrospective and prospective approaches have been reconciled so as to present a project with a unified research agenda is introduced at the beginning of this thesis. The approach of this project to tackling the series of 'linked objectives' described in Section 1.3 has resulted in a structure within which each chapter can be viewed as a separate body of research, and as such, each of these chapters includes discussion and evaluation of the conclusions reached therein. This concluding chapter does not intend to reiterate these, but rather to consider the degree to which these research objectives have successfully converged to allow this project to achieve its two central aims – that of exploring the geographical distribution and historic context (and thus the geoarchaeological character) of these topsoils, and, using this information, to investigate potential strategies for their conservation under modern land cover.

The achievement of this project is evaluated through this chapter with reference to the various themes identified throughout this thesis as having an influence upon not only the development and distribution, but also the survival of deep anthropogenic topsoils in Scotland. These have proven to be the key to this project, providing an intellectual context through which not only the developmental mechanisms and historic character of these soils may be understood, but also the nature and survival under different land uses of the physical and chemical cultural indicators found within them.

8.1 Manuring: from inputs to historical context

The initial focus of this project upon historical research, undertaken with detailed reference to both contemporary archaeo-historical analysis and historical source data (Chapters 2 and 3), set the tone of this project, and immediately made a bold statement: that these soils should be approached by the geoarchaeologist as, first and foremost, not simply as repositories of scientific data, but historical artefacts. The practical application of this philosophy was to approach the question of deep topsoil distribution and frequency through investigating the historic context of *manure resource availability and use* in Scotland. The success of previous research into deep anthropogenic topsoils on the Continent, within which archaeo-historical and ethnographic research has played a large part in advancing understanding of the factors influencing development of these soils, supported this approach (Section 2.1). Likewise, a comparative review of the current state of research into deep anthropogenic topsoils in Scotland, which has so far been strongly focused on the prehistoric and generally approached from a site-specific geoarchaeological perspective (Section 2.4), amply illustrated the requirement for this research, in order to fully realise its stated aims, to move into a consideration of the wider development of these soils through the later historic period. A validation of this approach is seen in the consideration of current classification schemes for deep anthropogenic topsoils at the end of this chapter. Here, it is argued that the failure of current soil classification schemes to reach a consensus on anthropogenic soil categorisation may be traceable to an overall reluctance to take this historical context as a starting point for understanding their considerable variability. The stated approach of this project to this ongoing quandary can be found at Section 2.5.2: that, for deep anthropogenic soils, '*the primary factor in their classification, in both a historical and geoarchaeological sense, should be the nature of their inputs*.'

In Chapter 3, the research programme undertaken as the backbone of this 'input history' -

led approach saw the two sources of information on Scottish cultivation and manuring through the historic period separate quite clearly by the type of information they could provide. Highly informative as sources for tillage and cropping traditions were modern historical analyses and archaeo-historical investigations, with a valuable contribution made by recent archaeo-historical landscape survey (for example, the RCAHMS survey publications referenced throughout Section 3.2.2.1). Meanwhile, the most valuable, area-specific information on the nature of the Scottish manure resource and its varying availability and patterns of use came almost entirely from the two primary Scotland-wide historical sources used in this project, namely the County Agricultural Reports and First Statistical Account (Section 3.3).

The ability of these different source types to combine to provide a comprehensive illustration of the agricultural situation in Scotland through the pre-Improvement and immediately post-Improvement period offered a glimpse of the potential for detailed historical sources of this kind (Section 4.1.2) to complement the current move within Scottish archaeological research towards a more holistic and landscape-oriented approach to understanding patterns of rural settlement and cultivation. This in-depth analysis of the historic context influencing the formation of medieval and later Scottish deep topsoils provided a solid basis for the manuring database constructed and evaluated in Chapter 4. Nevertheless, the historical investigation undertaken throughout Chapter 3 provided the first illustration of what was to become a key issue throughout the project: that even the most finely-resolved historic period source data could not penetrate to the localised, even site-specific context of manuring strategy, the visibility of which – as shown through the desktop archaeo-historical studies undertaken for the selected survey sites (Chapter 5) and further illustrated through the analytical programme (Chapters 6 and 7) - is vital in identifying the potential for deep topsoil development in individual locations. It transpired that this first objective – to define and characterise manuring practices throughout Scotland and their geographical variation (Section 1.3.1) – created a body of research which, although immensely valuable in identifying *general* patterns of soil amendment throughout Scotland, remained one step removed from indicating the location of the topsoils themselves. The limited success of the manuring database as a ‘tool’ for locating deep anthropogenic topsoils in Scotland can partly be traced to this (Section 8.5.1).

8.2 Distribution and frequency

Although not providing an historic-period ‘map’ for the location of deep anthropogenic topsoils, the historical research undertaken for the first objective of the project and its incorporation into the spatial database of the second objective instead made an arguably more valuable contribution to our understanding of Scottish of deep topsoil distribution and frequency. Chapters 3 and 4 identify and evaluate a series of key issues, products of the interaction of specific cultural, environmental and geographical factors, which, it is posited, hold the key to understanding the nature of deep topsoil development throughout Scotland. These factors, and their exploration through both the manuring database and survey programme, are revisited below.

8.2.1 Factors influencing the distribution and frequency of Scottish deep anthropogenic topsoils

The treatment of turf and similar bulk manures in the Scottish manuring system. Discussed in detail in Section 3.3.3, the identification in the historical record of a widespread prejudice against the stripping of turf for manure provides the strongest evidence refuting the existence of a extensive, well-organised ‘plaggen-type’ manuring system of the kind seen on the Continent, and appears likely to have been perhaps the most important limiting factor in the development of deep anthropogenic topsoils in Scotland. Exploration of this through the manuring database confirmed that evidence for the plaggen-style composting of turf and related bulk material such as peat for manure is limited in the Scottish historical record (Section 4.2.2.1). However, it would appear that, despite the restrictions placed upon the specific removal of turf for manure, bulk mineral material from both peat and turf sources *was* an important manure source in historic-period Scotland, but one typically channelled into the soil through the recycling of turf-based building materials and, particularly, the residues of peat and turf-based fuel sources. This latter observation is amply borne out through the micromorphological analysis undertaken for this project, within which carbonised fuel resides are found to be the most extensive and ubiquitous category of cultural indicator present in the sample set. Despite this presence of a certain amount of bulk material, with studies from the Continent reporting that a plaggen compost would typically contain as much as six times more turf or earth than dung (Stoklund 1999: 210) it is concluded that even a regular supply of recycled bulk mineral material entering the manure supply would be unlikely to result in the development of a deep anthropogenic topsoil.

The exploration of the dynamics of turf use through the survey programme was largely indirect, with the assumption that bulk manure additions of this nature would be a prerequisite to deep topsoil formation countered by the very limited amount of direct historical evidence for such additions within the manuring database. Of the deep topsoils identified, only that at Unst provided direct historical evidence for the use of composted turf and the existence of a manuring system comparable to that of the plaggen regions (Section 5.2.3.3). Nevertheless, the identification of five identifiable – with small deep topsoil areas identified at both Ruaig in Tiree, and at Dundrennan - and three extensive deep anthropogenic topsoil sites within areas of historic period cultivation in a variety of both mainland and island areas testifies to the fact that bulk manure additions, in whatever form, were certainly entering the Scottish manuring system in large enough amounts to create augmented topsoils in certain areas throughout this period of restricted turf use.

The role of seaweed manures in limiting bulk manure use in coastal areas. The widespread preference for seaweed in place of dung and certainly bulk manures reported in historical sources from the majority of coastal areas is discussed in Section 3.3.5. Again, the potential influence of this on the development of deep anthropogenic topsoils in Scotland is explored in Chapter 4 using the manuring database (Section 4.2.2.2). It would appear that the perceived superiority of seaweed as a manure for sandy coastal soils may have limited the development of deep topsoils in – significantly – many of the more marginal Scottish areas within which bulk manuring systems might traditionally have been expected to flourish. This was explored further in the Tiree survey (Section 5.2.4), and indeed, survey through the larger township areas of this historically fertile island confirmed that augmented soils were almost absent.

Here, an interesting contrast with the situation in the Continental plaggen areas is seen, and one which illustrates the potential importance of the interaction between geography, environment and available resources in influencing the development of deep anthropogenic topsoils. Evidence from historical sources dovetails with our knowledge of soil geography in these areas to reveal real differences in the dynamics of marginal farming in coastal Scotland compared with that of the plaggen regions: despite superficially comparable situations, the frequent availability of seaweed around the rocky Scottish coast, and the suitability of this particular resource to local soil conditions, appears to have allowed Scottish farmers to successfully cultivate light and sandy soils without recourse to the intensive manuring systems used by Continental farmers to sustain cultivation on similar soils: in fact, to choose to avoid a bulk manuring technique altogether.

Land division, cultivation and cropping patterns and the opportunity for bulk manure creation. The investigation into patterns of cultivation and manure availability in both inland and coastal Scottish farming townships (Section 3.2.2.3) strongly indicates that deep topsoil creation was likely to have been viewed as neither important nor easily achievable. Historical evidence suggests that where bulk manure additions can be identified in the Scottish system, these seem to be added for the sake of maximising a generally insufficient organic manure resource (Section 3.2.2.3). In addition, specific cultivation methods commonly employed throughout much of Scotland in the historic period – in particular, ridge and furrow cultivation (Section 3.2.2.1) and lazy-bed construction (Section 3.2.2.3) testify to a widespread tendency to create sufficient topsoil depth for effective crop growth not through soil amendment, but through localised systems of soil redeposition. Although outside the scope of either the manuring database or survey programme to explore, it is likely that these would have been significant factors militating against the development of deep topsoils in both marginal and intensively cultivated Scottish regions.

These observations, and the extent to which they are borne out in the survey programme and especially the spatial analyses undertaken through the manuring database, lead to the central conclusion to emerge from the first part of the thesis: ***that deep anthropogenic topsoils are very likely to be relatively rare in Scotland***.

However, more positive observations were also to emerge from both the historical research and, especially, the findings of the survey programme. While not directly relating to the question of *frequency* of these soils throughout Scotland, the interaction of these research objectives identified two additional factors potentially significant for their influence on the *patterning* of Scottish deep topsoil distribution. These are revisited below.

The potential significance of outside cultural influences in the formation of Scottish deep topsoils. The identification of a potential deep anthropogenic topsoil site apparently in association with the monastic centre at Dundrennan highlighted the potential significance of introduced agricultural practices to the location of deep topsoils in Scotland, a link already noted at other Scottish deep topsoil sites such as Marwick and Fearn Abbey, and one currently under investigation through geoarchaeological research into areas colonised by early Christian missionaries - the '*papar'* (Section 2.5.3). Although exploration of this hypothesis regarding deep topsoil distribution was beyond the scope of this project, it raises issues with a bearing upon our approach to the study and conservation of deep anthropogenic topsoils in general. Such possible correlation between deep topsoil occurrence and *specific* cultural influences indicates that areas of human-modified soil can act not only as repositories of geoarchaeological information, but may also represent cultural pointers of the kind normally associated with standing archaeological remains or material culture indicators, and further emphasises the need to investigate these soils from a multi-disciplinary perspective.

The potential significance of patterns of urban settlement on the formation of Scottish deep topsoils. Although not strongly indicated by the historical research programme, the correlation between areas of deep topsoil and urban influence was a key feature of the survey programme, with two of the three sample sites from an urban context. Micromorphology offered further refinement of this observation. Although an 'urban' micromorphological signal was expected from Nairn, it was actually the more ostensibly rural Tealing site which showed the higher concentration of typically urban fertiliser and bulk amendment inclusions (Section 7.4.1). It is concluded that, for the historic period in Scotland, patterns of disposal of the large-scale mineral wastes associated with intensive human activity – not only of 'nightsoil' and the like, but also industrial and building wastes - may be a significant factor in the distribution of deep anthropogenic topsoils throughout Scotland. Furthermore, as the Tealing site shows, these need not be the product of a large urban centre. The amount of, especially, industrial-type wastes need not reflect the physical size of the activity area, and a smaller locality may be able to provide just as intensive an input of this kind, creating a *localised* area of deep topsoil.

This last leads us to the second conclusion to be reached through the objectives undertaken for the first aim of this thesis: that the distribution of deep topsoils throughout Scotland appears likely to be dictated by ***localised patterns of manuring strategy, creating a deep topsoil resource which is highly individualistic and also highly reflective of local patterns of agricultural activity and waste disposal***.

8.3 The impact of modern land cover and use

The second aim of this thesis – to investigate the impact of land cover and modern agricultural activity on the retention of cultural information in Scottish deep topsoils – was undertaken through an analytical programme which combined bulk soil analyses – of pH, organic matter, and total phosphorus content – with micromorphological analysis for each of the soil horizons identified within each sample profile. The results of these analyses and a discussion of their significance are presented in Chapters 6 and 7.

Clearest evidence of the effect of modern land cover on the relict soil signature was provided by the bulk analyses. The most significant and most detrimental of these was the strong correlation between the presence of current vegetation cover (in the form of either pasture or woodland) and the influx of considerable amounts of modern organic matter. While the potential for this influx to swamp a relict soil organic matter signal resulting from manure amendment was noted, the more pernicious effect of this input of modern organic material appeared to be its potential to affect the survival of the relict phosphorus signature, the soil chemical indicator most widely utilised to identify past anthropogenic activity (Section 6.5.2). By contrast, profiles under current arable cultivation appeared to show less of a down-profile movement of this modern organic matter input, a feature ascribed to the effect of cropping in removing surface organic matter prior to decomposition (Section 6.4.2). The potential for arable cover to thus offer a degree of protection to relict organic matter and phosphorus signatures is discussed in Section 6.5.3.

Evidence for the effects of modern land use and cover were less well expressed in the micromorphological analysis, with the only clear relationship between land cover type and micromorphological character being the increased levels of faunal activity – itself connected to organic matter status – seen in the profiles under current vegetation cover. This is interpreted as a positive result in terms of the survival of micromorphological indicators for past anthropogenic activity under modern land cover. With each of the deep topsoil sites displaying a wide range of features showing good preservation – especially the carbonised remains already highlighted as potentially the most significant category of cultural indicator for Scottish deep topsoils (Section 7.4.2) – it would appear that modern land cover may not be a significant issue for the survival of the relict micromorphological cultural signature.

Paradoxically, the clearest indication of the potential negative effect of modern land use on the survival of deep anthropogenic topsoils appears to have emerged not from the analytical programme, but from the success of the project's earlier investigations into patterns of deep topsoil distribution. The strong association between urbanised or semi-urbanised areas and deep anthropogenic topsoils identified through the survey programme and further confirmed through micromorphological analysis makes it highly possible that urban development, particularly in areas within and immediately surrounding long-established urban centres, may in fact be a more serious threat than vegetation cover to the net survival of what has already been established as a potentially limited deep topsoil resource.

8.4 Conserving the Scottish deep topsoil resource

8.4.1 Challenges arising from current policy

The consideration of current policies concerning Scottish land use change and management presented in Section 1.1.2 highlighted two factors which, in the light of the outcomes of this project, would appear to be in conflict with the aim of deep topsoil protection and preservation, and thus the increased understanding of the place of these soils to the understanding of Scotland's historic landscape.

These are, firstly, the ongoing strategy for establishing new native woodlands throughout Scotland. Constant vegetation cover of this kind has been highlighted by the analytical component of this thesis as potentially damaging to the relict cultural signature held within deep anthropogenic topsoils, and thus the stated aim of the Scottish Executive - that woodland cover rise from its current 19% coverage to 25% within the next fifty years (Yarnell 2003: 84) – is potentially at odds with the aim of deep anthropogenic topsoil conservation.

An additional and related concern of perhaps particular importance to the Scottish historic landscape is the changing pattern of land use and management upon land parcels traditionally associated with the crofting regime. The correlation between long-established infield areas and deep anthropogenic topsoils examined in Section 3.2.2.2 suggests that a disproportionate percentage of the 'rural' deep topsoils of the kind identified at North House, Unst (Section 5.2.3) may be under especial threat. While the traditional pattern of light cropping upon these land parcels has been indicated by the analysis undertaken herein as potentially beneficial for deep anthropogenic topsoils, the modern crofting economy relies more heavily upon sheep grazing, with limited cultivation undertaken with extensive use of artificial fertilisers (Grantham 1996). A potentially more serious issue for deep topsoil conservation in marginal areas of this kind is diversification, notably into forestry, which is promoted as a way for farmers in these historically marginal regions to maintain economic viability (Forestry Commission Scotland 2006: 32). The aim of the Crofter Forestry Scheme to facilitate the establishment of woodland in the crofting regions is a point of particular concern for deep topsoil survival in these significant historic landscapes (Section 1.1.2).

Unforeseen at the beginning of this research project, urban encroachment has also been highlighted as a potentially serious threat to the deep anthropogenic topsoil resource in Scotland. Although there is a presumption within planning policy to protect the ‘green belt’ when urban development is considered (and certainly areas of archaeological importance) recent planning policy confirms that, where there is a ‘demonstrable requirement’ for additional housing, green belt boundaries adjacent to urban areas may be released for development (Scottish Executive 2003: 8-9) – i.e., those areas identified by this study as those most likely to show urban deep anthropogenic topsoils. Sympathetic development of such areas is unlikely to mitigate its negative effect on the deep topsoil resource: such initiatives can include, for example, the establishment of woodland in and around new-build development to act as a ‘screen’, as proposed within the Forestry Commission Scotland’s ‘Scottish Forestry Strategy’ for 2006 (Forestry Commission Scotland 2006: 31).

8.4.2 Solutions and strategies

In light of the above observations, what approaches to facilitate deep anthropogenic topsoil conservation can be suggested for the Scottish landscape?

With several key issues for deep topsoil conservation identified by this research focusing on the agricultural sector, it is the opinion of this project that the recent reforms to the Common Agricultural Policy (CAP) as applied to the Scottish landscape may provide a key opportunity to raise the profile of deep anthropogenic topsoils, and other historic soils, within the agricultural community. Introduced from 2005, the CAP ‘Single Payment Scheme’ requires farmers to meet a series of requirements for financial support which embrace a range of social and environmental issues. A key part of the CAP reform package has been the introduction of GAEC – Good Agricultural and Environmental Condition – measures. Many of these directly relate to soil care, with issues such as soil erosion, soil structure and organic matter status highly prioritised (DEFRA 2006), and, as a result, measures which have been identified by this project as of significance for the survival of deep anthropogenic topsoils are now the subject of government policy. Particularly relevant are those aimed at preserving the ‘status quo’ of soils under agriculture, such as the use of specific cultivation methods to avoid soil erosion, the maintenance of soil organic matter at levels matched to the needs of the crop, the avoidance of buildup of materials such as plant litter, and the protection of areas of rough grazing through controls on fertiliser application, including lime (Scottish Executive 2006: 22-31).

Complementing these reforms, and with particular import for the historic environment, is the Land Management Contract scheme. Devised as a means of encouraging farmers to respond further to the social, environmental and cultural issues now prioritised by the Single Payment Scheme and thus qualify for additional financial assistance, audits for Land Management Contracts include an assessment of 'cultural heritage resources' within the area in question, and care and maintenance of these forms a key part of the Contract (*ibid*.).

The provisions for soil care and consideration of the historic environment provided by this legislation may offer a sound baseline for highlighting the conservation requirements of deep anthropogenic topsoils and, more importantly, for devising strategies for their protection which not only complement GAEC initiatives but also address the potential conflict of interest for archaeologists discussed in Section 6.5.2. Here, it is observed that the most effective strategy for conserving the cultural information retained in areas of relict deep anthropogenic topsoil is a reduction of the impact of constant vegetation cover, most obviously by maintaining light cultivation activity. However, with plough disturbance recognised as a major cause of damage to structural archaeological remains (Section 1.1.1), preservation strategies for the historic landscape generally take the position that ploughing has a negative effect on the burial environment. A deep topsoil conservation strategy most likely to be successful in a practical and academic sense is one which takes into account these other concerns within historic landscape management. Within the structure of a Land Management Contract, an holistic approach to such issues could be devised, such as the encouragement to place known areas of deep topsoil not immediately adjacent to structural archaeological remains into, for example, a hay cropping rotation (likely to be successful for these typically fertile areas of land and one already in action in, for example, both Tealing and Unst (Sections 5.2.2.5; 5.2.3.5) and, most particularly, to protect deep topsoil areas from afforestation. Thus, the Land Management Contract Scheme could be seen to have the potential to expand on the more reductive elements of current legislation for archaeological remains, allowing the more 'hidden' element of the historic landscape represented by deep anthropogenic topsoils to be conserved - appropriately, under the aegis of the agricultural environment through which they were created. Here, the issue of continuing cultivation in known areas of cultural significance is addressed, highlighting the paradox at the heart of anthropogenic soil preservation - that strategies for arable change and development have themselves contributed to the formation of these soils, and to aim to preserve anthropogenic topsoils 'in aspic' is both impossible and a misunderstanding of their place in the development of the historic landscape. This more 'landscape-based' approach to management of the historic environment *within* agriculture offers up a policy of 'joined-up thinking' which fits neatly into the remit of the Soils Action Plan to consider soils as '*part of the totality of landscape and the broader historic environment*' (DEFRA 2004: 26).

To use *soil care* as a starting point for such strategies also has the potential to act as a conduit for dialogue between archaeology and other environmental bodies, facilitating understanding of the place of anthropogenic soils within the cultural landscape, and therefore potentially greater protection for these fragile resources. The potential for this to succeed is high: to use an example perhaps most crucial for deep anthropogenic topsoil conservation, the Forestry Commission Scotland's 2006 revision of the 'Scottish Forestry Strategy' identifies the need to '*recognise local landscape characteristics and geodiversity*' as a part of the commitment to maintain environmental quality, and cites the integration of '*online historical, landscape and environmental data sources*'- such as the Historic Landuse Assessment - as a way of achieving this (Forestry Commission Scotland 2006: 43-44).

The net result of such initiatives may be to facilitate the development of 'care plans' for significant archaeological landscapes similar in spirit to the Habitat and Biodiversity Action Plans (Scottish Biodiversity Forum 2004) which have proven such a useful model for not only raising awareness of, but also attracting government funding for sensitive environments within the natural heritage sphere (Wordsworth 2003). With limited resources available to undertake intensive, interdisciplinary research at the scale required to investigate historic landscapes such as that seen at, for example, Ben Lawers (Turner 2003), such strategies could prove invaluable in safeguarding the cultural information held within deep anthropogenic and other historic soils within their associated landscape context.

The issue of the spread of urban development and its potential effect on deep anthropogenic topsoils presents a thornier problem. Here, raising the profile of such ‘invisible’ features of the historic landscape as deep anthropogenic topsoils and bringing these to the attention of scheduling and preservation strategies would appear to be the only solution. That said, the success of this project in characterising the deep anthropogenic topsoils selected for study gives rise to the suggestion that for deep anthropogenic topsoils located within development areas, excavation and recording may be an entirely appropriate and highly informative means of conserving the cultural information they retain. It is suggested that auger survey to identify deep anthropogenic topsoils could be built into the early stages of developer-funded archaeological projects of this nature at a relatively cost-effective level, and, should deep topsoils be identified, the excavation of one or more soil pits for bulk soil and micromorphological characterisation could provide a level of information on the cultural history of that soil comparable to that seen within this project for comparatively small financial outlay.

8.4.3 The archaeological sector

One of the key conclusions of this project has been the individualistic and localised nature, and therefore the archaeological ‘uniqueness’ of each deep anthropogenic topsoil within the historic landscape. It therefore follows that a ‘one-size-fits-all’ approach to understanding and conserving these soils is unlikely to be appropriate. These observations are of interest to both the archaeological research and commercial sectors: in Scotland, it would appear that the presence of a deep anthropogenic topsoil within the landscape can mean the presence a real body of site- and settlement specific cultural indicators, rather than the general indicator for ‘intensive manuring’ that a deep topsoil may be presumed to represent.

It is argued that the approach taken by this thesis – particularly the focus upon historic contextualisation and the creation of a spatial tool with the potential for further development within the heritage management sector - will allow this project to be more usefully assimilated into, and utilised by, interdisciplinary research programmes currently active in Scotland with the stated aim of improving understanding, and thus raising awareness, of the relict Scottish rural landscape (e.g. Atkinson and Banks 2000; Carver and Lelong 2004). As stated in Section 1.1.3.1, it is as a result of this body of strongly survey-focused research that the scheduling of anthropogenic soils has been suggested. It is possible that the incorporation of anthropogenic soil conservation into agricultural Land Management Contracts, as suggested in Section 8.4.2, may offer scope for further co-operation between the research and heritage management sectors as regards this issue, and facilitate the extension of research programmes focused on the Scottish rural landscape. In addition, the predominantly urban context of the deep anthropogenic topsoils identified through this research project indicates that research programmes with a more urban focus may also benefit from a consideration of anthropogenic soil location and context, such as the Scottish Burgh Surveys. Such desktop-based research could prove invaluable in the building of deep anthropogenic topsoil study into the evaluation stage of developer-funded archaeological excavations.

8.5 Project methodologies: evaluation and suggestions for further work

Given the observations presented above, both in terms of likely threats to the deep topsoil resource and suggested approaches to mitigate these, this chapter concludes with an assessment of the perceived success of the methodologies adopted by this project, the advances made by each of these towards addressing the issue of deep anthropogenic topsoil conservation, and suggestions for future work featuring aspects of these methodologies.

8.5.1 The manuring database

The limitations of the various data sources utilised for the creation of the manuring database are discussed in Chapter 4. Specifically, these relate to problems of coverage – particularly that of the historical First Statistical Account dataset with regard to records for manuring practice, and that of the Soil Survey record, with regard to preservation of its (also ‘historic’) datasets informing on topsoil point depths. This is recognised as an unavoidable limitation of data of this nature. However, as discussed in the following section, the success rate of the survey programme, which chiefly used these features of the database as the basis for enquiry, testifies to the overall solidity of the logic employed, firstly in constructing a ‘manuring database’ and secondly in incorporating historic source data alongside that of the Soil Survey.

Given this basic utility of, especially, the historical datasets in informing upon manuring practice and thus identifying patterns of deep topsoil location through the database format, a suggestion for further augmentation of the historical spatial dataset can be made. With fuel resource use identified through both desktop historical research and the micromorphological analysis as being of significance to deep topsoil development in Scotland, it is suggested that further analysis of the First Statistical Account dataset for patterns of fuel resource use could be undertaken, and the results incorporated into the manuring database. This could prove of definite utility both in refining the assessment of deep topsoil distribution presented by the manuring database and in further historical contextualisation of the Scottish deep topsoil resource.

Proactive suggestions can also be made concerning the limitations of the archaeological survey databases incorporated into the manuring database with regard to locating and contextualising deep anthropogenic topsoils. The limited usefulness of the FESP and HLUA datasets to the project is discussed in Sections 5.2.4.2 and 5.2.5.2 with reference to their contributions to the Tiree and Solway coast surveys. The main limitation of the HLUA dataset proved to be its resolution to one hectare, a feature which meant that the individual field system features essential to locating specific areas of cultivation such as deep anthropogenic topsoils were not mapped. However, the similarly limited usefulness to the survey of the FESP dataset, within which such features *are* represented, indicated that the key element of mapped landscape data essential to investigations of sub-surface anthropogenic features may not be the depiction of above-ground features, but the placing of these in their relevant historic context. This was amply illustrated in the contribution made by historic map sources and their accompanying contemporary datasets to the survey programme. At both Nairn and Tiree, the conjunction of mapped information with historical context providing – albeit indirect - information on manuring practice facilitated an intelligent survey design (Sections 5.2.1.3; 5.2.4.1). The identification and incorporation of similar mapped datasets for other locations into not only the manuring database, but to the larger-scale survey tools represented by the FESP and HLUA projects has been demonstrated by this project to have clear potential.

8.5.2 The survey programme

The design of the survey programme aimed at a comprehensive coverage of different localities, cultural contexts, and topographies. However, the constraints of the project timescale necessarily resulted in a series of relatively small actual survey areas. It cannot be said that a detailed coverage of Scotland, and therefore a *detailed* assessment of the distribution and frequency of deep anthropogenic topsoils, was achieved. The association of deep anthropogenic topsoil areas with predominately urbanised localities identified as a result of this survey programme must therefore be viewed as a preliminary assessment. Given the effects upon the relict soil signature identified as arising from uncultivated land cover types, ongoing research aimed at identifying and examining deep topsoil contexts in rural as well as urbanised localities is vital.

Despite the necessary limitations of the survey programme, the identification of five visible and three sample-suitable deep topsoil sites from the surveys undertaken was a wholly positive result. Moreover, in that that furthering understanding of the *overall* context of distribution and frequency of deep anthropogenic topsoils was the first aim of the project, the success of the survey programme lies not only in its successful identification of topsoil sites for analysis, but also for the success with which it explored the extent to which the factors identified through historical research may have influenced the development of deep anthropogenic topsoils. In addition to this, if the first objective in the conservation of deep anthropogenic topsoils is to record and examine them within their landscape context, then the survey programme can be said to have made a significant contribution in this area.

It is possible that, should an attempt to highlight the significance of anthropogenic soils within Land Management Contracts be successful, that Environmental Audits undertaken as part of this scheme may not only help identify additional deep anthropogenic topsoil sites, but also extend survey ‘coverage’ to the point where more robust conclusions concerning the distribution and frequency of Scottish deep anthropogenic topsoils could be reached. A similar outcome may be anticipated should anthropogenic soil assessment be considered within developer-funded evaluation and excavation in Scotland.

8.5.3 The sample sites: a representative set?

Similar issues are raised with regard to the size and distribution of the sample set delivered through the survey programme discussed above. How valid are the conclusions made, either regarding the defining characteristics of deep anthropogenic topsoils in Scotland, or the effect of modern land cover when a relatively small sample set has been studied?

Certainly, for the suggestions made upon the likely effects of modern land cover on the survival of relict cultural indictors to have a general validity, further study of a larger body of source data is vital, and the suggestions for further work detailed at Section 8.5.1 look forward to the accumulation of a larger body of data through which to provide additional validation of the conclusions derived from the analytical programme. However, as discussed in Section 6.1.2.2, the potential *rarity* of deep anthropogenic topsoils in Scotland identified through this project may preclude this.

8.6 Concluding remarks

The dual aims of this project have been successfully completed within a research exercise which has fulfilled the ambition set out at its beginning: to present an interdisciplinary body of work combining historical, archaeological and scientific research to give a meaningful insight into the position of deep anthropogenic topsoils in the Scottish landscape. That a less holistic treatment of the subject matter of this project would have resulted in a different outcome for the analytical programme is debatable; that the significance of the conclusions reached as a result would have less import for geoarchaeologists and archaeologists alike is certain. The importance of deep anthropogenic topsoils as cultural artefacts central to our understanding of Scotland’s agricultural past cannot be understated, and the primacy given in this project design to historical research into the cultural context of both deep topsoils in general and the specific sample sites featured has been amply justified by the wealth of information obtained. The research design conceived to undertake the first aim of this project has succeeded in providing both localised and country-wide information which has both refined our understanding of the distribution and frequency of deep anthropogenic topsoils in Scotland, and highlighted research avenues for the future.

The success of the project design in illustrating the significance of this soil cultural resource for the historic landscape provided ample justification for the second aim of the project. Understanding the effect of modern land cover and management upon the survival of relict indicators in deep anthropogenic topsoils is vital to the success of not only geoarchaeological, but related interdisciplinary research into both the rural and urban historic landscape, and the research design utilised for this second aim of the project successfully identified features of the modern environment with the potential to affect relict soil signatures. Finally, a consideration of the structure of current policies of relevance to not only deep anthropogenic topsoil conservation, but also research and development in this area offered suggestions as to how the profile of these important cultural features might be raised, their conservation might be more effectively facilitated, and thus our understanding of their geoarchaeological and historical significance might be expanded.

In summary, this project has made a significant contribution to knowledge in this area, with regard to both the value of the cultural information retained by deep anthropogenic topsoils to the Scottish historical landscape, and the means by which this might be conserved.

9. Bibliography

Adderley, W.P., Simpson, I.A., Lockheart, M.J., Evershed, R.P. and Davidson, D.A. (2000) Modelling traditional manuring practice: soil organic matter sustainability of an early Shetland community? *Human Ecology* **28**, pp. 415-431.

Ainslie, J. (1794) *Map of the County of Forfar, or Shire of Angus.* Edinburgh.

Aiton, W. (1805) *A treatise on the origin, qualities and cultivation of moss-earth*. Glasgow.

Aiton, W. (1811) *General view of the agriculture of the county of Ayr, with observations on the means of its improvement*. Board of Agriculture, London.

Akeret, O. and Rentzel, P. (2001) Micromorphology and plant macrofossil analysis of cattle dung from the Neolithic lake shore settlement of Arbon Bleiche 3. *Geoarchaeology* **16 (6)**, pp. 687-700.

Anderson, J (1794) *General view of the agriculture and rural economy of the county of Aberdeen, with observations on the means of its improvement.* Board of Agriculture, Edinburgh.

Armit, I. (1998) Human responses to marginality. In Mills, C.M. and Coles, G. (eds.) *Life on the edge: human settlement and marginality*. Symposia of the Association for Environmental Archaeology 13: Oxbow Monograph 100, Oxford., pp. 31-38.

Atkinson, J.A. (1995) *Medieval or later rural settlement studies: recommendations towards a policy statement*. GUARD Report 202, Glasgow.

Atkinson, J.A., Banks, I. and MacGregor, G. (eds.) (2000) *Townships to farmsteads: rural settlement studies in Scotland, England and Wales*. BAR British Series 293/ Scottish Archaeological Forum.

Avery, B.W. (1990) *Soils of the British Isles*. C.A.B. International, Wallingford.

Bakels, C.C. (1988) Pollen from plaggen soils in the province of North Brabant, the Netherlands. In Groenman-van Waateringe, W. and Robinson, M. (eds.) *Man-made Soils*. Symposia of the Association for Environmental Archaeology No. 6. BAR International Series 410, pp. 35-64.

Baker, A.R.H. and Butlin, R.A. (1973) *Studies of field systems in the British Isles*. Cambridge University Press, Cambridge.

de Bakker, H. (1979) *Major soils and soil regions in the Netherlands*. Centre for Agricultural Publishing and Documentation, Wageningen. Dr. W. Junk B.V. Publishers, The Hague.

de Bakker, H. (1980) Anthropogenic soils in the Netherlands. *Roczniki Gleboznawcze* **31**, pp. 323-328.

de Bakker, H. and Schelling, J. (1966) *System van Bodemclassificatie Voor Nederland. De Hogre Niveaus*. (with English summary) Pudoc, Wageningen.

Bakkevig, S. (1980) Phosphate analysis in archaeology – problems and recent progress. *Norwegian Archaeological Review* **13**, pp. 73-100.

Ball, D.F. (1964) Loss-on-ignition as an estimate of organic matter and organic carbon in non-calcareous soils. *Journal of Soil Science* **15**, pp. 84-92.

Ballin-Smith, B., Hooper, J. and Thomas, J. (2005) *Pabbay, Harris: Data Structure Report*. GUARD Project 2057, Glasgow.

Bangor-Jones, M. (1993) The incorporation of documentary evidence and other historical sources into preservation and management strategies. In Hingley, R. (ed.) *Medieval or later rural settlement in Scotland: management and preservation*. Historic Scotland Ancient Monuments Division Occasional Paper 1, Edinburgh, pp. 36-42.

Barber, J. (1981) Excavations on Iona, 1979. *Proceedings of the Society of Antiquaries of Scotland* **111**, pp. 282-380.

Barber, J. (2001) *Guidelines for the preservation of areas of rig and furrow in Scotland*. Scottish Trust for Archaeological Research, Midlothian.

Barrow, G.W.S. (1962) Rural settlement in central and eastern Scotland: the medieval evidence. *Scottish Studies* **6**, pp. 123-144.

Bascomb, C.L. (1974) Physical and chemical analyses of <2mm samples. In Avery, B.W. and Bascomb, C.L. (eds.) *Soil Survey laboratory methods*. Soil Survey of England and Wales, Harpenden, pp. 14-41.

Beckel, A. (1962) *The application of soil classification in agriculture, forestry and other fields in the Federal Republic of Germany*. Transactions of the International Soil Conference, New Zealand, pp. 388-398.

Bell, M. (1981) Seaweed as a prehistoric resource. In Brothwell, D. and Dimbleby, G. (eds.) *Environmental aspects of coasts and islands*. First Symposium for Environmental Archaeology. BAR International Series 94, pp. 117-126.

Bell, M., Fowler, P.J. and Wilson, S.W. (eds.) (1996) *The Experimental Earthwork Project, 1960-1992*. CBA Research Report 100. Council for British Archaeology, York.

Bethell, P. and Mate, I. (1989) The use of soil phosphate analysis in archaeology: a critique. In Henderson, J (ed.) *Scientific Analysis in Archaeology*. Monograph 19, Oxford University Committee for Archaeology, Oxford, pp. 1-19.

Bibby, J.S. (1980) Soil research and land use capability interpretative maps. In Thomas, M.F. and Coppock, J.T. (eds.). *Land Assessment in Scotland. Proceedings of the Royal Scottish Geographical Society Symposium 1979.* Aberdeen University Press, Aberdeen, pp. 25-38.

Bjelajac, V., Luby, E.M. and Ray, R. (1996) A validation test of a field-based phosphate analysis technique. *Journal of Archaeological Science* **23**, pp. 243-248.

Blume, H.P. (1998) History and impact of plaggen soils in Europe. 16th World Congress of Soil Science, Montpellier, France: *CD ROM, Conference Proceedings.*

Bonney, D.J. (1980) Damage by medieval and later cultivation in Wessex. In Hinchcliffe, J. and Schadla-Hall, R.T. (eds.) *The past under the plough. Papers presented at the seminar on plough damage and archaeology held at Salisbury February 1977*. Directorate of Ancient Monuments and Historic Buildings Occasional Paper 3, Department of the Environment, London, pp.41-48.

Bowler, D., Cox, A. and Smith, C. (1995) Four Excavations in Perth, 1979-1984. *Proceedings of the Society of Antiquaries of Scotland* **125**, pp. 917-999.

Brady, N.C. (1974) *The nature and properties of soils*. Collier Macmillan, London.

Brady, N.C. and Weil, RR. (1999) *The nature and properties of soils*. Prentice-Hall International.

Brochier, J.E., Villa, P., Giacomarra, M. and Tagliacozzo, A. (1992) Shepherds and sediments: geo-ethnoarchaeology of pastoral sites. *Journal of Anthropological Archaeology* **11**, pp. 47-102.

Bruce, L.D., Dixon, P., Hingley, R. and Stevenson, J. (1999) *Historic landuse assessment (HLA): development and potential of a technique for assessing historic landuse patterns. Report of the pilot project 1996-1998*. Historic Scotland/RCAHMS, Edinburgh.

Buchan-Hepburn, G. (1794) *General view of the agriculture of the county of East Lothian, with observations on the means of its improvement*. Board of Agriculture, London.

Bull, I.D., Simpson, I.A., Dockrill, S.J. and Evershed, R.P. (1999) Organic geochemical evidence for the origin of ancient anthropogenic soil deposits at Toft's Ness, Sanday, Orkney. *Organic Geochemistry* **30**, pp. 535-556.

Bullock, P., Fedoroff, N., Jongerius, A., Stoops, G. and Tursina, T. (1985) *Handbook for soil thin section description*. Waine Research Publications, Wolverhampton.

Butzer, K.W. (1982) *Archaeology as human ecology*. Cambridge University Press, Cambridge.

Cachart, R. (2000) Excavations at 106-110 South Street, St. Andrews, with contributions by A. Cox, D. Gallagher, D.W. Hall and C. Smith. *Tayside and Fife Archaeological Journal* **6**, pp. 109-132.

Canti, M. (1997) An investigation of microscopic calcareous spherulites from herbivore dungs. *Journal of Archaeological Science* **24**, pp. 219-231.

Canti, M. (1999) The production and preservation of faecal spherulites: animals, environment and taphonomy. *Journal of Archaeological Science* **26**, pp. 251-258.

Canti, M. (2003a) Earthworm activity and archaeological stratigraphy: a review of products and processes. *Journal of Archaeological Science* **30**, pp. 135-148.

Canti, M. (2003b) Aspects of the chemical and microscopic characteristics of plant ashes found in archaeological soils. *Catena* **54**, pp. 339-361.

Carter, S.P. (1998) The use of peat and other organic sediments as fuel in northern Scotland: identifications derived from soil thin sections. In Mills, C.M. and Coles, G. (eds.) *Life on the edge: human settlement and marginality*. Oxbow Monograph 100, Oxford, pp. 99-109.

Carter, S.P. and Davidson, D.A. (1998) An evaluation of the contribution of soil micromorphology to the study of ancient arable agriculture. *Geoarchaeology* **13 (6)**, pp. 535-547.

Carter, S.P. and Davidson, D.A. (2000) A reply to Macphail's comments on 'An evaluation of the contribution of soil micromorphology to the study of ancient arable agriculture'. *Geoarchaeology* **15 (5)**, pp. 499-502.

Carter, S. (2001) A reassessment of the origins of the St. Andrews 'garden soil'. *Tayside and Fife Archaeological Journal* **7**, 87-92.

Carver, E. and Lelong, O. (eds.) (2004) *Modern views – ancient lands. New work and thought on cultural landscapes*. BAR British Series 377/ Scottish Archaeological Forum, Archaeopress, Oxford.

Catt, J.A. (1994) Long-term consequences of using artificial and organic fertilisers: the

Rothamstead experiments. In Foster, S. and Smout, T.C. (eds.) *The history of soils and field systems*. Scottish Cultural Press, Aberdeen, pp. 119-134.

Chaya, H.J. (1996) Studies of soils from an Aleutian Island site. In Orna, M.V. (ed.). *Archaeological chemistry: organic, inorganic and biochemical analysis*. American Chemical Society Symposium Series 625, Washington, D.C., pp. 131-138.

Coleman R.J. (1996) Burgage plots of medieval Perth: the evidence from excavations at Canal St. *Proceedings of the Society of Antiquaries of Scotland* **126**, pp. 689-732.

Conry, M.J. (1971) Irish Plaggen soils – their distribution, origin and properties. *Journal of Soil Science* **22 (4)**, pp. 401-416.

Conry, M.J. (1972) Pedological evidence of man's role in soil profile modification in Ireland. *Geoderma*, pp. 139-146.

Conry, M.J. (1974) Plaggen soils: a review of man-made raised soils. *Soils and Fertilisers* **37(11)**, pp. 319-326.

Conry, M.J. and Diamond, J.J. (1971) Proposed Classification of Plaggen Soils. *Pedologie* **21 (2)**, pp. 152-161.

Conry, M.J. and Mitchell, G.F. (1971) The age of Irish plaggen soils. In Yaalon (ed.) *Paleopedology – Origin, Nature and Dating of Paleosols*. International Soil Science and Israel Universities Press, Jerusalem, pp. 129-136.

Conry, MJ., MacNaeidhe, F. (1999). Comparative nutrient status of a peaty gleyed podzol and its plaggen counterpart on the Dingle peninsula in the south-west of Ireland. *European Journal of Agronomy* **11**, pp. 85-90.

Conway, J.S. (1983) An investigation of soil phosphorus distribution within occupation deposits from a Romano-British hut group. *Journal of Archaeological Science* **10**, pp. 117-128.

Coppock, J.T. (1980) The concept of land quality: an overview. In Thomas, M.F. and Coppock, J.T. (eds.) *Land assessment in Scotland: Proceedings of the Royal Scottish Geographical Society Symposium 1979*. Aberdeen University Press, Aberdeen, pp. 1-7.

Cox, A. (2002) The archaeology of a walled garden at Kinross House. *Tayside and Fife Archaeological Journal* **8**, pp. 168-181.

Courty, M-A., Goldberg, P. and Macphail, R.I. (1989) *Soils and micromorphology in archaeology*. Cambridge University Press, Cambridge.

Courty, M-A., Macphail, R.I. and Wattez, J. (1991) Soil micromorphological indicators of pastoralism: with special reference to Arene Candide, Finale Ligure, Italy. *Revista di Studi Liguri*, **LVII**, pp. 127-150.

Coutts, W. (1986) Farmers in Dumfries from 1600 to 1665 as seen through the Register of Testaments and Grants of Confirmation. *The Transactions of the Dumfries and Galloway Natural History and Antiquarian Society, Third Series* **61**, pp. 63-72.

Craddock, P.T., Gurney, D. and Pryor, F. (1985) The application of phosphate analysis to the location and interpretation of archaeological sites. *Archaeological Journal* **142**, pp. 361-376.

Crawford, B.E. (ed.) *The papar in the North Atlantic: environment and history*. *Proceedings of a day conference held on 24th February 2001*. St. John's House Papers 10, St. Andrews.

Cregeen, E. R. (Ed.) (1964) *Argyll Estate Instructions: Mull, Morvern, Tiree*. Scottish History Society, Constable, Edinburgh.

Crowther, J. (1997) Soil phosphate surveys: critical approaches to sampling, analysis and interpretation. *Archaeological Prospection* **4**, pp. 93-102.

Crowther, J. (2002) The experimental earthwork at Wareham, Dorset after 33 years: retention and leaching of phosphate released in the decomposition of buried bone. *Journal of Archaeological Science* **29**, pp. 405-411.

Cruise, G. and Macphail, R.I. (2000) Microstratigraphical signatures of experimental rural occupation deposits and archaeological sites. In Roskams, S. (ed.) *Interpreting stratigraphy: site evaluation, recording procedures and stratigraphic analysis*. BAR International Series 910, Oxford, pp. 183-191.

Crumley, C. L. (1994) Historical Ecology: a multidimensional ecological orientation. In Crumley, C.L. (ed.) *Historical Ecology*. School of American Research Press, New Mexico, pp. 1-16.

Dalglish, C. (2002) Highland rural settlement studies: a critical history. *Proceedings of the Society of Antiquaries of Scotland* **132**, pp. 475-497.

Dalglish, C. (2003) *Rural society in the age of reason. An archaeology of the emergence of modern life in the southern Scottish Highlands*. Kluwer Academic/Plenum, New York.

Darling, F.F. (ed.) (1955) *West Highland Survey: an essay in human ecology*. Oxford University Press, Oxford.

Dauncey, K.D.M. (1952) Phosphate content of soil in archaeological sites. *Advancement of Science* **9**, pp. 33-36.

Davidson, D.A. (1973) Particle size and phosphate analysis – evidence for the evolution of a Tell. *Archaeometry* **15**, pp. 143-152.

Davidson, D.A. (1976) Processes of tell formation and erosion. In Davidson, D.A. and Shackley, M.L. (eds.) *Geoarchaeology*. Duckworth, London, pp. 255-266.

Davidson, D.A. (1990) *Report to Whithorn Trust on soil samples*. University of Stirling, Stirling.

Davidson, D.A. (2002) Bioturbation in old arable soils: quantitative evidence from soil micromorphology. *Journal of Archaeological Science* **29**, pp. 1247-1253.

Davidson, D.A. and Simpson, I.A. (1984) The formation of deep topsoils in Orkney. *Earth Surface Processes and Landforms* **9**, pp. 75-81.

Davidson, D.A. and Simpson, I.A. (1994) Soils and landscape history: case studies from the Northern Isles of Scotland. In Foster, S. and Smout, T.C. (eds.) *The history of soils and field systems*. Scottish Cultural Press, Aberdeen, pp. 66-74.

Davidson, D.A. and Smout, T.C. (1996) Soil change in Scotland: the legacy of past land improvement processes. In Taylor, A.G., Gordon, J.E. and Usher, M.B. (eds.) *Soils, sustainability and the natural heritage*. HMSO, Edinburgh, pp.44-54.

Davidson, D.A. and Carter, S.P. (1998) Micromorphological evidence of past agricultural practices in cultivated soils: the impact of a traditional agricultural system on soils in Papa Stour, Shetland. *Journal of Archaeological Science* **25**, pp. 827-838.

Davidson, D.A., Carter, S.P. and Quine, T.A. (1992) An evaluation of micromorphology as an aid to archaeological interpretation. *Geoarchaeology* **7**, pp. 55-65.

Davidson, D.A., Harkness, D.D. and Simpson, I.A. (1996) The formation of farm mounds on the island of Sanday, Orkney. *Geoarchaeology* **1**, pp. 45-60.

DEFRA (Department for Environment, Food, and Rural Affairs) (2004) *The First Soil Action Plan for England: 2004-2006*. DEFRA Publications, Admail 6000, London.

DEFRA (Department for Environment, Food, and Rural Affairs) (2006). *Single Payment Scheme: Cross Compliance Guidance for Soil Management*. DEFRA Publications, Admail 6000, London.

Dennison, E.P. and Coleman, R. (1999) *Historic Nairn*. The Scottish burgh survey. Historic Scotland, Edinburgh.

Dennison, E.P. and Coleman, R. (2000) *Historic Forfar*. The Scottish burgh survey. Historic Scotland, Edinburgh.

Devine, T.M. (1994) *The transformation of rural Scotland: social change and the agrarian economy 1660-1815*. Edinburgh University Press, Edinburgh.

Devine, T.M. (2000) *The Scottish Nation 1700-2000*. Penguin, London.

Dickson, A. (1770) *Treatise of Agriculture*. Kincaid and Bell, Edinburgh.

Dietz, E.F. (1957) Phosphorus accumulation in soil of an Indian habitation site. *American Antiquity* **22**, pp. 405-409.

Dixon, P. (1994) Field systems, rig and other cultivation remains in Scotland: the field evidence. In Foster, S. and Smout, T.C. (eds.) *The history of soils and field systems*. Scottish Cultural Press, Aberdeen, pp. 26-52.

Dixon, P. (2003) Champagne country: a review of medieval rural settlement in Lowland Scotland. In Govan, S. (ed.) (2003) *Medieval or later rural settlement in Scotland: 10 years on*. Conference Proceedings, Edinburgh: Historic Scotland/Medieval Settlement Research Group, pp. 53-64.

Dockrill, S.J. and Simpson, I.A. (1994) The identification of prehistoric anthropogenic soils in the Northern Isles using an integrated sampling methodology. *Archaeological Prospection* **1**, pp. 75-92.

Dockrill, S.J., Bond, J.M., Milles, A., Simpson, I.A. and Ambers, J. (1994) Toft's Ness, Sanday, Orkney. An integrated study of a buried Orcadian landscape. In Luff, R. and Rowley-Conwy, P. (eds.) *Whither environmental archaeology?* Oxbow Monograph 38, Oxbow, Oxford, pp.115-132.

Dodd, J.P. (1979) The agriculture of south-western Scotland in the mid-nineteenth century. *Transactions of the Dumfries and Galloway Natural History and Antiquarian Society* **55**, pp. 133-143.

Dodgshon, R.A. (1977) Scottish township organisation during the medieval and early modern periods. *Geografiska Annaler* **59B**, pp. 39-51.

Dodgshon, R.A. (1980) The origins of traditional field systems. In Parry, M.L. and Slater, T.R. (eds.) *The making of the Scottish countryside*. Croom Helm, London, pp. 69-92.

Dodgshon, R.A. (1983) Agricultural change and its social consequences in the southern uplands of Scotland, 1600-1780. In Devine, T.M. and Dickson, D. (eds.) *Ireland and Scotland 1600-1850:*

parallels and contrasts in economic and social development. John Donald, Edinburgh, pp. 46-59.

Dodgshon, R.A. (1988) The ecological basis of Highland peasant farming, 1500-1800 A.D. In Birks, H.H., Birks, H.J.B., Kaland, P.E. and Moe, D. (eds.) *The Cultural Landscape: Past, Present and Future*. Cambridge University Press, Cambridge, pp. 139-151.

Dodgshon, R.A. (1992) Farming practice in the Western Highlands and Islands before crofting: a study in cultural inertia or opportunity costs? *Rural History* **3 (2)**, pp. 173-189.

Dodgshon, R.A. (1993b) West Highland and Hebridean landscapes: have they a history without runrig? *Journal of Historical Geography* **19 (4)**, pp. 383-398.

Dodgshon, R.A. (1994) Rethinking Highland field systems. In Foster, S. and Smout, T.C. (eds.) *The history of soils and field systems*. Scottish Cultural Press, Aberdeen, pp. 53-65.

Dodgshon, R.A. (1998a) *From chiefs to landlords: social and economic change in the western Highlands and Islands, c. 1493-1820*. Edinburgh University Press, Edinburgh.

Dodgshon, R.A. (1998b) Livestock production in the Scottish Highlands before and after the Clearances. *Rural History* **9 (1)**, pp. 19-42.

Dodgshon, R.A. (2004) Coping with risk: subsistence crises in the Scottish Highlands and Islands, 1600-1800. *Rural History* **15 (1)**, pp. 1-25.

Dodgshon, R.A. and Olson, E.G. (1988) Productivity and nutrient use in eighteenth-century Scottish Highland townships. *Geografiska Annaler* **70B**, pp. 39-51.

Donaldson, J. (1794a) *General view of the agriculture of the county of Banff, with observations on the means of its improvement*. Board of Agriculture, London.

Donaldson, J. (1794b) *General view of the agriculture of the county of Nairn, with observations on the means of its improvement*. Board of Agriculture, London.

Donaldson, J. (1795) *General view of the agriculture of the county of Kincardine, or the Mearns, with observations on the means of its improvement*. Board of Agriculture, London.

Donnachie, I.L. and MacLeod, I. (1974) *Old Galloway*. David and Charles, Newton Abbott.

Donnelly, J. (2000) In the territory of Auchencrow: long continuity or late development in early Scottish field systems? *Proceedings of the Society of Antiquaries of Scotland* **130**, 743-772.

Dormaar, J.F. and Beaudoin, A.B. (1991) Application of soil chemistry to interpret cultural events at the Calderwood Buffalo Jump (DkPj-27), Southern Alberta, Canada. *Geoarchaeology* **6 (1)**, pp. 85-98.

Edward, R. (1678a) *A description of the county of Angus, 1678*. (Translated from the Latin by James Trail, with map and preface: Edinburgh, 1883).

Edward, R. (1678b) *Angusia Proinciae Scotiae, sive The Shire of Angus*. Amsterdam.

Edwards, K.J. and Smout, T.C. (2000) Perspectives on human-environment interaction in prehistoric historical times. In Holmes, G. and Crofts, R. (eds.) *Scotland's Environment: the future*. Tuckwell Press, in association with the Royal Society of Edinburgh/Scottish Natural Heritage, Edinburgh, pp.3-29.

Eidt, R.C. (1973) A rapid chemical field text for archaeological site surveying. *American Antiquity*

38, pp. 206-210.

Eidt, R.C. (1977) Detection and examination of anthrosols by phosphate analysis. *Science* **197**, pp. 1327-1333.

Eidt, R.C. (1985) Theoretical and practical considerations in the analysis of anthrosols. In Rapp, G. and Gifford, J.A (eds.). *Archaeological Geology*. Yale University Press, New Haven, pp.155-190.

Ekholm, P., Turtola, E., Gronroos, J., Seuri, P. and Ylivainio, K. (2005) Phosphorus loss from different farming systems estimated from soils surface phosphorus balance. *Agriculture, Ecosystems and Environment* **110**, pp. 266-278.

English Heritage (2004a) *Farming the historic landscape: caring for archaeological sites on arable land*. English Heritage Information Leaflet 50910.

English Heritage (2004b) *Farming the historic landscape: caring for archaeological sites in grassland*. English Heritage Information Leaflet 50909.

English Heritage (2004c) *Geoarchaeology: using earth sciences to understand the archaeological record*. English Heritage Publishing, Swindon.

Entwhistle, J.A., Abrahams, P.W. and Dodgshon, R.A. (1998) Multi-element analysis of soils from Scottish historical sites. Interpreting land-use history through the physical and geochemical analysis of soil. *Journal of Archaeological Science* **25**, pp. 53-68.

Entwhistle, J.A., Dodgshon, R.A. and Abrahams, P.W. (2000) An investigation of former land-use activity through the physical and chemical analysis of soils from the Isle of Lewis, Outer Hebrides. *Archaeological Prospection* **7**, pp. 171-188.

Evershed, H. (1874) On the agriculture of the islands of Shetland. *Transactions of the Highland and Agricultural Society of Shetland*, 4th Series, pp. 186-294.

Ewart, G. (2001) Dundrennan Abbey: archaeological investigation within the south range of a Cistercian house in Kirkcudbrightshire. *Transactions of the Dumfries and Galloway Natural History and Antiquarian Society* **75**, pp. 159-171.

Food and Agriculture Organisation of the United Nations (2006) *World reference base for soil resources*. World Soil Resources Reports, United Nations.

Fenton, A.J. (1970) Paring and burning and the cutting of turf and peat in Scotland. In Gailey, A. and Fenton A. (eds.). *The Spade in Northern and Atlantic Europe*. Ulster Folk Museum Institute of Irish Studies, Queen's University, Belfast, pp. 155-193.

Fenton, A.J. (1976) *Scottish country life*. John Donald, Edinburgh.

Fenton, A.J. (1978) The Northern Isles: Orkney and Shetland. Reprinted 1997, Tuckwell, Scotland.

Fenton, A.J. (1980) The traditional pastoral economy. In Parry, M.L. and Slater, T.R. (eds.) *The making of the Scottish countryside*. Croom Helm, London, pp. 93-113.

Fenton, A.J. (1985) The shape of the past 1: essays in Scottish ethnology. John Donald, Edinburgh.

Fenton, A.J. (1986) The shape of the past 2: essays in Scottish ethnology. John Donald, Edinburgh.

Fenton, A.J. (1981) Early manuring techniques. In Mercer, R. (ed) *Farming practice in British prehistory*. University Press, Edinburgh, pp. 210-217.

Fisher, P.F. and Macphail, R.I. (1985) Studies of archaeological soils and deposits by micromorphological techniques. In Fieller, N.R.J., Gilbertson, D.D. and Ralph, N.G.A. *Palaeoenvironmental investigations: research design, methods and data analysis.* Symposium No. 5 (ii) of the Association for Environmental Archaeology. BAR International Series 258, Oxford, pp. 93-122.

Fordyce, G. (1796) Additional appendix. In Somerville, R. *Outline of the fifteenth chapter of the proposed General Report from the Board of Agriculture: on the subject of manures.* Board of Agriculture, London.

Forestry Commission Scotland (2006) *The Scottish Forestry Strategy 2006*. Scottish Executive, SE/2006/155

Fortun, A., Fortun, C. and Ortega, C. (1989) Effect of farmyard manure and its humic fractions on the aggregate stability of a sandy-loam soil. *Journal of Soil Science* **40**, pp. 293-298.

Foster, S. and Smout, T.C. (1994) *The history of soils and field systems*. Scottish Cultural Press, Aberdeen.

French, C.I.A. (2003) *Geoarchaeology in action: studies in soil micromorphology and landscape evolution*. Routledge, London.

Fullarton, A. (1793) *General view of the agriculture of the county of Ayr, with observations on the means of its improvement*. Board of Agriculture, London.

Geake, H. (2003) Plough damage on Anglo-Saxon cemeteries. *The Archaeologist* **47**, pp. 16-17.

Gebhardt, A. (1992) Micromorphological analysis of soil structure modifications caused by different cultivation implements. In A.D.L.T. Ronde (ed.) *Prehistoire de l'agriculture: nouvelles approaches experimentales et ethnographies.* C.N.R.S., Valborne, pp. 373-383.

Gebhardt, A. (1995) Soil micromorphological data from traditional and experimental agriculture. In Barham, A.J. and Macphail, R.I. (eds.) Archaeological sediments and soils: analysis, interpretation and management. Institute of Archaeology, University College London, pp. 25-39.

Gebhardt, A. and Langohr, R. (1999) Micromorphological study of construction materials and living floors in the Medieval Motte of Werken (West Flanders, Belgium). *Geoarchaeology* **14 (7)**, pp. 595-620.

Glentworth, R. (1954) The *soils of the country round Banff, Huntley and Turriff*. HMSO, Edinburgh.

Glentworth, R. (1963) *The soils of the country round Aberdeen, Inverness and Fraserburgh*. HMSO, Edinburgh.

Goldberg, P. and Macphail, R.I. (2006) *Practical and Theoretical Geoarchaeology*. Blackwell Science, Oxford.

Gormsen, G. (1991) Traditional heathland farming in Western Denmark. *Ethnologia Scandinavica* **54**, pp. 105-125.

Govan, S. (ed.) (2003) *Medieval or later rural settlement in Scotland: 10 years on*. Conference Proceedings, Edinburgh: Historic Scotland/Medieval Settlement Research Group.

Graham, P (1814) *General view of the agriculture of the counties of Kinross and Clackmannanshire, with observations on the means of their improvement*. Board of Agriculture, London.

Grantham, M.M. (1996) Soils and sustainability: a crofting view. In Taylor, A.G., Gordon, J.E. and Usher, M.B. (eds.) *Soils, sustainability and the natural heritage,* 225-235. HMSO, Edinburgh, pp. 225-235.

Gray, M. (1962) Settlement in the Highlands, 1750-1950. The documentary and the written record. *Scottish Studies* **6**, pp. 145-154.

Gray, M. (1984) Farm workers in north-east Scotland. In Devine, T.M. (ed.) F*arm servants and labour in Lowland Scotland 1770-1914*. John Donald, Edinburgh, pp. 10-28.

Groenman-van Waateringe, W. (1988) Palynology of plaggen soils on the Veluwe, Central Netherlands. In Groenman-van Waateringe, W. and Robinson, M. (eds.) *Man-made Soils*. Symposia of the Association for Environmental Archaeology 6. BAR International Series 410, pp.55-65.

Guttmann, E.B. (2001) *Continuity and change in arable land management in the Northern Isles: evidence from anthropogenic soils*. Unpublished PhD. Thesis, University of Stirling.

Guttmann, E.B., Simpson, I.A. and Dockrill, S.J. (2003) Joined-up archaeology at Old Scatness, Shetland: thin section analysis of the site and hinterland. *Environmental Archaeology* **8**, pp. 17-31.

Guttmann, E.B., Simpson, I.A., Davidson, D.A. and Dockrill, S.J. (2006) The management of arable land from prehistory to the present: case studies from the Northern Isles of Scotland. *Geoarchaeology* **21 (1)**, pp. 61-92.

Haggarty, A.M. (1988) Iona: some results from recent work. *Proceedings of the Society of Antiquaries of Scotland* **118**, pp. 203-213.

Halliday, S. (2003) Rig-and-furrow in Scotland. In Govan, S. (ed.) (2003) *Medieval or later rural settlement in Scotland: 10 years on*. Conference Proceedings, Edinburgh: Historic Scotland/Medieval Settlement Research Group, pp. 69-81.

Hamond, F.W. (1983) Phosphate analysis of archaeological sediments. In Reeves-Smith, T. and Hamond, F.W. *Landscape archaeology in Ireland*. BAR British Series 116, pp. 47-80.

Headrick, J. (1796) Essay on Manures. In Somerville, R. *Outline of the fifteenth chapter of the proposed General Report from the Board of Agriculture: on the subject of manures.* Board of Agriculture, London.

Havlin, J.L., Beaton, J.D., Tisdale, S.L. and Nelson, W.L. (1999) *Soil fertility and fertilisers: an introduction to nutrient management*. 6th ed. Prentice Hall, New Jersey.

Hedley, M.J., Stewart, J.W.B., Chauhan, B.S. (1982) Changes in inorganic and organic soil phosphorus fractions induced by cultivation practices and by laboratory incubations. *Soil Science Society of America Journal* **46**, pp. 970-976.

Heidinga, H. (1988) Climate and plaggen soils. In Groenman-van Waateringe, W. and Robinson, M. (eds.) *Man-made Soils*. Symposia of the Association for Environmental Archaeology No. 6. BAR International Series **410**, pp. 21-33.

Heron, D (1794) *General view of the Hebrides (and Bute) with observations on the means of their improvement*. Board of Agriculture, London.

Herz, N. and Garrison, E.G. (1998) *Geological methods for archaeology*. Oxford University Press, Oxford.

Highland Relief Board (1849) *Report on the Islands of Mull, Ulva, Iona, Tiree and Coll, and on part of the parish of Morvern*. W.M. Eadie, Glasgow.

Hill, P. (1997) *Whithorn and St. Ninian: the excavation of a monastic town, 1984-91*. The Whithorn Trust, Sutton.

Hill, P. and Kucharski, K. (1990) Early medieval ploughing at Whithorn and the chronology of plough pebbles. *Transactions of the Dumfries and Galloway Natural History and Antiquarian Society* **65**, pp. 73-83.

Hill, P. and Pollock, D. (1992) *The Whithorn dig*. Whithorn Board of Management, The Whithorn Trust.

Hingley, R. (ed.) (1993) *Medieval or later rural settlement in Scotland: management and preservation*. Historic Scotland Ancient Monuments Division Occasional Paper 1, Edinburgh.

Hingley, R. (2000) Medieval or later rural settlement in Scotland – the value of the resource. In Atkinson, J.A., Banks, I. and MacGregor, G. (eds.) (2000) *Townships to farmsteads: rural settlement studies in Scotland, England and Wales*. BAR British Series 293/ Scottish Archaeological Forum, pp. 11-19.

Historic Scotland (2005) *Listed Buildings Information Facility*, http://hsewsf.sedsh.gov.uk

Holliday, V.T. (2004) *Soils in archaeological research*. Oxford University Press, New York.

Hughes, R.C. (1980) Minimal cultivation: a non-plough approach to crop production. In Hinchcliffe, J. and Schadla-Hall, R.T. (eds.) *The past under the plough. Papers presented at the seminar on plough damage and archaeology held at Salisbury February 1977*. Directorate of Ancient Monuments and Historic Buildings Occasional Paper 3, Department of the Environment, London, pp.32-34.

Hinchcliffe, J. (1980) Effects of ploughing on archaeological sites: assessment of the problem and some suggested approaches. In Hinchcliffe, J. and Schadla-Hall, R.T. (eds.) *The past under the plough. Papers presented at the seminar on plough damage and archaeology held at Salisbury February 1977*. Directorate of Ancient Monuments and Historic Buildings Occasional Paper 3, Department of the Environment, London, pp.11-17.

Hinchcliffe, J. and Schadla-Hall, R.T. (1980) (eds.) *The past under the plough. Papers presented at the seminar on plough damage and archaeology held at Salisbury February 1977*. Directorate of Ancient Monuments and Historic Buildings Occasional Paper 3, Department of the Environment, London.

Historic Scotland (2005) *Archaeology and farming*. CSA Rural Archaeology Advice Note 1, Edinburgh.

Hoppenbrouwers, P. (1997) Agricultural production and technology in the Netherlands, c. 1000-1500. In Astill, G. and Langdon, J. (eds.) *Medieval Farming and Technology: The Impact of Agricultural Change in Northwest Europe Vol 1: Technological Change*. Brill, Leiden, pp. 89-114.

Hume, J.R. (1983) Introduction. In Withrington, D.J. and Grant, I.R. (Eds.), *The Statistical Account of Scotland 1791-1799, Volume V: Stewartry of Kirkcudbright and Wigtownshire*. EP Publishing, Wakefield, England, pp. ix-xxvi.

Jenny, H. (1941) *Factors of soil formation*. McGraw and Hill, New York.

Johnston, T. (1794) *General view of the agriculture of the county of Dumfries, with observations on the means of its improvement*. Board of Agriculture, London.

Jongerius, A. (1970). Some morphological aspects of regrouping phenomena in Dutch soils. *Geoderma* **4**, pp. 311-331.

Jongerius, A. (1983) The role of micromorphology in agricultural research. In Bullock, P. and Murphy, C.P. (eds.) *Soil Micromorphology. Volume 1: Techniques and Applications*. AB Academic Publishers Ltd., Herts., pp. 111-138.

Jongerius, A. and Schelling, J. (1960) Micromorphology of organic matter formed under the influence of soil organisms, especially soil fauna. In Stoops, G. and Eswaran, H. (eds.) (1986) *Soil Micromorphology*. Van Nostrand Reinhold Soil Science Series, Hutchinson Ross, New York, pp. 138-146. (*Reprinted from the International Congress of Soil Science, 7th Transaction, No. 3*).

Keeley, H.C.M., Hudson, G.E. and Evans, J. (1977) Trace element contents of human bones in various states of preservation 1: the soil silhouette. *Journal of Archaeological Science* **4**., pp. 19-24.

Kemp. R. A (1998) Role of micromorphology in palaeopedological research. *Quaternary International* **51/52**, pp. 133-141.

Kerr, R. (1809) *General view of the agriculture of the county of Berwick, with observations on the means of its improvement*. Board of Agriculture, London.

Kooistra, M.J. (1987) The effects of compaction and deep tillage on soils structure in a Dutch sandy loam soil. In Fedoroff, N., Bresson, L.M. and Courty, M-A. (eds.) *Micromorphologie des Sols – Soil Micromorphology*. AFES, Plaisir, pp. 445-450.

Korschens, M. (1998) Soil organic matter and sustainable land use. *Advances in GeoEcology* **31**, pp. 423-430.

Lambrick, G. (1980) Effects of modern cultivation equipment on archaeological sites. In Hinchcliffe, J. and Schadla-Hall, R.T. (eds.) *The past under the plough. Papers presented at the seminar on plough damage and archaeology held at Salisbury February 1977*. Directorate of Ancient Monuments and Historic Buildings Occasional Paper 3, Department of the Environment, London, pp.18-21.

de Laveleye, E. (1878) *Primitive Property*. Translated by G.R.L. Marriott. Macmillan, London.

Leigh, D.S. (2001) Buried artefacts in sandy soils: techniques for evaluating pedoturbation versus sedimentation. In Goldberg, P., Holliday, V.T. and Ferring, C.R. (eds.) *Earth sciences and archaeology*. Kluwer Academic/Plenum, New York, pp. 269-293.

Lelong, O. (2003) Finding medieval (or later) rural settlement in the Highlands and Islands: the case for optimism. In Govan, S. (ed.) (2003) *Medieval or later rural settlement in Scotland: 10 years on*. Conference Proceedings, Edinburgh: Historic Scotland/Medieval Settlement Research Group, pp. 7-16.

Lenman, B. (1976) Introduction. In Withrington, D.J. and Grant, I.R. (Eds.) *The Statistical Account of Scotland 1791-1799, Volume XIII: Angus*. EP Publishing, Wakefield, England, pp. ix-xxxiv.

Leonardi, G., Miglavacca, M. and Nardi, S. (1999) Soil phosphorus analysis as an integrative tool for recognising buried ancient ploughsoils. *Journal of Archaeological Science* **26**, pp. 343-352.

Lerche, G. (1970) Cutting of sod and heather turf in Denmark. In Gailey, A. and Fenton A. (eds.). *The Spade in Northern and Atlantic Europe*. Ulster Folk Museum Institute of Irish Studies, Queen's University, Belfast., pp. 148-154.

Lewis, H.A. (1998) *The characterisation and interpretation of ancient tillage practices through soil micromorphology: a methodological study*. Unpublished PhD thesis, University of Cambridge.

Lillios, K.T. (1992) Phosphate fraction of soils at Agroal, Portugal. *American Antiquity* **57 (3)**, pp. 495-506.

Lippi, R.D. (1988) Paleotopography and phosphate analysis of a buried jungle site in Ecuador. *Journal of Field Archaeology* **15**, pp. 85-97.

Lowe, A. (1794) *General view of the agriculture of the county of Berwick, with observations on the means of its improvement*. Board of Agriculture, London.

Lowe, C. (2000) *Archaeological evaluation in the Fey Field, Whithorn: Data Structure Report*. Headland Archaeology Ltd., Edinburgh.

Lucas, A.T. (1970) Paring and burning in Ireland: a preliminary survey. In Gailey, A. and Fenton A. (eds.). *The Spade in Northern and Atlantic Europe*. Ulster Folk Museum Institute of Irish Studies, Queen's University, Belfast, pp. 99-147.

Lythe, S.G.E. and Butt, J. (1975) *An economic history of Scotland 1100-1939*. Blackie, Glasgow.

MacArthur, E.M. (1990) *Iona: The living memory of a crofting community*. 2nd. Ed. Polygon, Edinburgh.

Macinnes, L. (1993) Archaeology as land use. In Hunter, J. and Ralston, I. (eds.) *Archaeological resource management in the UK: an introduction*. Alan Sutton Publishing Ltd., Stroud, pp. 243-255.

Macinnes, L. (2003) Medieval or later rural settlement in Scotland: ten years on. In Govan, S. (ed.) *Medieval or later rural settlement in Scotland: 10 years on*. Conference Proceedings, Edinburgh: Historic Scotland/Medieval Settlement Research Group, pp. 3-16.

Mackenzie, J.R. (1998) Excavations at Green's Playhouse, 106-110 Nethergate, Dundee, with contributions by D.W. Hall, A. Cox, C. Smith and T.G. Holden. *Tayside and Fife Archaeological Journal* **4**, 179-201.

Maclelland, T. (1875) On the agriculture of the Stewartry of Kirkcudbright and Wigtownshire. Transactions of the Highland and Agricultural Society of Scotland. Accessed at www.buittle. org.uk.

Macphail, R.I. (1983) The micromorphology of dark earth from Gloucester, London and Norwich: an analysis of urban anthropogenic deposits from the late Roman to early Medieval periods in England. In Bullock, P. and Murphy, C.P. (eds.) *Soil Micromorphology. Volume 1: Techniques and Applications*. AB Academic Publishers Ltd., Herts., pp. 245-252.

Macphail R.I. (1994) The reworking of urban stratigraphy by human and natural processes. In Kenward, H. and Hall, A. *Urban-rural connexions: perspectives from environmental archaeology*. Oxbow Monograph 47, Oxford, pp. 13-43.

Macphail, R.I. (1998) A reply to Carter and Davidson's 'An evaluation of the contribution of soil micromorphology to the study of ancient arable agriculture'. *Geoarchaeology* **13 (6)**, pp. 549-564.

Macphail, R.I. (2003) Industrial activities – some suggested microstratigraphic signatures: ochre, building materials and iron working. In Murphy, P. and Wiltshire, P.E.J. (eds.) *The Environmental Archaeology of Industry*. Symposium No 20 of the Association for Environmental Archaeology. Oxbow, Oxford, pp. 94-106.

Macphail. R.I. and Cruise, G.M. (2000) Rescuing our urban archaeological soil heritage: a multidisciplinary microstratigraphical approach. *Proceedings of the First International Conference on Soil of Urban, Industrial, Traffic and Mining Areas: The Unknown Urban Soil, Detection, Resources and Faces*. University of Essen, Germany, July 2000, pp. 9-14.

Macphail. R.I., Romans, J.C.C. and Robertson, L. (1987) The application of soil micromorphology to the understanding of Holocene soil development in the British Isles, with special reference to early cultivation. In Fedoroff, N., Bresson, L.M. and Courty, M-A. (eds.) *Micromorphologie des Sols – Soil Micromorphology*. AFES, Plaisir, pp. 647-656.

Macphail, R.I., Courty, M-A and Gebhardt, A. (1990) Soil micromorphological evidence of early agriculture in north-west Europe. *World Archaeology* **22**, pp. 53-69.

Macphail, R.I., Cruise, G.M., Mellalieu, S.J. and Niblett, R. (1998) Micromorphological interpretation of a 'turf-filled' funerary shaft at St. Albans, United Kingdom. *Geoarchaeology* **13 (6)**, pp. 617-644.

Macphail, R.I., Cruise, G., Engelmark, R. and Linderholm, J. (2000) Integrating soil micromorphology and rapid chemical survey methods: new developments in reconstructing past rural settlement and landscape organisation. In Roskams, (ed.) *Interpreting stratigraphy: site evaluation, recording procedures and stratigraphic analysis*. BAR International Series 910, Oxford, pp. 71-80.

Macphail, R.I., Galinie, H. and Verhaeghe, F. (2002) A future for Dark Earth ? *Antiquity* **77 (296)**, pp. 349-358.

Marshall, J. (1794) *General view of the agriculture of the Central Highlands, with observations on the means of its improvement*. Board of Agriculture, London.

Martin, A. (1794) *General view of the agriculture of the county of Renfrew, with observations on the means of its improvement*. Board of Agriculture, London.

Martin, M. (1695) *A Description of the Western Islands Of Scotland ca. 1695 and a Late Voyage to St. Kilda*. Reprinted: Berlinn, Edinburgh.

Matthiesen, H. (2004) In-situ measurement of soil pH. *Journal of Archaeological Science* **31**, pp. 1373-1381.

Mattingly, G.E.G. and Williams, R.J.B. (1962) A note on the chemical analysis of a soil buried since Roman times. *Journal of Soil Science* **13**, pp. 254-258.

Maxwell, H (1930) *The place-names of Galloway: their origin and meaning considered*. Jackson and Wylie, Glasgow.

McCawley, J.C. and McKerrell, H. (1972) Soil phosphorus levels at archaeological sites. *Proceedings of the Society of Antiquaries of Scotland* **104**, pp. 301-306.

McCobb, L.M.E., Briggs, D.E.G., Carruthers, W.J. and Evershed, R.P. (2003) Phosphatisation of seeds and roots in a Late Bronze Age deposit at Potterne, Wiltshire, UK. *Journal of Archaeological Science* **30**, pp. 1269-1281.

McCulloch, A. (2000) *Galloway: a land apart*. Birlinn, Edinburgh.

McFaulds, J. (1980) *Forfarshire landowners and their estates, 1660-1690*. Unpublished PhD thesis, University of Glasgow.

McGowan, I. (ed.) (1966) *Samuel Johnson and James Boswell: Journey to the Hebrides*. Canongate, London.

McKenzie, J.T. (forthcoming) *Soil micromorphology*. Prepared for: Excavations at Inveresk Roman Fort. GUARD, Glasgow.

Meharg, A.A., Deacon, C., Edwards, K.J., Donaldson, M., Davidson, D.A., Spring, C., Scrimgeour, C.M., Feldman, J. and Rabb, A. (2006) Ancient manuring practices pollute arable soils at the St. Kilda World Heritage site, Scottish North Atlantic. *Chemosphere* **64**, pp. 1818-1828.

Millard, A. (2001) The deterioration of bone. In Brothwell, D.R. and Pollard, A.M. (eds.) Handbook of Archaeological Sciences. John Wiley and Sons, Edinburgh, pp. 637-647.

Miller, N.F. and Gleason, K.L. (1994) *The archaeology of garden and field*. University of Pennsylvania Press, Philadelphia.

Monro, D. (1549) *Description of the Western Islands of Scotland, called Hybrides, by Mr. Donald Monro, who travelled through most of them in the year 1549*. John Wylie, Glasgow.

Moore, T.R. and Denton, D. (1988) The role of soils in the interpretation of archaeological sites in Northern Quebec. In Bintliff, J.L., Davidson, D.A. and Grant, E.G. *Conceptual Issues In Environmental Archaeology*. Edinburgh University Press, Edinburgh, pp. 25-37.

Morris, R. (2002) *Reshaping the landscape/re-thinking the land*. Lecture to the Royal Society for the Encouragement of Arts Manufactures and Commerce (RSA), January 2002. English Heritage.

Mucher, H.J., Slotboom, R.T. and ten Veen, W.J. (1990) Palynology and micromorphology of a man-made soil: a reconstruction of the agricultural history since late-medieval times of the Posteles in the Netherlands. *Catena* **17**, p. 55-67.

Murray, J.C. (1982) Conclusions. In Murray J.C. (ed.). Excavations in the Medieval burgh of Aberdeen 1973-1981. *Society of Antiquaries of Scotland Monograph Series* **2**, pp. 244-249.

Muckenhausen, E. (1962) The soil classification system of the Federal Republic of Germany. *Transactions of the International Soil Conference, New Zealand*, pp. 377-387.

Myhre, B. (1985) Arable fields and farm structure. *Archaeology and Environment* **4**, pp. 69-82.

Myrdal, J. (1997) The agricultural transformation of Sweden, 1000-1300. In Astill, G. and Langdon, J. (eds.) *Medieval Farming and Technology: The Impact of Agricultural Change in Northwest Europe Vol 1: Technological Change*. Brill, Leiden, pp. 147-171.

Nachtergaele, F.O., Spaargaren, O., Deckers, J.A. and Ahrens, B. (2000) New developments in soil classification: World Reference Base for Soil Resources. *Geoderma* **96**, pp. 345-357.

Naismith, J. (1794) *General view of the agriculture of the county of Clydesdale, with observations on the means of its improvement*. Board of Agriculture, London.

Nicolson, J.R. (1972) *Shetland*. David and Charles, Newton Abbott.

Nicolson, J.R. (1978) *Traditional life in Shetland*. Robert Hale, London.

Nicholson, R.J. (1980) Modern ploughing techniques. In Hinchcliffe, J. and Schadla-Hall, R.T. (eds.) *The past under the plough. Papers presented at the seminar on plough damage and archaeology held at Salisbury February 1977*. Directorate of Ancient Monuments and Historic Buildings Occasional Paper 3, Department of the Environment, London, pp. 22-25.

Norton, LD. and Schroeder, S.L. (1987) The effect of various cultivation methods on soils loss: a micromorphological approach. In Fedoroff, N., Bresson, L.M. and Courty, M-A. (eds.) *Micromorphologie des Sols – Soil Micromorphology*. AFES, Plaisir, pp. 431-436.

Nunez, M. (1990) Phosphate survey. *Norwegian Archaeological Review* **23**, pp. 120-127.

Nunez, M. and Vinberg, A. (1990) Determinations of anthropic soil phosphate on Aland. *Norwegian Archaeological Review* **23**, pp. 93-104.

Nys, C., Bullock, P. and Nys, A. (1987) Micromorphological and physical properties of a soil under three different species of trees. In Fedoroff, N., Bresson, L.M. and Courty, M-A. (eds.) *Micromorphologie des Sols – Soil Micromorphology*. AFES, Plaisir, pp. 459-464.

O'Danachair, C. (1970) The use of the spade in Ireland. In Gailey, A. and Fenton A. (eds.). *The Spade in Northern and Atlantic Europe*. Ulster Folk Museum Institute of Irish Studies, Queen's University, Belfast, pp. 49-56.

Odgaard, B.V. (1989) Heathland history in Western Jutland, Denmark. In Birks, H.H., Birks, H.J.B., Kaland, P.E. and Moe, D. (eds.) *The Cultural Landscape: Past, Present and Future*. Cambridge University Press, Cambridge, pp. 311-319.

Ottaway, J.H. (1984) Persistence of organic phosphates in buried soils. *Nature* **307**, pp. 257-259.

Pape, J.C. (1970) Plaggen soils in the Netherlands. *Geoderma* **4**, pp. 229-255.

Parnell, J.J., Terry, R.E. and Nelson, Z. (2002) Soil chemical analysis applied as an integrative tool for ancient human activities in Piedras Negras, Guatemala. *Journal of Archaeological Science* **29**, pp. 379-404.

Paterson, H. and Cushion, B. (2003) Managing monuments in Norfolk. *The Archaeologist* **47**, pp. 20-21.

Pettry, D.E. and Bense, J.A. (1989) Anthropic epipedons in the Tombigbee Valley of Mississippi. *Soil Science Society of America Journal* **53**, pp. 505-511.

Pollard, A.M. (1998) The chemical nature of the burial environment. In Corfield, M., Hinton, P., Nixon, T. and Pollard, A.M. (eds.) Preserving archaeological remains in situ. Museum of London Archaeology Service, London, pp. 60-65.

Poulsen, B. (1997) Agricultural technology in Medieval Denmark. In Astill, G. and Langdon, J. (eds.) *Medieval Farming and Technology: The Impact of Agricultural Change in Northwest Europe Vol 1: Technological Change*. Brill, Leiden, pp. 115-145.

Prosch-Danielsen, L. and Simonsen, A. (1988) Principal components analysis of pollen, charcoal and soil phosphate data as a tool in prehistoric land-use investigation at Forsandmoen, southwest Norway. *Norwegian Archaeological Review* **21**, pp. 85-102.

Proudfoot, B. (1976) The analysis and interpretation of soil phosphorus in archaeological contexts. In Davidson, D.A. and Shackley, M.L. (eds.). *Geoarchaeology*. Duckworth, London, pp. 93-113.

Provan, D.M.J. (1971) Soil phosphate analysis as a tool in archaeology. *Norwegian Archaeological*

Review **4**, pp. 37-50.

Provan, D.M.J. (1973) The soils of an Iron Age farm site, Bjellandsoynae, S. W. Norway. *Norwegian Archaeological Review* **6**, pp. 30-41.

Ramage, C. (1910) *Map of Nairn*. Glasgow.

Rampini, C. J.G. (1987) *History of Moray and Nairn*. Edinburgh.

RCAHMS (1993) *Strath of Kildonan: an archaeological survey*. Afforestable Land Survey, RCAHMS, Edinburgh.

RCAHMS (1994a) *Glenesslin, Nithsdale: an archaeological survey*. Afforestable Land Survey, RCAHMS, Edinburgh.

RCAHMS (1994b) S*outhdean Borders: an archaeological survey*. Afforestable Land Survey, RCAHMS, Edinburgh.

RCAHMS (1994c) *Braes of Doune: an archaeological survey*. Afforestable Land Survey, RCAHMS, Edinburgh.

RCAHMS (1994d) *South-east Perth: an archaeological landscape.* HMSO, Edinburgh.

RCAHMS/Historic Scotland (2002) *But the walls remained: a survey of unroofed rural settlement depicted on the first edition of the Ordnance Survey 6-inch map of Scotland*. Historic Scotland/RCAHMS, Edinburgh.

Reedy, C.L. (1994) Thin-section petrography in studies of cultural materials. *Journal of the American Institute for Conservation* **33 (2)**, pp. 115-129.

Renfrew, C. and Bahn, P. (1996) *Archaeology: theories, methods and practice*. Thames and Hudson, London.

Reynolds, P.J. and Schadla-Hall, R.T. (1980) Measurement of plough damage and the effects of ploughing on archaeological material. In Hinchcliffe, J. and Schadla-Hall, R.T. (eds.) *The past under the plough. Papers presented at the seminar on plough damage and archaeology held at Salisbury February 1977*. Directorate of Ancient Monuments and Historic Buildings Occasional Paper 3, Department of the Environment, London, pp.114-122.

Robertson, D. (1794) *General view of the agriculture of the southern districts of Perth, with observations on the means of their improvement*. Board of Agriculture, London.

Robertson, G. (1795) *General view of the agriculture of the county of Mid-Lothian, with observations on the means of its improvement*. Board of Agriculture, London.

Robertson, J (1799) *General view of the agriculture of the county of Perth, with observations on the means of its improvement*. Board of Agriculture, London.

Robertson, J (1808) *General view of the agriculture of the county of Inverness, with observations on the means of its improvement*. Board of Agriculture, London.

Robinson, M. and Straker, V. (1991) Silica skeletons of macroscopic plant remains from ash. In Renfrew, J.M. (ed.) *New light on early farming: recent developments in palaeoethnobotany*. Edinburgh University Press, Edinburgh, pp. 3-13.

Robson, M. (1984) The Border farm worker. In Devine, T.M. (ed.) F*arm servants and labour in*

Lowland Scotland 1770-1914. John Donald, Edinburgh, pp. 71-96.

Roger, J. (1794) *General view of the agriculture of the county of Angus or Forfar, with observations on the means of its improvement*. Board of Agriculture, London.

Romans, J.C.C. and Robertson, L. (1983) The general affects of early agriculture on the soil profile. In Maxwell, G.S. (ed.) The impact of aerial reconnaissance on archaeology. CBA Research Report 49. Council for British Archaeology, London, pp. 136-141.

Rowell, D.L. (1994) *Soil science: methods and applications*. Longman Scientific and Technical, Harlow.

Sanchez, A., Canabate, M.L. and Lizcaino, R. (1996) Phosphorus analysis at archaeological sites: an optimization of the method and interpretation of the results. *Archaeometry* **38**, pp. 151-164.

Sanchez, A. and Canabate, M.L. (1999) Identification of activity areas by soil phosphorus and organic matter analysis in two rooms of the Iberian Sanctuary 'Cerro El Pajarillo'. *Geoarchaeology* **14 (1)**, pp. 47-62.

Sandison, C. (1968) *Unst: my island home and its story*. The Shetland Times, Lerwick.

Sandor, J.A., Gersper, P.L. and Hawley, J.W. (1986a) Soils at prehistoric agricultural terracing sites in New Mexico: II. Organic matter and bulk density changes. *Soil Science Society of America Journal* **50**, pp. 173-177.

Sandor, J.A., Gersper, P.L. and Hawley, J.W. (1986b) Soils at prehistoric agricultural terracing sites in New Mexico: III. Phosphorus, selected micronutrients, and pH. *Soil Science Society of America Journal* **50**, pp. 177-180.

Schiffer, M.J. (1987) *Formation processes of the archaeological record*. University of New Mexico Press, Alberquerque.

Schlezinger, D.R. and Howes, B.L. (2000) Organic phosphorus and elemental ratios as indicators of prehistoric human occupation. *Journal of Archaeological Science* **27**, pp. 479-492.

Schwarz, G.T. (1967) A simplified chemical test for archaeological field work. *Archaeometry* **10**, pp. 57-63.

Scottish Biodiversity Forum (2004) *An Overview of the Implementation Plans 2005-2008. Scotland's Biodiversity – It's In Your Hands. A strategy for the conservation and enhancement of biodiversity in Scotland*. Scottish Biodiversity Forum/Scottish Executive.

Scottish Executive (2003) *Scottish Planning Policy SPP3: Planning for Housing*. Scottish Executive Development Department.

Scottish Executive (2006) *Cross Compliance: Notes for Guidance*. Scottish Executive/Natural Scotland.

Shaw, F.J. (1980) *The Northern and Western Islands of Scotland: their economy and society in the seventeenth century*. John Donald, Edinburgh.

Shevtsova, L., Romanenkov, V., Sirotenko, O., Smith, P., Smith, J., Leech, P., Kanzyvaa, S. and Rodionova, V. (2003) Effect of natural and agricultural factors on long-term soil organic matter dynamics in arable soddy-podzolic soils – modelling and observation. *Geoderma* **116**, pp. 165-189.

Siderius, W. and de Bakker, H. (2003) Toponymy and soil nomenclature in the Netherlands.

Geoderma **111**, pp. 521-536.

Simpson, I.A. (1985) *Anthropogenic sedimentation in Orkney: the formation of deep top soils and farm mounds.* Unpublished PhD. thesis, University of Strathclyde.

Simpson, I.A. (1993) The chronology of anthropogenic soil formation in Orkney. *Scottish Geographical Magazine* **109(1**), pp. 4-11.

Simpson, I.A. (1997) Relict properties of anthropogenic deep top soils as indicators of infield management in Marwick, West Mainland, Orkney. *Journal of Archaeological Science* **24**, pp. 365-380.

Simpson, I.A. (1998) Early land management at Toft's Ness, Sanday, Orkney: the evidence of thin section micromorphology. In Mills, C.M. and Coles, G. (eds.) *Life on the edge: human settlement and marginality*. Oxbow Monograph 100, Oxford, pp. 91-98.

Simpson, I.A. and Barrett, J.H. (1996) Interpretation of midden formation processes at Robert's Haven, Caithness, Scotland using thin section micromorphology. *Journal of Archaeological Science* **23**, pp. 543-556.

Simpson, I.A. and Guttmann, E.B. (2002) Transitions in early arable land management in the Northern Isles: the *papar* as agricultural innovators? In Crawford, B.E. (ed.) *The papar in the North Atlantic: environment and history*. St. John's House Papers 10, St. Andrews., pp. 59-67.

Simpson, I.A., Dockrill, S.J., Bull, I.D. and Evershed, R.P. (1998a) Early anthropogenic soil formation at Toft's Ness, Sanday, Orkney. *Journal of Archaeological Science* **25**, pp. 729-746.

Simpson, I.A., Dockrill, S.J. and Lancaster, J. (1998b) Making arable soils: anthropogenic soil formation in a multi-period landscape. In Nicholson, R.J. and Dockrill, S.J. (eds.) *Old Scatness Broch: Retrospect and Prospect*. North Atlantic Biocultural Organisation Monograph 2, University of Bradford, Bradford, pp. 112-126.

Simpson, I.A., Bryant, R.G., Tveraabak, U. (1998c) Relict soils and early arable land management in Lofoten, Norway. *Journal of Archaeological Science* **25**, pp. 1185-1198.

Simpson, I.A., Bol, R., Bull, I.D., Evershed, R.P., Petzke, K.-J. and Dockrill, S.J. (1999) Interpreting early land management through compound specific stable isotope analyses of archaeological soils. *Rapid Communications in Mass Spectrometry* **13**, pp. 1315-1319.

Simpson, I.A., Perdikaris S., Cook G., Campbell J.L. and Teesdale, W.J. (2000) Cultural sediment analyses and transitions in early fishing activity at Langenesvaeret, Vesteralen, Northern Norway. *Geoarchaeology* **15 (8)**, pp. 743-763.

Simpson, I.A., Vesteinsson, O., Adderley, W.P. and McGovern, T.H. (2003) Fuel resource utilisation in landscapes of settlement. *Journal of Archaeological Science* **30**, pp. 1401-1420.

Simpson, I.A., Gudmundsson, G., Thomson, A.M. and Cluett, J. (2004) Assessing the role of winter grazing in historic land degradation, Myvatnssveit, Northeast Iceland. *Geoarchaeology* **19**, pp. 471-502.

Simpson, I.A., Milek, K. B. and Barrett, J.H. (2005) Interpreting the Viking age to Medieval period transition in Norse Orkney through cultural soil and sediment analyses. *Geoarchaeology* **20**, pp. 357-379.

Simpson, J.B. (1956) *Nairn and its neighbourhood in 1770*. Address given to the Nairn Literary Society, 7th February 1956.

Simson, A (1684) A large description of Galloway, M.DC.LXXX.IV, with an appendix, containing original papers, from the Sibbald and Macfarlane MSS. Thomas Maitland, Lord Dundrennan.

Sinclair, J. (1791-1799) (ed.) *The First Statistical Account of Scotland*. Edinburgh.

Sinclair, J. (1795) *General view of the agriculture of the northern counties and islands of Scotland, including the counties of Cromarty, Ross, Sutherland and Caithness, and the islands of Orkney and Shetland: with observations on the means of their improvement*. Board of Agriculture, London.

Sinclair, J. (1796) *Plan for reprinting the agricultural surveys*. Great Britain Board of Agriculture, London.

Sinclair, J. (1798) *History of the Origin and Progress of the Statistical Account*. Edinburgh.

Sinclair, J. (1813) *An account of some of the systems of husbandry adopted in the more improved districts of Scotland: with some observations on the improvements of which they are susceptible*. Board of Agriculture, Edinburgh.

Sinclair, J. (1814) *General Report on the Agricultural State and Political Circumstances of Scotland, drawn up for the Consideration of the Board of Agriculture*. Edinburgh.

Sinclair, J. (1826) *Analysis of the Statistical Account of Scotland, with a General View of the History of that Country, and discussions on some important branches of Political Economy*. Constable, Edinburgh.

Sjoberg, A. (1976) Phosphate analysis of anthropic soils. *Journal of Field Archaeology* **3**, pp.447-454.

Skene-Keith, G. (1811) *General view of the agriculture of the county of Aberdeenshire, with observations on the means of its improvement*. Board of Agriculture, London.

Slicher van Bath, B.H. (1963) *The Agrarian History of Western Europe AD 500-1850*. Edward Arnold, London.

Small, A. (1966) Excavations at Underhoull, Unst, Shetland. *Proceedings of the Society of Antiquaries of Scotland* 98, pp. 225-248.

Smeck, N. (1985) Phosphorus dynamics in soils and landscapes. *Geoderma* **36**, pp. 185-199.

Smith, B. (2000) *Toons and tenants: settlement and society in Shetland, 1299-1899*. Shetland Times, Lerwick.

Smith, B.F. and Bain, D.C. (1982) A sodium hydroxide fusion method for the determination of total phosphate in soils. *Communications in Soil Science and Plant Analysis* **13 (3)**, pp. 185-190.

Smith, H. (1994) Middening in the Outer Hebrides: an ethnoarchaeological approach. Unpublished PhD thesis, University of Sheffield.

Smout, T.C. (1969) *A history of the Scottish people 1560-1830*. Collins & Sons, Glasgow.

Smout, T.C. (2002) *Nature contested. Environmental history in Scotland and Northern England since 1600*. University Press, Edinburgh.

Soil Survey for Scotland (1970) 1:63,360 Soil Map of Latheron and Wick. Macaulay Institute for Soil Research, Aberdeen.

Soil Survey for Scotland (1974) 1:63,360 Soil Map of Nairn and Cromarty. Macaulay Institute for Soil Research, Aberdeen.

Soil Survey for Scotland (1981) 1:63,360 Soil Map of Orkney Hoy. Macaulay Institute for Soil Research, Aberdeen.

Soil Survey for Scotland (1981) 1:63,360 Soil Map of Orkney Mainland. Macaulay Institute for Soil Research, Aberdeen.

Soil Survey for Scotland (1985) 1:63,360 Soil Map of Auchentoul and Reay. Macaulay Institute for Soil Research, Aberdeen.

Somerville, R. (1796) *Outline of the fifteenth chapter of the proposed General Report from the Board of Agriculture: on the subject of manures.* Board of Agriculture, London.

Spek, T. (1992) The age of plaggen soils: an evaluation of dating methods for plaggen soils in the Netherlands and Northern Germany. In Verhoeve, A. and Vervloet, J.A.J. (eds.) *The Transformation of the European Rural Landscape: methodological issues and agrarian change 1770-1914. Papers from the 1990 meeting of the Standing European Conference for the Study of the Rural Landscape*. National Fund for Scientific Research, Brussels, pp. 72-87.

Spek, T., Groenman-van Waateringe, W., Kooistra, M. And Bakker, L. (2003) Formation and land-use history of Celtic fields in north-west Europe – an interdisciplinary case study at Zeijen, The Netherlands. *European Journal of Archaeology* **6 (2)**, pp. 141-173.

Spoor, G. (1980) Agronomic justification and technique for subsoil disturbance. In Hinchcliffe, J. and Schadla-Hall, R.T. (eds.) *The past under the plough. Papers presented at the seminar on plough damage and archaeology held at Salisbury February 1977*. Directorate of Ancient Monuments and Historic Buildings Occasional Paper 3, Department of the Environment, London, pp. 26-31.

Stein, J.K. (1992) Organic matter in archaeological contexts. In Holliday, V.T. (ed.) *Soils in archaeology: landscape evolution and human occupation.* Smithsonian Institute Press, Washington, D.C., pp. 193-216.

Stevenson, S.J. and Torrie, E.P.D. (1988) Historic Dundee: the archaeological implications of development. Scottish Burgh Survey for the Historic Buildings and Monuments Directorate. Scottish Urban Archaeological Trust, Perth.

Stoklund, B. (1999) Turf manuring on the Danish island of Laeso. *Geografisk Tidsskrift: Danish Journal of Geography (Special Issue)* **1**, pp. 209-214.

Stoops, G. (2003) *Guidelines for analysis and description of soil and regolith thin sections.* Soil Science Society of America, Inc. Madison, Wisconsin.

Syers, J.K., Williams, J.D.H. and Walker, T.W. (1968) The determination of total phosphorus in soils and parent materials. *New Zealand Journal of Agricultural Research* **11**, pp. 757-762.

Symon, J.A. (1959) *Scottish farming: past and present*. Oliver and Boyd, Edinburgh.

Tate, R.L. (1992) *Soil organic matter: biological and ecological effects*. Malabar, FL.

Terry, R.E., Hardin, P.J., Houston, S.D., Nelson, S.D., Jackson, M.W., Carr, J. and Parnell, J. (2000) Quantitative phosphorus measurement: a field test procedure for archaeological site analysis at Piedras Negras, Guatemala. *Geoarchaeology* **15 (2)**, pp. 151-166.

Thomson, J. (1825) *Map of Angus-shire.* J. Thomson and Co., Edinburgh.

Thomson, J. (1830) *Nairn and Elgin*. J. Thomson and Co., Edinburgh.

Thurley, S. (2003) Opinions. *The Archaeologist* **47**, pp. 24-25.

Thy, P., Segobye, A.K. and Ming, D.W. (1995) Implications of prehistoric glassy biomass slag from East-Central Botswana. *Journal of Archaeological Science* **22**, pp. 629-637.

Trow, S. (2001) Energy crops and the historic environment. Paper delivered to the National Energy Crops Conference, 27th September 2001 by Stephen Trow, Head of Countryside Policy http//www.defra.gov.uk /farm/acu/nat conf/heritage.pdf.

Turnbull, J. (1768) *A plan of the Island of Tiree in Argyle-shire, the Property of His Grace the Duke of Argyle, Surveyed and Plan'd, with Contents of the Farms*. Private Publication, Argyle Estates.

Turner, R. (2003) The Ben Lawers historic landscape project. In Govan, S. (ed.) (2003) *Medieval or later rural settlement in Scotland: 10 years on*. Conference Proceedings, Edinburgh: Historic Scotland/Medieval Settlement Research Group, pp. 31-33.

Ure, D. (1794a) *General view of the agriculture of the county of Dumbarton, with observations on the means of its improvement*. Board of Agriculture, London.

Ure, D. (1794b) *General view of the agriculture of the county of Roxburgh, with observations on the means of its improvement*. Board of Agriculture, London.

Usai, M. Raimonda (2001) Textural pedofeatures and pre-Hadrian's Wall ploughed paleosols at Stanwix, Carlisle, Cumbria, UK. *Journal of Archaeological Science* **28**, pp. 541-553.

USDA (1960) *Soil Taxonomy*. Soil Conservation Service, U.S. Department of Agriculture.

Van der Merwe, N.J. and Stein, P.H. (1972) Soil chemistry of postmolds and rodent burrows: identification without excavation. *American Antiquity* **37**, pp. 245-254.

Van de Westeringh, W. (1988) Man-made soils in the Netherlands, especially in sandy areas ('plaggen soils'). In Groenman-van Waateringe, W. and Robinson, M. (eds.) *Man-made Soils*. Symposia of the Association for Environmental Archaeology No. 6. BAR International Series 410, pp. 5-19.

de Vries, J. (1974) *The Dutch rural economy in the Golden Age, 1500-1700*. Yale University Press, London.

Walker, J.D. (1771) *Report on the Hebrides* (ed. McKay, M.). John Donald, Edinburgh.

Walker, T.W. and Syers, J.K. (1976) The fate of phosphorus during pedogenesis. *Geoderma* **15**, pp. 1-19.

Warden, A.J. (1885) *Angus or Forfarshire: the land and people, descriptive and historical. Vol. 5.* Charles Alexander and Co., Dundee.

Wattez, M.R. (1992) *Principles of geoarchaeology: an American perspective*. University of Arizona Press, Arizona.

Webster, J. (1794) *General view of the agriculture of the county of Galloway, with observations on the means of its improvement*. Board of Agriculture, London.

Wheeler, P.T. (1964) The Island of Unst, Shetland. Geographical Field Group Regional Studies No. 11. Geographical Field Group, Nottingham, England.

Whittington, G. (1973) Field systems of Scotland. In Baker, A.R.H. and Butlin, R.A. (1973) *Studies of field systems in the British Isles*. Cambridge University Press, Cambridge., pp. 530-579.

Widgren, M. (1997) Fields and field systems in Scandinavia in the Middle Ages. In Astill, G. and Langdon, J. (eds.) *Medieval Farming and Technology: The Impact of Agricultural Change in Northwest Europe Vol. 1: Technological Change*. Brill, Leiden, pp. 173-191.

Wilkinson, T.J. (1982) The definition of ancient manured zones by means of extensive sherd-sampling techniques. *Journal of Field Archaeology* **9**, pp. 323-333.

Williams, E.G. and Saunders, W.M.H. (1956) Distribution of phosphorus in profiles and particle-size fractions of some Scottish soils. *Journal of Soil Science* **7**, pp. 90-108.

Willis, D. (1991) *The story of crofting in Scotland*. John Donald, Edinburgh.

Wilson, C.A. (2000) *Processes of post-burial change in soils under archaeological monuments: a micromorphological study with particular reference to the processes of clay and iron redistribution*. Unpublished PhD. thesis, University of Stirling.

Withers, C.W.J. (1995) How Scotland came to know itself: geography, national identity and the making of a nation, 1680-1790. *Journal of Historical Geography* **21**, pp. 371-397.

Woods, W. I. (1977) The quantitative analysis of soil phosphate. *American Antiquity* **42**, pp. 248-252.

Woodward, D. (1990) 'An essay on manures': changing attitudes to fertilisation in England, 1500-1800. In Chartres, J.A. and Hey, D. (eds.) *English Rural Society 1500-1800*. Cambridge University Press, Cambridge, pp. 251-278.

Woodward, D. (1994) 'Gooding the earth': manuring practices in Britain 1500-1800. In Foster, S. and Smout, T.C. (eds.) *The history of soils and field systems*. Scottish Cultural Press, Aberdeen, pp. 101-110.

Wordsworth, J. (2003) Archaeology and agriculture in Scotland. *The Archaeologist* **47**, pp. 22-23

Yarnell, T. (2003) Not another one! Land use change, forestry and medieval or later rural settlement in Scotland. In Govan, S. (ed.) *Medieval or later rural settlement in Scotland: 10 years on*. Conference Proceedings, Edinburgh: Historic Scotland/Medieval Settlement Research Group, pp. 83-86

Yule, B. (1990) The 'dark earth' and late Roman London. *Antiquity* **64**, pp. 620-628.

Appendix 1: Manures cited in the County Agricultural Reports

County	Account	Manures Cited																						
		DUNG	COMPOSTS				SEAWEED	TURF		REDEPOSITION				LIME	MARL	SHELL/ SAND	TEATHING	TOWN DUNG	VEG WASTE	ASH	WATER	PARING & BURNING		OTHER MANURES
			used	traditional	w/ lime	w/ seaweed	alone	manure	dykes/building	earth	peat	sand	other soils									for	against	
Aberdeen	Anderson 1794	●	●	●	●		●	●	●					●		●	●	●		●	●	●	●	●
Angus (Forfar)	Roger 1794	●			●		●							●	●		●				●			
Argyll	Robson 1794	●	●	●	●		●		●		●			●	●	●	●			●		●	●	●
Ayr	Fullarton 1793	●	●	●	●		●							●	●		●		●			●	●	●
Banff	Donaldson 1974	●	●	●				●	●	●				●			●							
Berwick	Lowe 1794	●	●	●			●	●	●					●	●		●	●		●		●	●	
Caithness	Sinclair 1795	●	●	●	●	●	●	●	●					●	●	●						●		
Carse of Gowrie	Donaldson 1794	●												●	●									
Central Highlands	Marshall 1794	●						●	●					●	●		●					●		
Clackmannanshire	Graham 1814	●	●	●	●	●	●							●	●									
Clydesdale	Naismith 1794	●	●	●	●			●	●					●	●		●	●		●		●		●
Cromarty (& the Black Isle)	Sinclair 1795	●	●	●		●	●	●	●									●		●		●	●	
Dumbarton	Ure 1794	●			●	●	●		●	●	●	●		●		●	●	●		●				●
Dumfries	Johnston 1794	●			●				●				●	●	●	●	●	●	●	●	●	●		
East Lothian	Buchan-Hepburn 1794	●	●	●	●			●	●	●				●			●							●
Elgin or Moray	Donaldson 1974	●	●	●			●							●	●		●							
Fife	Beatson 1794	●	●	●			●		●					●	●							●	●	
Galloway	Webster 1794	●					●						●	●	●	●								
Hebrides (& Bute)	Heron 1794	●					●		●	●		●	●	●	●	●	●					●		
Inverness	Robertson 1808	●	●	●	●	●	●	●	●	●	●	●		●	●	●		●	●			●	●	
Kincardine, or the Mearns	Donaldson 1975	●	●	●		●	●							●	●			●						
Kinross	Graham 1814	●	●	●										●						●	●	●		
Mid Lothian	Robertson 1795	●			●									●	●			●						
Nairn	Donaldson 1794	●	●	●				●				●		●	●		●							
Orkney	Sinclair 1795	●	●	●			●		●					●	●					●				
Perth	Robertson 1799	●	●	●	●			●	●		●	●		●	●	●	●		●	●	●	●	●	●
Perth: Southern Districts	Robertson 1794	●	●	●	●			●		●				●	●	●	●				●	●		
Renfrew	Martin 1794	●	●	●	●					●				●				●				●		
Ross	Sinclair 1795	●	●	●	●		●							●	●	●				●				●
Roxburgh	Ure 1794	●		●	●				●					●	●		●							●
Selkirk	Johnston 1794	●			●				●					●	●		●					●	●	
Shetland	Sinclair 1795	●	●	●		●	●	●	●					●										
Stirlingshire	Graham 1812	●	●	●					●		●			●	●	●		●	●			●		●
Sutherland	Sinclair 1795	●	●	●		●	●	●	●		●			●		●	●			●				●
Tweedale	Johnston 1794	●	●	●	●			●	●					●			●		●	●	●		●	
West Lothian	Trotter 1794	●			●									●	●			●		●				●

Appendix 2: County and parish data integration

There are a significant number of discrepancies between the list of parishes in the Historic Scotland GIS database and those listed in the First Statistical Account. Parish names have changed, parish boundaries altered, and some parishes have disappeared altogether. Before a link code could be assigned to the two datasets, these discrepancies had to be investigated and corrected, and a perfect fit between the First Statistical Account and the Historic Scotland parish lists achieved. The following appendix explains the methodology behind these corrections and the assignation of parish codes. This appendix forms an important part of the archive to the manuring database which allows the user to query how the database has handled information from those parishes whose name or position has changed since the compilation of the First Statistical Account.

Several county areas have also undergone reorganisation since the compilation of the County Agricultural Reports. The end part of this section lists the changes made to the County manures list at Appendix 1 in order to correct discrepancies between the county areas defined in the Agricultural Reports and modern Scottish county boundaries.

Abbreviations:

FSA – First Statistical Account

SSA – Second Statistical Account

HS database – Historic Scotland database

1. Joined parishes

Some parishes that were separate areas at the time of the First Statistical Account are now united in the Historic Scotland database. As the Historic Scotland database is the one used to identify plaggen areas, these joined parishes are grouped under one code in the ArcView database.

County:	First Statistical Account:	Historic Scotland data:	Code:
Aberdeen	Cushnie		
	Leochel	Leochel-Cushnie	ABR19
Fife	Dysart		
	Kirkcaldy	Kirkcaldy and Dysart	FIF41
Forfar	Arbroath		
	St. Vigeans	Arbroath and St. Vigeans	FOR04
Linlithgow	Borrowstowness		
	Carriden	Bo'ness and Carriden	LIN03
Peebles	Broughton		
	Glenholm		
	Kilbucho	Broughton, Glenholm and Kilbucho	PEB01
Perth	Dunblane		
	Leocropt	Dunblane and Leocropt	PER27
Aberdeen	Auchindour		
	Forbes and Keane	Auchindour and Keane*	ABR05
	Tullynessle	Tullynessle and Forbes*	ABR77

* The First Statistical Account parish of Forbes and Keane is referenced to the accounts of both Auchindour and Tullynessle.

2. Separated parishes

Likewise, some united parishes have become separate since the First Statistical Account. Both parishes are referenced to the First Statistical Account reference for the united parish.

County:	Historic Scotland parish:	First Statistical Account parish:	Code:
Argyle	Strachur		
	Strathlachlan	Strachur and Stralachlan	ARG33
Argyle	Coll		
	Tiree	Tiree and Coll	ARG34

Forfar	Lundie		
	Fowlis Easter	Lundie and Foulis	FOR 37
Orkney	Cross and Burness		
	Lady	Cross, Burness, N. Ronaldshay and Ladykirk	ORK02
	Firth		
	Stenness	Firth and Stenness	ORK04
	Stromness		
	Sandwick	Stromness and Sandwick	ORK13
	Stronsay		
	Eday	Stronsay and Eday	ORK14
Roxburgh	Stitchill		
	Hume	Stitchell and Hume	ROX29
Shetland	Fetlar		
	Yell	Fetlar and North Yell* Yellmid and South*	SHL04 SHL12
Stirling	Larbert		
	Dunipace	Larbert and Dunipace	STR16

* The Historic Scotland parish of Fetlar is referenced to the First Statistical Account for Fetlar and North Yell, while that of Yell is referenced to the Accounts for both Yellmid and South, and Fetlar and North Yell.

3. Missing parishes

Some parishes on the Historic Scotland database have no entry in the First Statistical Account, being within the confines of another parish at 1799. These parishes carry the code for the parish they are within in the First Statistical Account:

County:	Historic Scotland parish:	Is within FSA parish:	Code:
Aberdeen	Old Machar	Aberdeen	ABR01
Argyle	Arisaig and Moidart	Ardnamurchan	ARG02
Argyle	Colonsay and Oronsay	Jura and Colonsay	ARG 11

Bute	North Bute	Rothesay	BUT04
Dumfries	Half Morton	Langholm	DUF27
Forfar	Dundee Combination	Dundee	FOR13
Inverness	Ardgour	N. area - Kilmalie	INV17
		S. area - Kilmonivaig	INV18
Orkney	Papa Westray	Westray	ORK16
Perth	Ardoch	Muthill	PER61
	Logiealmond	Moneydie	PER56
Roxburgh	Teviothead	Hawick	ROX10
Selkirk	Kirkhope	Yarrow	SEL04
	Caddonfoot	Stow	EDB23
Stirling	Grangemouth	Bothkennar	STR05
		Polmont	STR19

Additional notes:

Old Machar

The First Statistical Account groups Old Machar with the parish of Aberdeen, although they are treated as separate areas (FSA XIX: 144).

Arisaig and Moidart:

These areas are referenced as being part of Ardnamurchan parish throughout the Statistical Accounts (SSA VII: 118).

Colonsay and Oronsay:

The island of Oronsay does not feature in the parish name in either Account, but is discussed within the Jura and Colonsay parish (FSA X11: 317).

North Bute:

This area is referenced as being part of Rothesay parish throughout the Statistical Accounts (FSA I: 308).

Half Morton:

This area was annexed to Langholm parish during the period in which the Statistical Accounts were compiled: ‘small parish, which annexation still continues by the name of Halfmorton’ (FSA XIII: 588).

Dundee Combination:

Modern administrative area.

Ardgour:

The two polygons representing Ardgour in the Historic Scotland database appear to have been covered by two different parishes, in two different counties, at the compilation of the Statistical Account. The northern area of Ardgour appears to have been in Kilmalie (FSA VIII: 408) and the southern area in Kilmonivaig: ‘…bounded by the parish of Kilmalie to the west, by Fortingal to the south east, by Laggan to the east, by Glenelg and Kintail to the north, and by Boleskine to the north-east’ (FSA: XVII: 543). The FSA return for Ardgour gives no manuring detail, and thus the Historic Scotland parish is bracketed for convenience with just one of these (Kilmonivaig).

Papa Westray:

‘The parish of Westray comprehends in it the islands of Westray and Papa Westray’ (FSA XVI: 251)

Ardoch:

This parish seems to be treated as a part of Muthill in both First and Second Statistical Accounts, e.g. FSA VIII: 495, SSA X: 27.

Logiealmond:

This parish is treated within the Statistical Account of Moneydie, which describes ‘…the annexed district of Logiealmond, which extends to more than double the size of the original parish…’ (SSA X: 200).

Teviothead:

The Historic Scotland database shows Teviothead as sitting between the parishes of Hawick to the east and Eskdalemuir and Westerkirk to the west. However, the Statistical Account data describes Hawick as being '…bounded on the north, by the parishes of Roberton and Wilton; on the east, by the parish of Cavers; on the south, by Cavers and Kirktoun; and on the west, by Eskdalemuir and Westerkirk…' (SSA III: 380).

- *The Teviothead area appears to have been a part of Hawick during the Statistical Account.*

Kirkhope:

The Second Statistical Account refers to the Kirkhope district as part of Yarrow (SSA III: 29).

Caddonfoot:

This parish appears in the Historic Scotland database between the parishes of Stow, Melrose, Galashiels, Selkirk, Yarrow, Traquair and Innerleithen, on the north-east boundary of Selkirk, but there is no reference to Caddonfoot as either a parish or a place in the Statistical Accounts. However, the Statistical Account descriptions of the positions of the parishes of Selkirk ('…bounded on the north by the parishes of Galashiels and Stow…' (SSA III: 1)) and of Yarrow ('…on the north, by Traquair, Innerleithen, and Stow…'(SSA III: 29)) implies that the area covered by the Caddonfoot parish was a part of the parish of Stow at the time of the Statistical Account.

Grangemouth:

The Grangemouth parish is divided into two polygons in the Historic Scotland database, of which the northern one appears to be Bothkennar (see the note for Bothkennar, and FSA XVII: 295). The area of the southern polygon appears to be Polmont, which is '…bounded on the north, by the Frith of Forth; on the east…by the parish of Muiravonside; on the south, by Muiravonside and Slamanan parishes; and on the west, by the parish of Falkirk' (SSA VIII: 191) – the exact area covered by the southern Grangemouth polygon.

- The Grangemouth northern and southern parish polygons are referenced to the Statistical Accounts of Bothkennar and Polmont respectively.

4. Merged parishes

Likewise, some First Statistical Account parishes have been merged with nearby parishes during the last two centuries and are not referenced in the Historic Scotland data. Those parishes which can be firmly located as being within the area of another parish have their First Statistical Account data linked to that parish. Some, however, have disappeared within two or more parish areas, and their First Statistical Account data is therefore not referenced to any current parish.

County:	FSA parish:	Is within Historic Scotland parish:	Code:
Ayr	Newton-upon-Ayr	Ayr	AYR03
	St. Quivox	Ayr	AYR03
Edinburgh	Colinton	Edinburgh	EDB11
	Corstorphine	Edinburgh	EDB11
	Duddingston	Edinburgh	EDB11
	Liberton	Edinburgh	EDB11
Fife	Abbotshall	Kirkcaldy	FIF41
Forfar	Mains of Fintry	Mains and Strathmartine	FOR38
Lanark	Barony of Glasgow	Glasgow	LAN25
	Gorbals	Govan	LAN26
Linlithgow	Queensferry	Dalmeny	LIN04
Perth	Monzie	---	---
Renfrew	Abbey of Paisley	Paisley	REN14
Roxburgh	Kirktoun	Cavers	ROX06
	Wilton	---	---
Stirling	Bothkennar	Grangemouth (north)	STR05
	Polmont	Grangemouth (south)	STR19

Additional notes:

Newton upon Ayr: ‘on the banks of the Ayr…only a mile and a half in length…It is bounded on the north by the parish of Prestwick, on the east by the parishes of St. Quivox and Wallacetown on the south by the River Ayr, separating it from the town and parish of Ayr; and on the west by the Frith of Clyde’ (SSA V: 86).

St. Quivox: ‘It is bounded on the south by the River Ayr, and on the east, north and west, by the parishes of Tarbolton, Monkton and Newton’ (SSA V: 118).

- *Both Newton upon Ayr and St. Quivox now appear to be in the parish of Ayr.*

Colinton:

‘It is bounded on the north-west, by the parishes of Corstorphine and St. Cuthberts; on the north-east, by the parishes of Morningside (a new parish, quod sacra, separated from St. Cuthberts), and Liberton; on the south-east, by the parishes of Lasswade and Glencorse; and on the south-west, by those of Pencuik and Currie’ (SSA I: 108) – *Colinton appears now to be in the south-west area of the parish of Edinburgh.*

Corstorphine:

‘It is bounded on the north, by Cramond and Kirkliston; on the east, by St. Cuthberts; on the south, by Colinton, Currie and Ratho; and on the west, by Ratho and Kirkliston’ (SSA I: 205) – *Corstorphine appears now to be in the west part of the parish of Edinburgh.*

Duddingston:

‘Upon the south it is bounded by part of the parishes of Inveresk and Liberton, upon the west and north by those of St. Cuthberts, Canongate, and south Leith, and upon the east by the Frith of Forth’ (FSA XVIII: 359) – *Duddingston appears now to be in the east corner of the parish of Edinburgh.*

Liberton:

'between the parishes of Newton and Inveresk on the one side, and Duddingstone on the other…It is bounded on the north and west, by the parish of St. Cuthberts, on the north-east, by Duddingstone; on the east, by Inveresk; on the south-east, by Inveresk, Newton, and Dalkeith; on the south, by Lasswade, and on the south-west, by Colinton.' (SSA I: 1). – *Liberton appears now to be in the south-east corner of the parish of Edinburgh.*

Abbotshall:

'It is bounded by Kerkaldy (sic) on the E. Kinghorn and Auchtertool on the W. Auchterderran on the N. and the frith of Forth on the S.' (FSA IV: 185)

'…was disjoined from the parish of Kirkcaldy in the year 1650' (SSA IX: 146)

– *Abbotshall seems to be treated as part of the parish of Kirkcaldy.*

Mains of Fintry:

Mains and Strathmartine, 1845: 'The original name of Mains was Strathdighty…It appears to have been afterwards called the Mains of Fintry, the castle of that name being the principal object in the parish…For a number of years past, the parish has been called by the name of Mains' (SSA XI: 54) – *Mains of Fintry is the same as Mains and Strathmartine, the division being obsolete by the time of the Second Statistical Account.*

Barony of Glasgow:

'…extending from 2 to 5 or 6 miles around the city of Glasgow, except on the south side' (FSA XII: 109).

- *but is missing as a separate account in the 1845 parish list. The Barony of Glasgow parish therefore appears to now be part of Glasgow.*

Gorbals:

'The Gorbals of Glasgow was disjoined from the parish of Govan, and erected in to a separate parish the 21st of February 1771' (FSA V: 539)

but:

Govan: 'is now bounded by Renfrew on the west; New Kilpatrick, Barony and Glasgow on the north; Barony, Gorbals, and Rutherglen on the east; and the Abbey parish of Paisley on the south' (SSA VI: 668)

- *Gorbals is now part of the parish of Glasgow, as this now lies to the east of Govan.*

Queensferry:

'It is an erection, within the parish of Dalmeny, which took place in the year 1636; is surrounded by that parish on the south-west and east, and bounded by the Frith of Forth on the north' (FSA XVII: 489).

- *The Queensferry account is therefore referenced with Dalmeny.*

Monzie:

'It is bounded on the north by Dull, Weem, and Kenmore; on the east by Fowlis; on the south by Crieff; and on the west by Monievaird and Comrie' (SSA X: 262).

- *The parish of Monzie has disappeared between the boundaries of all these parishes and cannot reasonably be assigned to any one parish according to the Historic Scotland data.*

Abbey of Paisley:

'Till 1736, the parish extended over the town of Paisley; but…the town was erected into a separate parish…' (FSA VII: 74)

but:

by 1845 the parish is missing from the Second Statistical Account list, and the 1845 Account of the parish of Paisley states that 'It is bounded on the north and north-east by the parishes of Renfrew and Govan' (SSA VII.: 139).

- *Abbey of Paisley is therefore now within the area of the parish of Paisley.*

Kirktoun:

'It is bounded on all sides the parish of Cavers: on the west, it is partly bounded also the parish of Hawick; and on the north-east, by the parish of Hobkirk' (SSA III: 377).

- *Kirktoun now appears to be within the confines of the parish of Cavers, being too far east to be described as the missing Teviothead.*

Wilton:

'The parish of Wilton is bounded by Ashkirk and Roberton on the west; by Hawick on the south; by Cavers on the east; and by Minto and Lilliesleaf on the north.' (SSA III: 76).

-*The parish of Wilton has disappeared between the boundaries of all these parishes and cannot reasonably be assigned to any one parish according to the Historic Scotland data.*

Bothkennar:

'It is bounded on the north by the parish of Airth; on the west, by the parish of Larbert; on the south, by the parishes of Falkirk and Polmont; and on the east, by the river Forth' (FSA XVII: 295)

- *The parish of Bothkennar appears to be the polygon referenced in the Historic Scotland database as the northern section of Grangemouth – this could be a mistake in the database, or a renamed parish area. The Bothkennar account is therefore referenced to this polygon. See also the Grangemouth parish notes.*

Polmont:

The parish of Polmont is '…bounded on the north, by the Frith of Forth; on the east…by the parish of Muiavoside; on the south, by Muiravonside and Slamanan parishes; and on the west, by the parish of Falkirk' (SSA VIII: 191) – the exact area covered by the southern Grangemouth polygon.

- *The parish of Polmont is referenced to the southern polygon of the parish of Grangemouth in the Historic Scotland database.*

5. Changing county names and boundaries

Some parishes are listed in both the First Statistical Account and Historic Scotland data, but have moved counties since the First Statistical Account. The codes refer to the First Statistical Account county, giving an easy reference back to the FSA location of the parish if needed (the current county is shown in the database anyway and has its own theme within the GIS data).

Parish:	FSA county:	Current county:	Code:
Cumbrae/Cimbraes	Ayr	Bute	AYR21
Gartly	Banff	Aberdeen	BAN13
Glass	Banff	Aberdeen	BAN14
Arrochar	Dunbarton	Stirlingshire	DUB01
Kirkliston	Edinburgh (Midlothian)	Linlithgow (West Lothian)	EDB16
Ardclach	Elgin	Nairn	ELG02
Auldearn	Elgin	Nairn	ELG03
Nairn	Elgin	Nairn	ELG15
Cawdor	Inverness	Nairn	INV07
Cromdale, Inverallan and Advie	Inverness	Morayshire	INV08
Croy and Dalcross	Inverness	Nairn	INV09
Culross	Perth	Fife	PER22
	Perth	Kinross	PER33
Eastwood and Pollock	Renfrew	Lanark	REN03
Ashkirk	Roxburgh	Selkirk	ROX02
Hume (Stitchell and Hume)	Roxburgh	Berwick	ROX29
Alva	Stirling	Clackmannan	STR02

Some county names have also changed since the time of the First Statistical Account:

First Statistical Account:	Historic Scotland data:
Edinburgh	Midlothian
Elgin	Moray
Forfar	Angus
Haddington	East Lothian
Linlithgow	West Lothian

N.B. The Historic Scotland data county of Nairn is not included in the First Statistical Account data, which assigns the parishes within Nairn to either Elgin or Inverness.

6. Parish name changes

Finally, some parishes cover the same area but have different, or slightly different names in the FSA and Historic Scotland data:

County:	First Statistical Account:	Historic Scotland data:
Aberdeen	Deer	Old Deer (SSA XII: 138)
	Inverury	Inverurie
Argyle	Kilcalmonell and Kilberry	Kilcalmonell
	Kilfinichen and Kilviceuen	Kilfinichen and Kilviceon
	Kilmadan	Kilmodan
Ayr	Island and Parish of Cimbraes	Cumbrae
Banff	Boidie	Boyndie
Berwick	Dunse	Duns
	Merton	Mertoun
	Swinton and Simprin	Swinton
	Whitsome and Hilton	Whitsom
Caithness	Olrick	Olrig
Dunbarton	Row	Rhu
Dumfries	Graitney	Gretna
Forfar	Foulis	Fowlis Easter
	Strickathrow	Stracathro

Haddington	Salton	Saltoun
Inverness	Calder	Cawdor (FSA: IV: 349)
	Cromdale	Cromdale, Inverallan and Advie (SSA XIV: 432)
	Inverness	Inverness and Bona
	Pettie	Petty
Kincardine	Kinneff	Kinneff and Catterline
Orkney	Holme and Paplay	Holm
	Kirkwall	Kirkwall and St. Ola
	Ronaldshay and Burray	South Ronaldshay
	Rousay and Eagleshay	Rousay and Egilsay
Peebles	Linton	West Linton
	Manner	Manor
Perth	Dowally	Dunkeld and Dowally
	Gask	Findo Gask
Renfrew	Eastwood and Pollock	Eastwood
Ross and Cromarty	Kilmuir and Suddy	Knockbain (FSA XII: 263)
	Kirkmichael and Culliecudden	Resolis (SSA XIV: 38)
Roxburgh	Hownam	Hounam
	Stitchell (of Stitchell and Hume)	Stitchill
Shetland	Bressay, Burra and Quarff	Bressay
	Northmaving	Northmaven
	Sandsting and Aithsting	Sandsting
	Tingwall, Whiteness and Weesdale	Tingwall

- **County Agricultural Reports: boundary and name changes**

The County Agricultural Reports from the Carse of Gowrie, Central Highlands and the Southern Districts of Perth are all now within the county of Perth. The manuring details of all these counties are therefore linked to the Historic Scotland area of Perth.

The counties of Ross and Cromarty, separate at the time of the County Agricultural Report, are now joined. The manuring data for each of these Reports has therefore been combined.

The areas brought together in the County Agricultural Report for the Hebrides are all within separate counties, with the islands of Lewis within the county of Ross and Cromarty, those of Harris within Inverness, and the Inner Hebrides within Argyll. The manuring data for each of these regions has been reallocated accordingly. Bute is also included in the County Agricultural Report for the Hebrides, but is now a separate county in the Historic Scotland data. Manuring data relating to Bute has therefore been extracted from the Hebrides record and assigned to the Bute county area.

The County Agricultural Report for Galloway covers two modern county areas, Wigtownshire and Kirkcudbrightshire. As there is no detail assigning any of the manuring information in the Galloway report to either of these regions, manuring details for Galloway have been reallocated to each area.

Two counties have different names in the County Agricultural Reports: Tweedale is now known as Peebles, and Clydesdale as Lanark. The areas covered are the same.

Appendix 5: Deep topsoil polygon site information and sample pit descriptions and illustrations

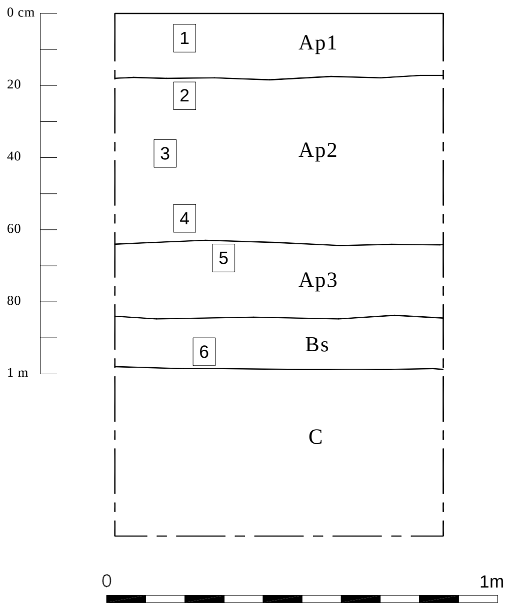
Site 1: Nairn, Nairnshire. Deep topsoil polygon information

Solid geology	Middle Old Red Sandstone
Drift geology	Recent and Pleistocene glacial sands and gravels and morainic gravels
Soil Association	Boyndie
Soil Series	Nairn (specifically 'deep phase' topsoil areas having an A horizon thicker than 40 cm)
Sampled profiles	NA1, NA2, NA3

Profile NA1: Ruallan Field

Grid Reference	288120/855500
Land cover/ vegetation	Grassland
Land use	Occasional pasturing, unfertilised
Macrorelief	Flat
Microrelief	Flat
Drainage	Well drained
Area surface features	None
Other information	Some aeolian deposition
Date of sampling	01/05/02

NA1: North facing section showing position of Kubiena samples



Horizon	Ap1
Depth	0-18 cm
Field Colour	7.5YR2.5/2: very dark brown
Description	Friable to very friable sandy loam, no mottles, of slightly sticky and plastic consistency. Weak to moderate granular, subangular blocky and crumb soil structures ranging from very fine to medium in size. Many (>2/cm^2) small to medium (1-5 mm) vesicular and tubular pores. Few (2%) subangular red pebbles, generally unweathered, 1-10 mm^2. No rock fragments. Frequent roots, diameter 2-5 mm. Common (6-8%) charcoal inclusions, 1-10 mm^2. Many (20%) smaller charcoal inclusions, <1 mm^2. Smooth, abrupt (<2 mm width) boundary with horizon Ap2. **Deep anthropogenic topsoil**.

Horizon	Ap2
Depth	19-64 cm
Field Colour	7.5YR3/2: dark brown
Description	Friable sandy loam, no mottles, of non-sticky and slightly plastic consistency. Weak to moderate granular, columnar, subangular blocky and crumb soil structures ranging from very fine to fine in size. Many (>2/cm^2) very small to medium (>1-5 mm) vesicular and tubular pores. Few (2-3%) subangular red and yellow pebbles, generally unweathered, 1-10 mm^2. Rare (<1%) subangular red rock fragments, unweathered, 11-20 mm^2. Common roots, diameter 1-2 mm. Common (6-8%) charcoal inclusions, 1-5 mm^2. Frequent (16%) smaller charcoal inclusions, <1 mm^2. Smooth, abrupt (<2 mm width) boundary with horizon Ap3. **Deep anthropogenic topsoil**.

Horizon	Ap3
Depth	64-84 cm
Field Colour	7.5YR3/1: very dark grey
Description	Friable sandy loam, no mottles, of non-sticky and slightly plastic consistency. Moderate granular, subangular blocky and crumb soil structures ranging from very fine to medium in size. Many (>2/cm^2) very small (<1 mm) vesicular and tubular pores. Common (7%) rounded red pebbles, unweathered, 1-10 mm^2. No rock fragments. Common roots, diameter 1-2 mm. Common (6%) charcoal inclusions, 1-2 mm^2. Common (6%) smaller charcoal inclusions, <1 mm^2. Wavy, clear (2-5 mm width) boundary with horizon Bs. **Deep anthropogenic topsoil**.

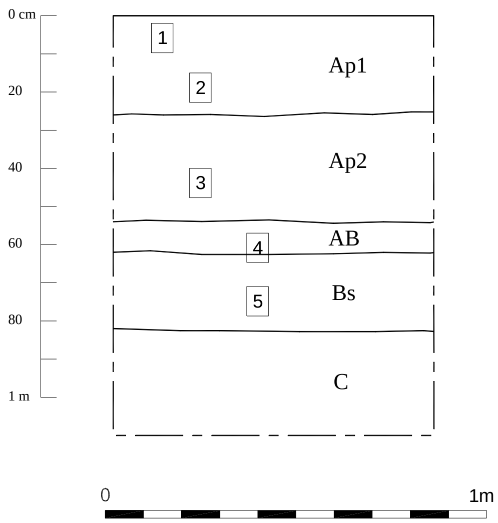
Horizon	Bs
Depth	84-98 cm
Field Colour	7.5YR4/3: brown
Description	Friable loamy sand, no mottles, of non-sticky and non plastic consistency. Weak columnar, subangular blocky and massive soil structures ranging from very fine to fine in size. Many (>2/cm^2) very small (<1 mm) vesicular and tubular pores. Few (2%) rounded red and yellow pebbles, unweathered, 5-10 mm^2. Rare (<1%) rounded red rock fragments, unweathered, 11-20 mm^2. Few roots, diameter <1 mm. Few (2%) charcoal inclusions, <1 mm^2. Broken and irregular diffuse (>12 mm width) boundary with horizon C. **B horizon showing illuviation characteristics**.

Horizon	C
Depth	>98 cm
Field Colour	7.5YR5/4: brown
Description	Loose sand, no mottles, of non-sticky and non plastic consistency. Many (>2/cm^2) very small (<1 mm) vesicular pores. Few (1%) rounded red and yellow pebbles, unweathered, 1-10 mm^2. Rare (<1%) rounded red rock fragments, 11-20 mm^2. No roots. Rare (<1%) small charcoal inclusions, <1 mm^2. **Natural fluvoglacial sand**.

Profile NA2: Firhall House

Grid Reference	288000/855130
Land cover/ vegetation	Deciduous woodland
Land use	Recreational
Macrorelief	Flat
Microrelief	Flat
Drainage	Well drained
Area surface features	None
Other information	Small area of recreational woodland planted in the grounds of Firhall House, assumed to date from the building of the House in the 1870s.
Date of sampling	03/05/02

NA2: North facing section showing position of Kubiena samples



Horizon	Ap1
Depth	0-26 cm
Field Colour	7.5YR3/1: very dark grey
Description	Friable to very friable sandy loam, no mottles, of sticky and slightly plastic consistency. Weak to moderate granular, subangular blocky and crumb soil structures ranging from very fine to fine in size. Many (>2/cm^2) very small to large (<1->5 mm) vesicular and tubular pores. Few (1%) rounded red and grey pebbles, unweathered, 1-10 mm^2. Rare (<1%) rounded red and grey rock fragments, unweathered, 11-20 mm^2. Frequent roots, diameter (<1->5 mm). Common (10%) charcoal inclusions, 1-2 mm^2. Frequent (20%) smaller charcoal inclusions, <1 mm^2. Smooth, abrupt (<2 mm width) boundary with horizon Ap2. **Deep anthropogenic topsoil**.

Horizon	Ap2
Depth	27-54 cm

Field Colour	7.5YR3/2: dark brown
Description	Friable sandy loam, no mottles, of slightly sticky and slightly plastic consistency. Weak to moderate granular, columnar, subangular blocky and crumb soil structures ranging from very fine to fine in size. Many (>2/cm^2) very small to medium (>1-5 mm) vesicular and tubular pores. Few (1-2%) subangular and rounded red and grey pebbles, unweathered, 1-10 mm^2. Few (1%) subangular and rounded red and grey rock fragments, unweathered, 11-60 mm^2. Common roots, diameter (<1->5 mm). Common (6%) charcoal inclusions, 1-2 mm^2. Frequent (18%) smaller charcoal inclusions, <1 mm^2. Smooth, abrupt (<2 mm width) boundary with horizon AB. **Deep anthropogenic topsoil**.

Horizon	AB
Depth	55-62 cm
Field Colour	7.5YR3/2: dark brown
Description	Friable to very friable sandy loam to loamy sand, no mottles, of slightly sticky and slightly plastic consistency. Weak to moderate granular, subangular blocky and crumb soil structures ranging from very fine to fine in size. Common (.5-2/cm^2) very small (<1 mm) vesicular and tubular pores. Common (10-15%) rounded red and grey pebbles, unweathered, 1-10 mm^2. Few (2%) rounded red and grey rock fragments, unweathered, 11-30 mm^2. Common roots, diameter <1-5 mm. Few (1%) charcoal inclusions, <1 mm^2. Wavy, abrupt (<2 mm width) boundary with horizon Bs. **Transitional horizon.**

Horizon	Bs
Depth	63-82 cm
Field Colour	10YR3/4: dark yellowish brown
Description	Very friable loamy sand, no mottles, of non-sticky and non plastic consistency. Moderate granular, subangular blocky, crumb and massive soil structures ranging from very fine to fine in size. Many (>2/cm^2) very small (<1 mm) vesicular and tubular pores. Few (3-5%) rounded red and grey pebbles, unweathered, 1-10 mm^2. Few (1%) rounded red rock fragments, unweathered, 11-30 mm^2. Common roots, diameter <1-2 mm. Few (2%) charcoal inclusions, <1 mm^2. Wavy, abrupt (<2 mm width) boundary with horizon C. **B horizon showing illuviation characteristics**.

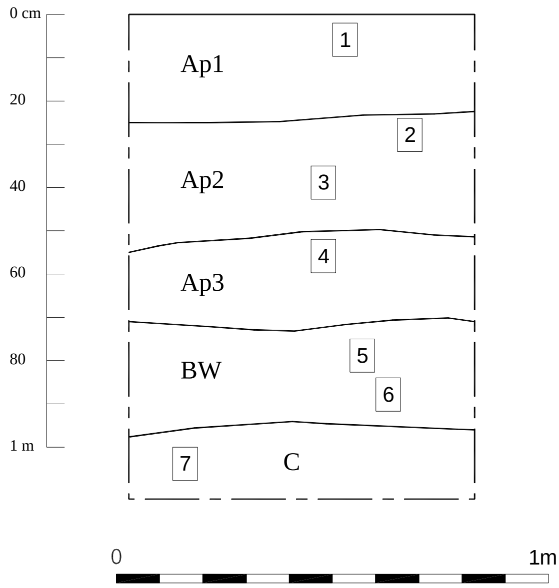
Horizon	C
Depth	>83 cm
Field Colour	10YR4/6: dark yellowish brown
Description	Loose coarse sand, no mottles, of non-sticky and non plastic consistency. Many (>2/cm^2) very small (<1 mm) vesicular pores. Common (10-15%) rounded red and grey pebbles, unweathered, 2-10 mm^2. Few (2%) rounded red and grey rock fragments, 11-15 mm^2. Few roots, diameter <1 mm. Few (1%) charcoal inclusions, <1 mm^2. **Natural fluvoglacial sand**.

Profile NA3: Loch Ddu Farm

Grid Reference	288100/855400
Land cover/ vegetation	Ploughed stubble
Land use	Arable.
Macrorelief	Flat
Microrelief	Gentle plough-created microrelief throughout field
Drainage	Well drained

Area surface features	None
Other information	Recently cropped of winter barley and ploughed and dusted in preparation for re-sowing. Some possible aeolian deposition.
Date of sampling	04/09/02

NA3: North facing section showing position of Kubiena samples



Horizon	Ap1
Depth	0-25 cm
Field Colour	7.5YR4/1: dark grey
Description	Very friable sand and loamy sand, no mottles, of slightly sticky and slightly plastic consistency. Moderate granular, subangular blocky and crumb soil structures ranging from very fine to medium in size. Many (>2/cm^2) small (1-2 mm) vesicular pores. Rare (<1%) rounded to flat red and grey pebbles, unweathered, 1-10 mm^2. Rare (<1%) flattish red and grey rock fragments, unweathered, 11-25 mm^2. Frequent roots, diameter 1-2 mm. Common (6%) charcoal inclusions, 1-2 mm^2. Frequent (20%) smaller charcoal inclusions, <1 mm^2. Smooth, clear (2-5 mm width) boundary with horizon Ap2. **Deep anthropogenic topsoil**.

Horizon	Ap2
Depth	26-55 cm
Field Colour	7.5YR4/2: brown
Description	Friable to very friable sand and loamy sand, no mottles, of slightly sticky and slightly plastic consistency. Moderate granular, columnar, subangular blocky and crumb soil structures ranging from very fine to fine in size. Common (.5-2/cm^2) very small to small (>1-2 mm) vesicular and tubular pores. Few (1-3%) subangular red and grey pebbles, unweathered, 2-10 mm^2. Few (1%) subangular red and grey rock fragments, 11-25 mm^2. Few roots, diameter <1-2 mm. Common (7%) charcoal inclusions, 1-2 mm^2. Common (10%) smaller charcoal inclusions, <1 mm^2. Smooth, abrupt (2 mm width) boundary with horizon Ap3. **Deep anthropogenic topsoil**.

Horizon	Ap3
Depth	56-71cm
Field Colour	7.5YR3/2: dark brown
Description	Friable to very friable loamy sand, no mottles, of slightly sticky and slightly plastic consistency. Weak granular, subangular blocky and crumb soil structures ranging from very fine to fine in size. Common (.5-2/cm^2) very small to small (<1-2 mm) vesicular and tubular pores. Few (1-3%) subangular red and grey pebbles, unweathered, 1-10 mm^2. Few (2%) subangular red and grey rock fragments, unweathered, 11-40 mm^2. Few roots, diameter <1-2 mm. Few (5%) charcoal inclusions, <1 mm^2. Wavy, clear (2-5 mm width) boundary with horizon Bw. **Deep anthropogenic topsoil**.

Horizon	Bw
Depth	72-96 cm
Field Colour	10YR4/4: dark yellowish brown
Description	Very friable sand and loamy sand, no mottles, of slightly sticky and slightly plastic consistency. Weak granular, subangular blocky and crumb soil structures ranging from very fine to fine in size. Few (<.5cm^2) very small to small (<1-2 mm) vesicular and tubular pores. Few (1%) subangular red and grey pebbles, unweathered, average size 1-10 mm^2. Few (2%) subangular red and grey rock fragments, unweathered, 11-40 mm^2. Few roots, diameter <1-2 mm. Few (4%) charcoal inclusions, <1 mm^2. Broken, gradual (5-12 mm width) boundary with horizon C. **Slightly weathered and leached B horizon**.

Horizon	C
Depth	>97 cm
Field Colour	10YR6/6: brownish yellow
Description	Loose sand, no mottles, of non-sticky and non plastic consistency. Few (<.5/cm^2) very small to small (<1-2 mm) vesicular pores. No pebbles or rocks. Few roots, diameter <1-2 mm. Few (1%) charcoal inclusions, size <1 mm^2. **Natural fluvoglacial sand**.

Site 2: Tealing, Dundee. Deep topsoil polygon 1*: information

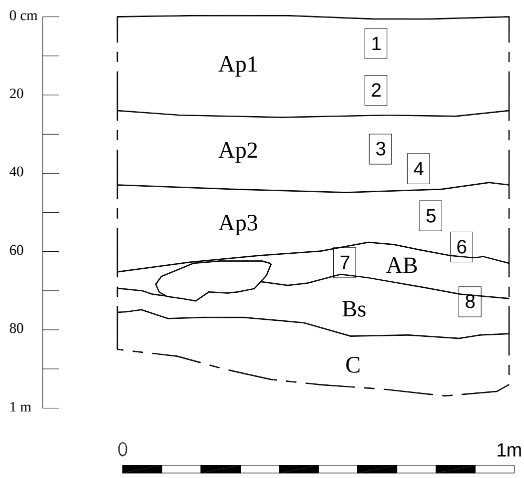
Solid geology	Igneous extrusive rocks: basic pyroxene andesite, mainly olivine-bearing and transitional to basalt; of Lower Devonian age
Drift geology	Till: compact sandy clay containing cherts of local rocks and far-travelled erratics
Soil Association	Balrownie
Soil Series	Balrownie: imperfectly drained brown forest soils
Sampled profiles	TE1

***** It is noted that although all three soil profiles sampled at Tealing are present on the same parent and soil materials, the deep topsoil polygon they represent is physically bisected by a deposit of alluvium which continues roughly NW-S-SSW across the grounds of Tealing House (see Figure 5.6). Although it is assumed that all three profiles are representative of the same deep topsoil forming process, this physical separation is acknowledged in the record.

Profile TE1: Tealing Village

Grid Reference	741050/338280
Land cover/ vegetation	Young crop (winter barley)
Land use	Arable.
Macrorelief	Flat
Microrelief	Gentle plough-created microrelief throughout field
Drainage	Imperfectly drained: water table at C horizon (82cm below surface)
Area surface features	None
Other information	Recently ploughed to a depth of 10cm. Groundwater on areas of field to south of soil profile. An Iron Age souterrain is located approximately 200m to the south-east of the soil profile.
Date of sampling	28/10/02

TE1: North facing section showing position of Kubiena samples



Horizon	Ap1
Depth	0-24 cm
Field Colour	7.5YR3/2: dark brown
Description	Friable to firm silty clay, no mottles, of slightly sticky and slightly plastic consistency. Moderate to strong granular and subangular blocky soil structures of medium size. Many (>2/cm^2) medium (2-5 mm) vesicular, interstitial and tubular pores. Common (10%) rounded and subangular yellow pebbles, slightly weathered, 1-10 mm^2. Few (5%) rounded and subangular yellow rock fragments, 11-40 mm^2. Common roots, diameter 1-2 mm. Common (7%) charcoal inclusions, 1-5 mm^2. Frequent (20%) smaller charcoal inclusions, <1 mm^2. Wavy, clear (2-5 mm width) boundary with horizon Ap2. **Deep anthropogenic topsoil**.

Horizon	Ap2
Depth	25-43cm
Field Colour	7.5YR3/3: dark brown
Description	Friable silty clay, with few (<2%) fine (<5 mm) faint diffuse dark brown (7.5YR3/2) mottles. Slightly sticky and slightly plastic consistency. Moderate to

strong granular and subangular blocky soil structures of medium size. Common (.5-2/cm^2) small (1-2 mm) vesicular and interstitial pores. Few (2%) rounded and subangular yellow pebbles, slightly weathered, 1-10 mm^2. Few (2%) rounded and subangular yellow rock fragments, unweathered, 11-20 mm^2. Few roots, diameter <1-2 mm. Common (6%) charcoal inclusions, 1-2 mm^2. Common (10%) smaller charcoal inclusions, <1 mm^2. Wavy, abrupt (<2 mm width) boundary with horizon Ap3. **Deep anthropogenic topsoil**.

Horizon	Ap3
Depth	44-63cm
Field Colour	7.5YR4/3: brown
Description	Friable to firm silty clay loam, with abundant (>40%) medium (5-15 mm) distinct diffuse yellowish brown (10YR5/6) and light yellowish brown (10YR6/4) mottles. Slightly sticky and slightly plastic consistency. Moderate to strong granular and subangular blocky soil structures of medium size. Common (.5-2/cm^2) very small to small (<1-2 mm) vesicular and interstitial pores. Common (10%) rounded and subangular red and yellow pebbles, weathered, 5-10 mm^2. Common (10%) subangular red and yellow rock fragments, slightly weathered, 11-200 mm^2. Few roots, diameter <1 mm. Few (2%) charcoal inclusions, <1 mm^2. Wavy, clear (2-5 mm width) boundary with horizon AB. **Deep anthropogenic topsoil**.

Horizon	AB
Depth	64-72cm
Field Colour	7.5YR3/4: dark brown
Description	Friable silt loam, with abundant (>40%) medium (5-15 mm) distinct diffuse yellowish brown (10YR6/4) mottles. Sticky and slightly plastic consistency. Moderate granular and subangular blocky soil structures of medium size. Common (.5-2 cm^2) medium (2-5 mm) vesicular pores. Common (10%) rounded and subangular red and yellow pebbles, weathered, 2-10 mm^2. Many (20%) subangular red and yellow rock fragments, slightly weathered, 20-200 mm^2. No roots. Few (2%) charcoal inclusions, <1 mm^2. Broken and irregular, gradual (5-12 mm width) boundary with horizon C. **Transitional horizon**.

Horizon	Bs
Depth	73-84 cm
Field Colour	10YR6/4: light yellowish brown
Description	Firm silty clay loam, with common (2-20%) fine (<5 mm) faint diffuse dark brown (7.5YR3/4) mottles. Sticky and slightly plastic consistency. Moderate granular, subangular blocky and crumb soil structures of fine to medium size. Common (.5-2 cm^2) medium (2-5 mm) vesicular pores. Few (5%) subangular red and yellow pebbles, slightly weathered, 1-10 mm^2. No rock fragments. No roots. Few (2%) charcoal inclusions, size <1 mm^2. Wavy and irregular, clear (2-5 mm width) boundary with horizon C. **B horizon showing illuviation characteristics**.

Horizon	C
Depth	<82 cm
Field Colour	5YR5/4: reddish brown
Description	Extremely firm silty clay loam, with common (2-20%) medium (5-15 mm) distinct diffuse yellowish brown (10YR6/4) mottles. Non-sticky and slightly plastic consistency. Moderate to strong granular, angular blocky, subangular blocky and massive soil structures of fine to medium size. No visible pores. No pebbles. Common (10%) rounded and subangular red and yellow rock fragments, weathering, 20-40 mm^2. No roots. Rare (<1%) charcoal inclusions, <1 mm^2. **Natural till**.

Site 2: Tealing, Dundee. Deep topsoil polygon 2*: information

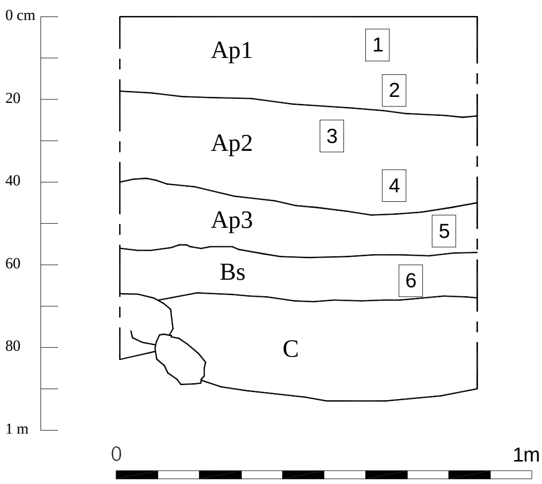
Solid geology	Igneous extrusive rocks: basic pyroxene andesite, mainly olivine-bearing and transitional to basalt, of Lower Devonian age
Drift geology	Till: compact sandy clay containing cherts of local rocks and far-travelled erratics
Soil Association	Balrownie
Soil Series	Balrownie: imperfectly drained brown forest soils
Sampled profiles	TE2, TE3

***** It is noted that although all three soil profiles sampled at Tealing are present on the same parent and soil materials, the deep topsoil polygon they represent is physically bisected by a deposit of alluvium which continues roughly NW-S-SSW across the grounds of Tealing House (see Figure 5.6). Although it is assumed that all three profiles are representative of the same deep topsoil forming process, this physical separation is acknowledged in the record.

Profile TE2: Tealing House copse

Grid Reference	741620/388050
Land cover/ vegetation	Deciduous woodland
Land use	Recreational
Macrorelief	Flat
Microrelief	Uneven ground and recently felled tree stumps around sample profile area.
Drainage	Moderately well drained
Area surface features	As above
Other information	None
Date of sampling	09/11/02

TE2: North facing section showing position of Kubiena samples



Horizon Ap1
Depth 0-24 cm
Field Colour 7.5YR3/2: dark brown
Description Friable silt loam, with few (<2%) fine (<5 mm) faint diffuse brown (7.5YR4/2) mottles. Slightly sticky and slightly plastic consistency. Moderate granular, subangular blocky and crumb soil structures of medium size. Many (>2/cm^2) small (1-2 mm) vesicular, interstitial and tubular pores. Few (5%) subangular red pebbles, slightly weathered, 1-10 mm^2. No rock fragments. Frequent roots, diameter <1->5 mm. Frequent (20%) charcoal inclusions, 1-5 mm^2. Frequent (20%) smaller charcoal inclusions, size <1 mm^2. Common (8%) recent ceramic building material, 5-10 mm^2. Smooth, gradual (5-12 mm width) boundary with horizon Ap2. **Deep anthropogenic topsoil**.

Horizon Ap2
Depth 25-45 cm
Field Colour 7.5YR4/2: brown
Description Friable silt loam, no mottles, of slightly sticky and slightly plastic consistency. Weak to moderate prism, angular blocky, granular and crumb soil structures of fine to medium size. Few (.5/cm^2) very small (<1 mm) vesicular and interstitial pores. Few (5%) subangular red pebbles, slightly weathered, 1-10 mm^2. Few (5%) subangular red rock fragments, 15-150 mm^2. Frequent roots, diameter <1->5 mm. Common (10%) charcoal inclusions, 1-2 mm^2. Frequent (18%) smaller charcoal inclusions, <1 mm^2. Smooth, clear (2-5 mm width) boundary with horizon Ap3. **Deep anthropogenic topsoil**.

Horizon Ap3
Depth 46-57 cm
Field Colour 7.5YR4/4: brown
Description Friable silt loam, with few (<2%) fine (<5 mm) faint diffuse brown (7.5YR4/2) mottles. Slightly sticky and slightly plastic consistency. Weak to moderate granular, subangular blocky and crumb soil structures of fine to medium size. Few (<.5/cm^2) very small (<1 mm) vesicular and interstitial pores. Common (10%) subangular red pebbles, weathered, 1-10 mm^2. Few (5%) subangular red rock fragments, weathered, 200-400 mm^2. Frequent roots, diameter <1->5 mm. Few (3%) charcoal inclusions, 1-2 mm^2. Few (5%) smaller charcoal inclusions, <1 mm^2. Irregular, clear (2-5 mm width) boundary with horizon Bs. **Deep anthropogenic topsoil**.

Horizon Bs
Depth 58-68 cm
Field Colour 7.5YR4/6: strong brown
Description Firm silt loam, with many (>20%) coarse (>15 mm) distinct diffuse and occasionally sharply defined dark reddish brown (5YR3/2) mottles. These appear related to root penetration and decay. Non-sticky and slightly plastic consistency. Weak to moderate platy, granular and subangular blocky soil structures of fine to medium size. Few (<.5/cm^2) small (1-2 mm) vesicular pores. Few (5%) rounded red and yellow pebbles, weathered, 1-10 mm^2. Few (5%) subangular red rock fragments, slightly weathered, 50-100 mm^2. Common roots, diameter <1-2 mm. Weakly cemented. Few (5%) charcoal inclusions, <1 mm^2. Irregular, clear (2-5 mm width) boundary with horizon C. **B horizon showing illuviation characteristics.**

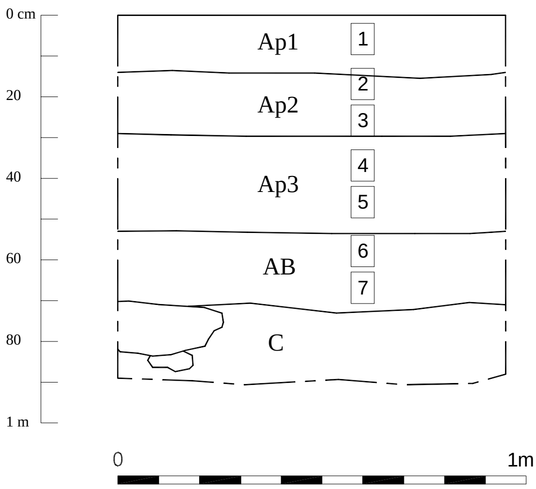
Horizon C
Depth <69 cm
Field Colour 5YR5/4: reddish brown

Description	Firm silt loam, with many (>20%) coarse (>15 mm) distinct diffuse and occasionally sharply defined reddish brown (5YR4/3) mottles. These appear related to root penetration and decay. Non-sticky and non plastic consistency. Moderate to strong granular, subangular blocky and crumb soil structures of medium to coarse size. No visible pores. Few (<3%) rounded red pebbles, some weathering, 1-10 mm^2. Many (20%) subangular red rock fragments, 50-200 mm^2. Few roots, diameter <1-2 mm. Strongly cemented. Few (2%) charcoal inclusions, <1 mm^2. **Natural till**.

Profile TE3: Tealing House walled garden

Grid Reference	741580/338020
Land cover/ vegetation	Grassland
Land use	Recreational
Macrorelief	Flat
Microrelief	Occasional gravel pathways, relating to twentieth century use of garden and greenhouses, occasionally visible beneath grass cover and 1-2cm of topsoil throughout walled area.
Drainage	Moderately well drained
Area surface features	None
Other information	Walled garden now acting as unused long term pasture, from which greenhouses were removed in 1998. Some small scale vegetable cultivation in raised beds undertaken within the last 10 years, but no known episodes of large-scale fertiliser addition known for at least the previous 25 years.
Date of sampling	11/11/02

TE3: South facing section showing position of Kubiena samples



Horizon	Ap1
Depth	0-14 cm
Field Colour	7.5YR3/3: dark brown
Description	Friable to firm silty clay loam, no mottles, of slightly sticky and plastic consistency. Moderate prism, granular, subangular blocky and crumb soil structures of fine to coarse size. Few (>.5/cm^2) small (1-2 mm) vesicular and tubular pores. Few (1%) subangular and rounded grey and yellow pebbles, weathered, 1-10 mm^2. No rock fragments. Common roots, diameter <1-2 mm. Frequent (20%) charcoal inclusions, 1-5 mm^2. Frequent (20%) smaller charcoal inclusions, <1 mm^2. Common (7%) recent ceramic building material and glass, 10-50 mm^2. Smooth, abrupt (<2 mm width) boundary with horizon Ap2. **Deep anthropogenic topsoil**.

Horizon	Ap2
Depth	15-29 cm
Field Colour	7.5YR3/2: dark brown
Description	Friable to firm silty clay loam, no mottles, of slightly sticky and plastic consistency. Weak subangular blocky, granular and crumb soil structures of fine to medium size. Common (.5-2/cm^2) small (1-2 mm) vesicular and interstitial pores. Few (5%) subangular and rounded yellow and grey pebbles, slightly weathered, 1-10 mm^2. No rock fragments. Few roots, diameter <1 mm. Frequent (20%) charcoal inclusions, 1-5 mm^2. Frequent (20%) smaller charcoal inclusions, <1 mm^2. Smooth, abrupt (<2 mm width) boundary with horizon Ap3. **Deep anthropogenic topsoil**.

Horizon	Ap3
Depth	30-53 cm
Field Colour	7.5YR4/2: brown
Description	Friable to firm silt loam, with many (2-20%) fine (<5 mm) faint diffuse dark brown (7.5YR3/2) mottles. Slightly sticky and slightly plastic consistency. Weak granular, subangular blocky and crumb soil structures of fine to medium size. Common (.5-2/cm^2) medium (2-5 mm) vesicular and interstitial pores. Few (5%) subangular and rounded red and yellow pebbles, weathered, 1-10 mm^2. Few (1%) subangular and angular red rock fragments, weathered, 70-200 mm^2. No roots. Frequent (20%) charcoal inclusions, 1-2 mm^2. Common (7%) smaller charcoal inclusions, <1 mm^2. Smooth, clear (2-5 mm width) boundary with horizon AB. **Deep anthropogenic topsoil**.

Horizon	AB
Depth	54-71 cm
Field Colour	7.5YR4/4: brown
Description	Firm silt loam, with many (>20%) medium (5-15 mm) distinct diffuse strong brown (7.5YR5/6) mottles and occasional larger patches of the same colour. Non-sticky and slightly plastic consistency. Weak granular, subangular blocky and crumb soil structures of fine size. Many (>2/cm^2) medium to large (2->5 mm) vesicular, interstitial and tubular pores. Common (10%) subangular and angular red, yellow and grey pebbles, weathered, 1-10 mm^2. Common (10%) rounded, subangular and angular red and grey rock fragments, slightly weathered, 50-100 cm^2. Few roots, diameter <1 mm^2. Few (1%) charcoal inclusions, 1-5 mm^2. Few (2%) small charcoal inclusions, <1 mm^2. Wavy and irregular, clear (2-5 mm width) boundary with horizon C. **Transitional horizon**.

Horizon	C
Depth	<72 cm
Field Colour	7.5YR5/6: strong brown

Description Firm silt loam, with few (<2%) fine (<5 mm) distinct clear light reddish brown (5YR6/3) mottles. Non-sticky and non plastic consistency. Weak granular and crumb soil structures of fine size. Few (<.5/cm^2) small (1-2 mm) vesicular and interstitial pores. Common (15%) rounded red and grey pebbles, some weathering, 1-10 mm^2. Many (16-20%) subangular and angular red and grey rock fragments, 150-250 mm^2. No roots. Weakly cemented. Few (1%) charcoal inclusions, <1 mm^2. **Natural till**.

Site 3: Unst. Deep topsoil polygon 1*: information

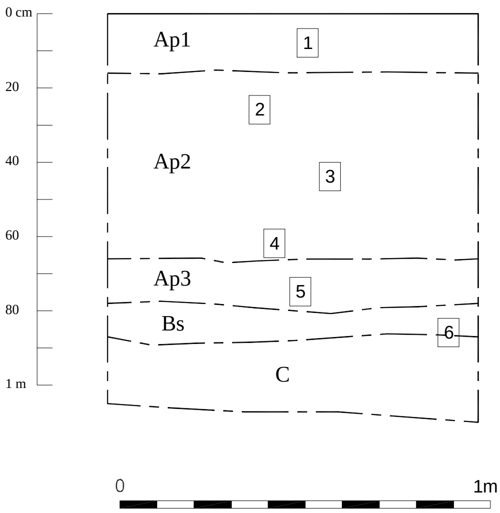
Solid geology	Striped and banded granulitic hornblende-gneiss in metamorphic rocks of sedimentary, contemporaneous, volcanic, mixed and uncertain origin
Drift geology	Undifferentiated drift, including rubbly surface deposits
Soil Association	No survey data available
Soil Series	No survey data available
Sampled profiles	UN1, UN4

* Topsoil polygon 1 extends through the adjoining infield areas of the North House and New House crofts and is physically separated from deep topsoil polygon 2 which is located approximately 200 metres to the NW (Figure 5.8). The two deep topsoil polygons and their sample soil profiles are therefore treated separately.

Profile UN1: North House infield area

Grid Reference	457700/1204220
Land cover/ vegetation	Grassland
Land use	Unused
Macrorelief	Sloping (8-16% at steepest) from NE-SW throughout field, base of slope at approximately 10m to east of sample profile.
Microrelief	Flat
Drainage	Imperfectly drained. Slightly boggy conditions approximately 20m to SW of sample profile.
Area surface features	Small field dyke runs NE-SW to N of sample profile
Other information	Last ploughed and cultivated approximately 10 years previously as part of the North House croft infield area.
Date of sampling	04/08/02

UN1: North-west facing section, showing position of Kubiena samples



Horizon Ap1
Depth 0-16 cm
Field Colour 7.5YR3/2: dark brown
Description Friable to very friable silt loam, with few (<2%) fine (<5 mm) faint diffuse dark grey (7.5YR3/1) mottles. Slightly sticky and slightly plastic consistency. Weak to moderate granular, angular blocky, subangular blocky and crumb soil structures of fine to coarse size. Common (.5-2/cm^2) very small to small (<1-2 mm) vesicular and interstitial pores. Few (2%) subangular and rounded grey and greenish grey pebbles, some very weathered, 1-5 mm^2. No rock fragments. Frequent roots, diameter 1->5 mm. Frequent (20%) charcoal inclusions, 1-10 mm^2. Frequent (20%) smaller charcoal inclusions, <1 mm^2. Wavy, clear (2-5 mm width) boundary with horizon Ap2. **Deep anthropogenic topsoil**.

Horizon Ap2
Depth 17-66 cm
Field Colour 7.5YR3/2: dark brown
Description Friable silt loam, with common (2-20%) fine to medium (<.5-15 mm) faint and some distinct diffuse brown (7.5YR4/3) mottles. Slightly sticky and non-plastic consistency. Weak to moderate angular blocky, subangular blocky, granular and crumb soil structures of very fine to fine size. Common (.5-2/cm^2) very small to small (<1-2 mm) vesicular, interstitial and tubular pores. Few (2%) subangular and rounded light grey pebbles, slightly weathered, 1-10 mm^2. Few (<5%) subrounded light and pinkish grey rock fragments, 11-100 mm. Common roots, diameter 1-2 mm. Frequent (20%) charcoal inclusions, 1-6 mm^2. Frequent (20%) smaller charcoal inclusions, <1 mm^2. Wavy, clear (2-5 mm width) boundary with horizon Ap3. **Deep anthropogenic topsoil**.

Horizon Ap3
Depth 67-78 cm
Field Colour 5YR3/3: dark reddish brown
Description Friable silt loam, with many (2-20%) fine (<5 mm) faint and some distinct diffuse reddish brown (5YR4/4) mottles. Sticky and non-plastic consistency. Weak to moderate prism, granular, subangular blocky and crumb soil structures of fine to medium size. Common (.5-2/cm^2) very small to small (<1-2 mm) vesicular and interstitial pores. Rare (<1%) subangular light grey pebbles, weathered, 5-10

mm^2. Few (5%) angular pinkish grey rock fragments, weathered, 80-120 mm^2. Few roots, diameter <1 mm. Frequent (16%) charcoal inclusions, 1-5 mm^2. Common (10%) smaller charcoal inclusions, <1 mm^2. Smooth, abrupt (<2 mm width) boundary with horizon Bs. **Deep anthropogenic topsoil**.

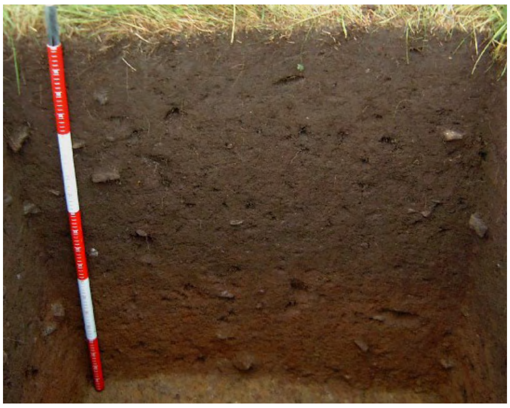
Horizon	Bs
Depth	79-88 cm
Field Colour	5YR3/4: dark reddish brown
Description	Friable to firm silty clay loam, with abundant (>40%) fine to medium (<5-15 mm) distinct clear reddish brown (5YR4/4) mottles. Sticky and slightly plastic consistency. Weak angular blocky, granular, subangular blocky and crumb soil structures of fine to medium size. Many (>2/cm^2) very small to small (<1-2 mm) vesicular and interstitial pores. Few (5%) rounded light grey pebbles, weathered, 1-10 mm^2. Common (10%) subangular pinkish grey rock fragments, slightly weathered, 50-100 mm^2. No roots. Few (5%) charcoal inclusions, <1 mm^2. Wavy, abrupt (<2 mm width) boundary with horizon C. **B horizon showing slight illuviation characteristics**.

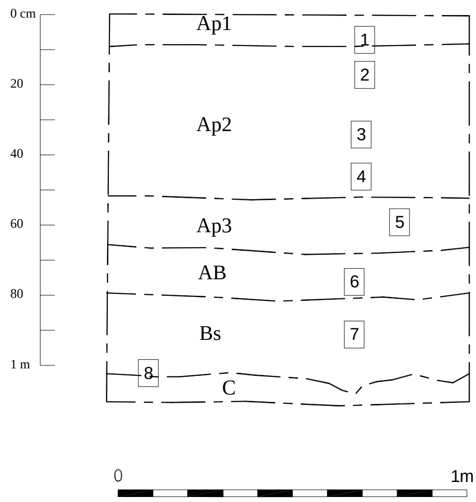
Horizon	C
Depth	<89 cm
Field Colour	10YR6/6: brownish yellow
Description	Friable to firm clay loam, with abundant (>40%) medium to coarse (5->1 5mm) distinct and prominent clear yellowish red (5YR5/8) mottles. Sticky and plastic consistency. Weak subangular blocky, granular and crumb soil structures of medium to coarse size. Common (.5-2/cm^2) small (1-2 mm) vesicular, interstitial and tubular pores. Many (20%) rounded and subangular yellow pebbles, some weathering, 1-10 mm^2. Very many (40%) subrounded, subangular and angular yellow rock fragments, 200-300 mm^2. No roots. No visible charcoal inclusions. **Natural mica schist bedrock**.

Profile UN4: New House infield area

Grid Reference	457640/1204280
Land cover/ vegetation	Grassland
Land use	Unused
Macrorelief	Sloping (8-16% at steepest) from NE-SW throughout field, base of slope at approximately 20m to east of sampled profile
Microrelief	Flat
Drainage	Imperfectly drained
Area surface features	Small field dyke runs E-W to N of sample profile
Other information	Last ploughed and cultivated approximately 60 years previously as part of the New House croft infield area
Date of sampling	304/06/03

UN4: North-facing section showing position of Kubiena samples





Horizon	Ap1
Depth	0-8 cm
Field Colour	7.5YR3/2: dark brown
Description	Friable silty clay loam, with many (2-20%) medium (5-15 mm) distinct clear reddish brown (5YR4/4) mottles. Non-sticky and non-plastic consistency. Moderate granular, subangular blocky and crumb soil structures of fine size. Common (.5-2/cm^2) small (1-2 mm) vesicular and tubular pores. Few (2-5%) rounded grey pebbles, weathered, 1-2 mm^2. No rock fragments. Frequent roots, diameter 1-5 mm. Frequent (20%) charcoal inclusions, 1-10 mm^2. Frequent (20%) smaller charcoal inclusions, <1 mm^2. Smooth, clear (2-5 mm width) boundary with horizon Ap2. **Deep anthropogenic topsoil**.

Horizon	Ap2
Depth	9-52 cm
Field Colour	7.5YR3/3: dark brown
Description	Very friable silty clay loam, with few (<2%) fine (<.5 mm) faint diffuse dark reddish brown (5YR3/2) mottles. Slightly sticky and non-plastic consistency. Moderate subangular blocky, crumb and massive soil structures of fine size. Common (.5-2/cm^2) small to medium (1-5 mm) vesicular and tubular pores. Few (2-5%) subangular and rounded grey pebbles, weathered, 1-5 mm^2. Common (6-8%) subrounded and subangular grey and yellow rock fragments, 200-300 mm. Common roots, diameter 1-2 mm. Frequent (20%) charcoal inclusions, 1-10 mm^2. Frequent (20%) smaller charcoal inclusions, <1 mm^2. Smooth, clear (2-5 mm width) boundary with horizon Ap3. **Deep anthropogenic topsoil**.

Horizon	Ap3
Depth	53-66 cm
Field Colour	5YR3/3: dark reddish brown
Description	Very friable clay loam, with few (<2%) fine (<5 mm) faint and diffuse dark reddish grey (5YR4/2) mottles. Slightly sticky and non-plastic consistency. Weak to moderate subangular blocky, crumb and massive soil structures of fine to medium size. Few (<.5/cm^2) small to medium (1-5 mm) vesicular pores. No pebbles or rock fragments. Few roots, diameter <1mm. Common (7%) charcoal inclusions, 1-2 mm^2. Common (6%) smaller charcoal inclusions, <1 mm^2. Wavy and irregular, gradual (5-12 mm width) boundary with horizon AB. **Deep**

anthropogenic topsoil.

Horizon	AB
Depth	67-79 cm
Field Colour	5YR4/3: reddish brown
Description	Very friable silty sand loam, with frequent (2-20%) fine (<5mm) faint diffuse dark reddish grey (5YR4/2) mottles. Non-sticky and non-plastic consistency. Weak prism, subangular blocky and crumb soil structures of fine size. Few (<.5/cm^2) small (1-2 mm) vesicular and tubular pores. Few (2%) subangular grey pebbles, unweathered, 1-5 mm^2. Few (1%) subangular pinkish grey rock fragments, unweathered, 100-400 mm^2. Few roots, diameter <1 mm. Few (5%) charcoal inclusions, <1 mm^2. Wavy, clear (2-5 mm width) boundary with horizon Bs. **Transitional horizon**.

Horizon	Bs
Depth	80-102 cm
Field Colour	5YR4/4: reddish brown
Description	Friable silty sand loam, with many (>20%) medium (5-15 mm) faint diffuse strong brown (7.5YR5/6) mottles. Non-sticky and non-plastic consistency. Moderate subangular blocky, crumb and massive soil structures of fine size. Few (<.5/cm^2) small (1-2 mm) vesicular and tubular pores. Few (1%) subangular grey pebbles, unweathered, 1-5 mm^2. Few (5%) subangular grey rock fragments, unweathered, 100-300 mm^2. No roots. Few (4%) charcoal inclusions, <1 mm^2. Smooth, abrupt (<2 mm width) boundary with horizon C. **B horizon showing faint illuviation characteristics**.

Horizon	C
Depth	<103 cm
Field Colour	10YR6/6: brownish yellow
Description	Friable to firm clay loam, with common (2-20%) medium (5-15 mm) distinct and clear yellowish brown (10YR5/6) mottles. Non-sticky and non-plastic consistency. Moderate columnar, subangular blocky and crumb soil structures of medium size. No pores. Many (20%) rounded and subangular yellow pebbles, unweathered, 2-10 mm^2. Many (20%) subrounded, subangular and angular yellow rock fragments, 200-300 mm^2. No roots. No visible charcoal inclusions. **Natural mica schist bedrock**.

Site 3: Unst. Deep topsoil polygon 2*: information

Solid geology	Striped and banded granulitic hornblende-gneiss in metamorphic rocks of sedimentary, contemporaneous, volcanic, mixed and uncertain origin
Drift geology	Undifferentiated drift, including rubbly surface deposits
Soil Association	No survey data available
Soil Series	No survey data available
Sampled profiles	UN2, UN3

* Topsoil polygon 2 extends through two adjoining fields, the southernmost of which is the location of the excavated Underhoull Viking House and Underhoull Broch. This polygon is physically separated from deep topsoil polygon 1which is located approximately 200 metres to the SE (Figure 5.8). The two deep topsoil polygons and their sample soil profiles are therefore treated separately.

Profile UN2: Underhoull field 1

Grid Reference 457340/1204350

Land cover/ vegetation Grassland, unimproved

Land use Unused

Macrorelief Steeply sloping (16-30% at steepest) from NE-SW throughout field from ramparts of Underhoull broch. Base of slope at approximately 40m to east of sampled profile. Occasional small rock outcrops to east of sample profile

Microrelief Flat.

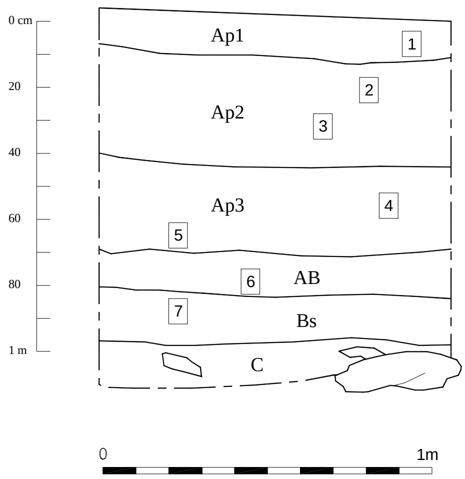
Drainage Moderately well drained

Area surface features Excavated site of Underhoull Viking house located approximately 40m to E of sample profile. Assumed excavation spoil heap of redeposited soil material located approximately 40m to N of sample profile. Unused and unimproved area of grassland, partly due to inaccessibility of site but also to the presence of scheduled ancient monument.

Other information Underhoull House excavation undertaken in 1960s

Date of sampling 7/08/02

UN2: North-west facing section showing position of Kubiena samples



Horizon Ap1
Depth 0-11 cm
Field Colour 7.5YR4/1: dark grey
Description Friable silty clay loam, with few (<2%) fine (<5 mm) faint diffuse dark brown (7.5YR3/2) mottles. Slightly sticky and non-plastic consistency. Weak to moderate prism, granular, subangular blocky and crumb soil structures of medium to coarse size. Many (>2/cm^2) small to medium (1-5 mm) vesicular, interstitial and tubular pores. Few (2%) rounded grey pebbles, weathered, 1-5 mm^2. No rock fragments. Frequent roots, diameter 1-2 mm. Frequent (20%) charcoal inclusions, 1-7 mm^2. Frequent (25%) smaller charcoal inclusions, <1 mm^2. Smooth, clear (2-5 mm width) boundary with horizon Ap2. **Deep anthropogenic topsoil**.

Horizon Ap2
Depth 12-44 cm
Field Colour 7.5YR3/2: dark brown
Description Very friable to friable silty clay loam, with common (2-20%) fine (<.5 mm) faint diffuse brown (7.5YR5/4) mottles. Slightly sticky and non-plastic consistency. Weak to moderate angular blocky, subangular blocky, granular and crumb soil structures of very fine to medium size. Common (.5-2/cm^2) very small to small (<1-2 mm) vesicular and interstitial pores. Few (2%) rounded grey to white pebbles, slightly weathered, 1-5 mm^2. Few (5%) subrounded, angular and subangular grey and yellow rock fragments, 50-200 mm^2. Common roots, diameter 1-2 mm. Frequent (18%) charcoal inclusions, 1-6 mm^2. Frequent (20%) smaller charcoal inclusions, <1 mm^2. Wavy, gradual (5-12 mm width) boundary with horizon Ap3. **Deep anthropogenic topsoil**.

Horizon Ap3
Depth 45-69 cm
Field Colour 5YR3/2: dark reddish brown
Description Friable slightly sandy clay loam, with few (<2%) fine (<5 mm) faint and diffuse light brown (7.5YR5/4) mottles. Slightly sticky and slightly plastic consistency. Weak to moderate prism, angular blocky, subangular blocky, granular and crumb soil structures of fine to medium size. Few (<.5/cm^2) very small to small (<1-2 mm) interstitial pores. Few (5%) rounded grey and yellow pebbles, slightly weathered, 1-5 mm^2. Common (10-15%) subrounded, subangular and angular grey and yellow rock fragments, 200-400 mm^2. Few roots, diameter <1 mm. Common (10%) charcoal inclusions, 1-2 mm^2. Few (5%) smaller charcoal inclusions, <1 mm^2. Wavy, diffuse (>12 mm width) boundary with horizon AB. **Deep anthropogenic topsoil**.

Horizon AB
Depth 70-84 cm
Field Colour 5YR4/2: dark reddish grey
Description Friable silty sand loam, with few (<2%) fine (<5 mm) faint diffuse yellowish red (5YR4/6) mottles. Slightly sticky and slightly plastic consistency. Weak to moderate subangular blocky, granular and crumb soil structures of fine size. Common (.5-2/cm^2) very small (<1 mm) interstitial pores. Common (10%) rounded and subrounded yellow pebbles, unweathered, 1-5 mm^2. Common (10-15%) angular and subangular yellow and grey rock fragments, unweathered, 100-300 mm^2. No roots. Few (1%) charcoal inclusions, <1 mm^2. Smooth, gradual (5-12 mm width) boundary with horizon Bs. **Transitional horizon**.

Horizon Bs
Depth 85-98 cm
Field Colour 5YR4/3: reddish brown
Description Very friable sandy clay loam, with common (2-20%) medium (5-15 mm) distinct clear yellowish red (5YR4/6) mottles. Slightly sticky and slightly plastic consistency. Weak to moderate angular blocky, subangular blocky, granular and crumb soil structures of fine to medium size. Common (.5-2/cm^2) very small (<1 mm) vesicular and interstitial pores. Common (10%) rounded and subrounded yellow pebbles, unweathered, 1-10 mm^2. Many (30%) angular and subangular yellow, red and grey rock fragments, unweathered, 100-400 mm^2. No roots. Few (2%) charcoal inclusions, <1 mm^2. Wavy, clear (2-5 mm width) boundary with horizon C. **B horizon**.

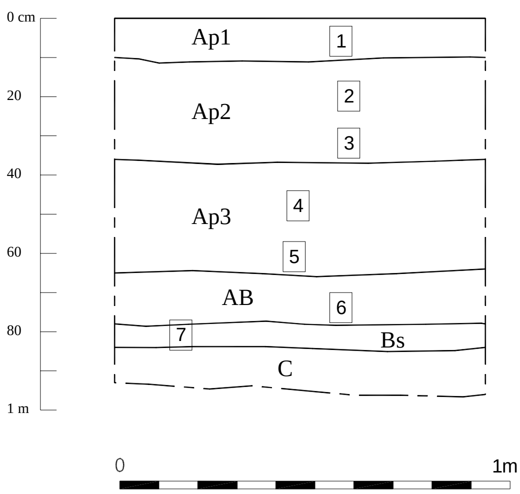
Horizon C
Depth <99 cm
Field Colour 2.5YR5/2: greyish brown
Description Very friable sandy loam, with common (2-20%) medium (5-15 mm) distinct and

diffuse yellowish brown (10YR6/4) mottles. Slightly sticky and non-plastic consistency. Weak to moderate angular blocky, subangular blocky, granular and crumb soil structures of fine to coarse size. Many (>2/cm^2) small to medium (1-5 mm) vesicular and interstitial pores. Many (30%) rounded and angular yellow and grey pebbles, unweathered, 1-10 mm^2. Many (30%) subrounded, rounded and angular yellow and grey rock fragments, 200-450 mm^2. No roots. Weakly cemented with broken Fe pan of massive structure. No visible charcoal inclusions. **Natural mica schist bedrock**.

Profile UN3: Underhoull field 2

Grid Reference	457300/1204400
Land cover/ vegetation	Grassland, improved
Land use	Grazed
Macrorelief	Steeply sloping (16-30% at steepest) from NE-SW throughout field from ramparts of Underhoull broch. Base of slope at approximately 30m to east of sampled profile.
Microrelief	Flat.
Drainage	Moderately well drained
Area surface features	Excavated site of Underhoull Viking house located approximately 60m to SE of sample profile. Assumed excavation spoil heap of redeposited soil material located approximately 20m to S of sample profile.
Other information	Sheep-grazed area of grassland, improved through re-seeding, though not for at least 15 years. Last fertilised with lime and phosphate prior to silage removal 4 years previously.
Date of sampling	26/08/02

UN3: North-west facing section showing position of Kubiena samples



Horizon Ap1
Depth 0-10 cm
Field Colour 7.5YR5/2: brown
Description Very friable sandy loam, no mottles, of non-sticky and non-plastic consistency. Weak to moderate columnar, granular, subangular blocky and crumb soil structures of fine to coarse size. Many (>2/cm^2) large (>5 mm) vesicular, interstitial and tubular pores. No pebbles or rock fragments. Frequent roots, diameter 2-5 mm. Frequent (18%) charcoal inclusions, 1-6 mm^2. Frequent (20%) smaller charcoal inclusions, <1 mm^2. Smooth, clear (2-5 mm width) boundary with horizon Ap2. **Deep anthropogenic topsoil**.

Horizon Ap2
Depth 11-36 cm
Field Colour 7.5YR4/2: brown
Description Friable sandy loam, with few (<2%) fine (<.5 mm) faint diffuse strong brown (7.5YR5/6) mottles. Non-sticky and non-plastic consistency. Weak to moderate angular blocky, subangular blocky, granular and crumb soil structures of fine to medium size. Common (.5-2/cm^2) small (1-2 mm) vesicular and tubular pores. Common (6-10%) subangular yellow pebbles, weathered, 1-10 mm^2. Common (6-10%) rounded and subangular grey rock fragments, 200-300 mm^2. Common roots, diameter 1-5 mm. Common (10%) charcoal inclusions, 1-5 mm^2. Common (15%) charcoal inclusions, <1 mm^2. Wavy, clear (2-5 mm width) boundary with horizon Ap3. **Deep anthropogenic topsoil**.

Horizon Ap3
Depth 37-64 cm
Field Colour 7.5YR4/2: brown
Description Friable sandy clay loam, with few (<2%) fine (<5 mm) faint and diffuse strong brown (7.5YR5/6) mottles. Slightly sticky and slightly plastic consistency. Weak to moderate prism, subangular blocky, granular, crumb and massive soil structures of very fine to medium size. Few (<.5/cm^2) medium (2-5 mm) vesicular, interstitial and tubular pores. Few (2%) subangular yellow to orange pebbles, slightly weathered, 1-10 mm^2. Common (7-10%) subangular grey and yellow rock fragments, 200-300 mm^2. Few roots, diameter 1-2 mm. Common (10%) charcoal inclusions, 1-2 mm^2. Common smaller charcoal inclusions, <1mm^2. Wavy, clear (2-5 mm width) boundary with horizon AB. **Deep anthropogenic topsoil**.

Horizon AB
Depth 65-78 cm
Field Colour 7.5YR4/1: dark grey
Description Firm sandy clay loam, with many (>20%) medium (5-15 mm) distinct diffuse strong brown (7.5YR5/6) mottles. Sticky and slightly plastic consistency. Weak to moderate angular blocky, subangular blocky, granular and crumb soil structures of fine to medium size. Common (.5-2/cm^2) very small to small (<1-2 mm) vesicular, interstitial and tubular pores. No pebbles. Few (2%) subangular and rounded red and grey rock fragments, unweathered, 200-600 mm^2. Few roots, diameter <1 mm. Few (2%) charcoal inclusions, <1 mm^2. Wavy and irregular, clear (2-5 mm width) boundary with horizon Bs. **Transitional horizon**.

Horizon Bs
Depth 79-84 cm
Field Colour 7.5YR4/6: strong brown
Description Firm sandy clay loam, with common (2-20%) fine (<5 mm) distinct clear light grey (10YR7/2) mottles. Sticky and slightly plastic consistency. Weak to moderate subangular blocky, granular, crumb and massive soil structures of very

fine to medium size. Few (<.5/cm^2) small (1-2 mm) vesicular pores. Common (10%) rounded and subrounded yellow pebbles, unweathered, 1-10 mm^2. No rock fragments. No roots. No visible charcoal inclusions. Wavy, clear (2-5 mm width) boundary with horizon C. **B horizon**.

Horizon	C
Depth	<85 cm
Field Colour	10YR6/6: yellow
Description	Friable to firm sandy clay loam, with common (2-20%) medium (5-15 mm) distinct clear and diffuse light grey (10YR4/2) mottles. Slightly sticky and non-plastic consistency. Moderate subangular blocky, crumb and massive soil structures of fine to medium size. Common (.5-2/cm^2) very small (<1 mm) vesicular and interstitial pores. Common (10%) rounded yellow pebbles, unweathered, 1-10 mm^2. Few (5%) subrounded and subangular yellow and grey rock fragments, 200-400 mm^2. No roots. Weakly cemented. No visible charcoal inclusions. **Natural mica schist bedrock**.

Appendix 6: Bulk chemical and physical data

Table 1: Soil pH

Site	Soil profile	Land cover type	Sample	pH	pH $CaCl_2$
Nairn	NA1	Long-term pasture	NA1AP1	5.1	5.0
			NA1AP2.1	5.1	4.9
			NA1AP2.2	5.6	4.9
			NA1AP2.3	5.7	5.1
			NA1AP3	5.5	5.1
			NA1BS	5.1	4.7
			NA1C	4.9	4.6
	NA2	Deciduous woodland	NA2AP1.1	5.0	4.5
			NA2AP1.2	4.6	4.1
			NA2AP2	4.5	4.1
			NA2AB	4.4	4.0
			NA2BS	4.5	4.0
			NA2C	4.3	3.9
	NA3	Ploughed arable	NA3AP1	5.6	5.1
			NA3AP2.1	5.9	5.4
			NA3AP2.2	5.6	5.1
			NA3AP3	5.6	5.2
			NA3BW1.1	5.5	5.1
			NA3BW1.2	5.4	5.1
			NA3C	5.2	5.1
Tealing,	TE1	Ploughed arable	TE1AP1.1	7.2	6.8
Dundee			TE1AP1.2	7.3	7.0
			TE1AP2.1	7.2	6.9
			TE1AP2.2	7.1	6.8
			TE1AP3.1	6.9	6.5
			TE1AP3.2	6.9	6.4
			TE1AB	6.9	6.4
			TE1BW	6.9	6.2
			TE1C	6.7	6.0
	TE2	Deciduous woodland	TE2AP1.1	6.4	6.0
			TE2AP1.2	6.2	5.8
			TE2AP2.1	6	5.4
			TE2AP2.2	6.1	5.5
			TE2AP3	6.2	5.6
			TE2BS	6.3	5.6
			TE2C	6.4	5.7
	TE3	Long-term pasture	TE3AP1.1	5.4	4.8
			TE3AP2.1	5.4	4.8
			TE3AP2.2	5.4	4.9
			TE3AP3.1	5.8	5.3
			TE3AP3.2	6	5.5
			TE3AB1.1	6.2	5.6
			TE3AB1.2	6.2	5.7
			TE3C	6.4	5.8

Unst,	UN1	Arable, ploughed	UN1AP1	4.9	4.5
Shetland		within 10 years	UN1AP2	5.2	4.6
			UN1AP3	5.3	4.8
			UN1BS	5.3	4.8
			UN1C	5.4	4.8
	UN2	Unimproved pasture	UN2AP1	4.8	4.2
			UN2AP2	5.4	4.6
			UN2AP3	5.8	5.1
			UN2AB	5.8	5.1
			UN2BS	5.9	5.2
			UN2C	6	5.3
	UN3	Improved pasture	UN3AP1	5.1	4.2
			UN3AP2	5.3	4.6
			UN3AP3	5.6	4.8
			UN3AB	5.8	5
			UN3BS	5.8	5.1
			UN3C	6	5.2
	UN4	Arable, not ploughed	UN4AP1.1	4.4	4.0
		within 50 years	UN4AP2.1	4.6	3.9
			UN4AP2.2	4.8	4.2
			UN4AP2.3	5.0	4.3
			UN4AP3.1	5.2	4.4
			UN4AB	5.2	4.5
			UN4BS1.1	5.2	4.6
			UN4BS1.2	5.2	4.7
			UN4C	5.3	4.7

Table 2: Soil organic matter by Loss on Ignition and Wet Oxidation

Site	Soil profile	Land cover type	Sample	LOI (%)	WO (%)
Nairn	NA1	Long-term pasture	NA1AP1	5.5	5
			NA1AP2.1	4.3	4.5
			NA1AP2.2	3.9	4.0
			NA1AP2.3	4.0	3.9
			NA1AP3	4.8	5.7
			NA1BS	2.0	1.3
			NA1C	0.5	0.5
	NA2	Deciduous woodland	NA2AP1.1	9.4	9.1
			NA2AP1.2	5.6	6.2
			NA2AP2	4.7	4.6
			NA2AB	4.7	5
			NA2BS	2.8	2.8
			NA2C	0.9	0.5
	NA3	Ploughed arable	NA3AP1	3.7	4.0
			NA3AP2.1	3.8	3.3
			NA3AP2.2	3.3	4.0
			NA3AP3	3.5	2.8

			NA3BW1.1	3.2	2.5
			NA3BW1.2	2.6	1.9
			NA3C	1.8	1.1
Tealing,	TE1	Ploughed arable	TE1AP1.1	7	6.2
Dundee			TE1AP1.2	6.8	6.2
			TE1AP2.1	6.0	5.0
			TE1AP2.2	5.7	4.1
			TE1AP3.1	6.1	4.5
			TE1AP3.2	6.9	6.2
			TE1AB	7.2	5.6
			TE1BW	4.8	3.0
			TE1C	1.8	0.6
	TE2	Deciduous woodland	TE2AP1.1	11.2	10.0
			TE2AP1.2	10.3	8.2
			TE2AP2.1	5.8	4.5
			TE2AP2.2	9.2	4.8
			TE2AP3	6.5	4.6
			TE2BS	6.2	4.5
			TE2C	3.7	2.2
	TE3	Long-term pasture	TE3AP1.1	7.9	6.1
			TE3AP2.1	7.4	5.4
			TE3AP2.2	6.9	4.4
			TE3AP3.1	4.6	4.7
			TE3AP3.2	5.4	4.5
			TE3AB1.1	5.4	4.4
			TE3AB1.2	5.0	3.7
			TE3C	6.5	1.9
Unst,	UN1	Arable, ploughed	UN1AP1	13.1	11.7
Shetland		within 10 years	UN1AP2	8.8	7.4
			UN1AP3	7.1	5.3
			UN1BS	6.5	4.7
			UN1C	2.8	1.1
	UN2	Unimproved pasture	UN2AP1	8.3	7.2
			UN2AP2	5.7	4.7
			UN2AP3	4.9	3.1
			UN2AB	4.4	3.5
			UN2BS	4.8	3.3
			UN2C	2.3	1.6
	UN3	Improved pasture	UN3AP1	11.2	9.1
			UN3AP2	5.7	4.5
			UN3AP3	5.9	3.9
			UN3AB	6.0	4.7
			UN3BS	5.0	2.9
			UN3C	2.1	0.7
	UN4	Arable, not ploughed	UN4AP1.1	13.6	11.8
		within 50 years	UN4AP2.1	12.4	10.7
			UN4AP2.2	11.4	9.7
			UN4AP2.3	8.8	7.7
			UN4AP3.1	7.7	6.5

			UN4AB	7.1	5.7
			UN4BS1.1	5.3	3.2
			UN4BS1.2	5.3	3.2
			UN4C	3.0	1.0

Table 3: Soil total phosphate determinations for all samples

Site	Soil profile	Land cover type	Sample	Total P (mg/100g)
Nairn	NA1	Long-term pasture	NA1AP1	65
			NA1AP2.1	86
			NA1AP2.2	99
			NA1AP2.3	90
			NA1AP3	127
			NA1BS	63
			NA1C	25
	NA2	Deciduous woodland	NA2AP1.1	70
			NA2AP1.2	92
			NA2AP2	112
			NA2AB	97
			NA2BS	117
			NA2C	65
	NA3	Ploughed arable	NA3AP1	43
			NA3AP2.1	74
			NA3AP2.2	62
			NA3AP3	64
			NA3BW1.1	28
			NA3BW1.2	29
			NA3C	15
Tealing,	TE1	Ploughed arable	TE1AP1.1	103
Dundee			TE1AP1.2	142
			TE1AP2.1	134
			TE1AP2.2	129
			TE1AP3.1	118
			TE1AP3.2	124
			TE1AB	123
			TE1BW	100
			TE1C	52
	TE2	Deciduous woodland	TE2AP1.1	162
			TE2AP1.2	213
			TE2AP2.1	201
			TE2AP2.2	231
			TE2AP3	242
			TE2BS	258
			TE2C	118
	TE3	Long-term pasture	TE3AP1.1	266
			TE3AP2.1	232
			TE3AP2.2	242

			TE3AP3.1	241
			TE3AP3.2	213
			TE3AB1.1	252
			TE3AB1.2	123
			TE3C	132
Unst,	UN1	Arable, ploughed	UN1AP1	384
Shetland		within 10 years	UN1AP2	409
			UN1AP3	144
			UN1BS	122
			UN1C	43
	UN2	Unimproved pasture	UN2AP1	499
			UN2AP2	448
			UN2AP3	418
			UN2AB	335
			UN2BS	374
			UN2C	151
	UN3	Improved pasture	UN3AP1	267
			UN3AP2	275
			UN3AP3	322
			UN3AB	414
			UN3BS	269
			UN3C	90
	UN4	Arable, not ploughed	UN4AP1.1	278
		within 50 years	UN4AP2.1	330
			UN4AP2.2	366
			UN4AP2.3	305
			UN4AP3.1	316
			UN4AB	347
			UN4BS1.1	181
			UN4BS1.2	167
			UN4C	73

Sample Replicates

pH

Sample	pH	pH CaCl
NA3AP2.1-a	5.9	5.4
NA3AP2.1-b	5.9	5.3
NA3AP2.1-c	5.9	5.4
NA3AP2.1-d	5.9	5.4
TE2AP1.1-a	6.4	6.0
TE2AP1.1-b	6.4	5.9
TE2AP1.1-c	6.4	5.9
TE2AP1.1-d	6.4	5.9
UN1AP1-a	4.9	4.5
UN1AP1-b	4.9	4.5
UN1AP1-c	4.9	4.5
UN1AP1-d	4.9	4.5
UN3BS-a	5.8	5.1
UN3BS-b	5.8	5.1
UN3BS-c	5.8	5.1
UN3BS-d	5.8	5.1
UN4AP3.1-a	5.2	4.4
UN4AP3.1-b	5.2	4.4
UN3AP3.1-c	5.2	4.4
UN3AP3.1-d	5.2	4.4

Summary Statistics – pH CaCl

Replicate Sample	NA3AP3.1	TE2AP1.1	UN1AP1	UN3BS	UN4AP3.1
Mean	5.375	5.925	4.5	5.1	4.4
Standard Error	0.025	0.025	0	0	0
Median	5.4	5.9	4.5	5.1	4.4
Mode	5.4	5.9	4.5	5.1	4.4
Standard Deviation	0.05	0.05	0	0	0
Sample Variance	0.0025	0.0025	0	0	0
Range	0.1	0.1	0	0	0
Minimum	5.3	5.9	4.5	5.1	4.4
Maximum	5.4	6	4.5	5.1	4.4
Sum	21.5	23.7	18	20.4	17.6
Count	4	4	4	4	4
Largest(1)	5.4	6	4.5	5.1	4.4
Smallest(1)	5.3	5.9	4.5	5.1	4.4
Confidence Level(95.0%)	0.079561232	0.079561	0	0	0

Organic matter by Loss-on-ignition and Wet Oxidation

Sample	LO1	WO
NA3AP2.1-a	3.8	3.3
NA3AP2.1-b	3.8	3.2
NA3AP2.1-c	3.8	3.2
NA3AP2.1-d	3.8	3.2
TE2AP1.1-a	11.1	10.0

TE2AP1.1-b	11.1	10.0
TE2AP1.1-c	11.2	10.0
TE2AP1.1-d	11.2	9.9
UN1AP1-a	13.1	11.8
UN1AP1-b	13.1	11.8
UN1AP1-c	13.0	11.7
UN1AP1-d	13.1	11.7
UN3BS-a	4.9	2.9
UN3BS-b	5.0	2.9
UN3BS-c	4.8	3.0
UN3BS-d	4.9	2.9
UN4AP3.1-a	7.7	6.5
UN4AP3.1-b	7.7	6.4
UN3AP3.1-c	7.7	6.5
UN3AP3.1-d	7.7	6.5

Summary Statistics - LOI

Replicate Sample	NA3AP3.1	TE2AP1.1	UN1AP1	UN3BS	UN4AP3.1
Mean	3.8	11.15	13.075	4.9	7.7
Standard Error	0	0.028868	0.025	0.040825	0
Median	3.8	11.15	13.1	4.9	7.7
Mode	3.8	11.1	13.1	4.9	7.7
Standard Deviation	0	0.057735	0.05	0.08165	0
Sample Variance	0	0.003333	0.0025	0.006667	0
Range	0	0.1	0.1	0.2	0
Minimum	3.8	11.1	13	4.8	7.7
Maximum	3.8	11.2	13.1	5	7.7
Sum	15.2	44.6	52.3	19.6	30.8
Count	4	4	4	4	4
Largest(1)	3.8	11.2	13.1	5	7.7
Smallest(1)	3.8	11.1	13	4.8	7.7
Confidence Level(95.0%)	0	0.091869	0.079561	0.129923	0

Summary Statistics – WO

Replicate Sample	NA3AP3.1	TE2AP1.1	UN1AP1	UN3BS	UN4AP3.1
Mean	3.225	9.975	11.75	2.925	6.475
Standard Error	0.025	0.025	0.028868	0.025	0.025
Median	3.2	10	11.75	2.9	6.5
Mode	3.2	10	11.8	2.9	6.5
Standard Deviation	0.05	0.05	0.057735	0.05	0.05
Sample Variance	0.0025	0.0025	0.003333	0.0025	0.0025
Range	0.1	0.1	0.1	0.1	0.1
Minimum	3.2	9.9	11.7	2.9	6.4
Maximum	3.3	10	11.8	3	6.5
Sum	12.9	39.9	47	11.7	25.9
Count	4	4	4	4	4

Largest(1)	3.3	10	11.8	3	6.5
Smallest(1)	3.2	9.9	11.7	2.9	6.4
Confidence Level(95.0%)	0.079561232	0.079561	0.091869	0.079561	0.079561

Total Phosphate

Sample	Total P (mg/100g)
NA3AP2.1-a	72
NA3AP2.1-b	70
NA3AP2.1-c	69
NA3AP2.1-d	74
TE2AP1.1-a	160
TE2AP1.1-b	154
TE2AP1.1-c	161
TE2AP1.1-d	158
UN1AP1-a	380
UN1AP1-b	384
UN1AP1-c	387
UN1AP1-d	381
UN3BS-a	265
UN3BS-b	260
UN3BS-c	268
UN3BS-d	262
UN4AP3.1-a	322
UN4AP3.1-b	312
UN3AP3.1-c	315
UN3AP3.1-d	323

Summary Statistics – Total Phosphate

Replicate Sample	NA3AP3.1	TE2AP1.1	UN1AP1	UN3BS	UN4AP3.1
Mean	71.25	158.25	383	263.75	318
Standard Error	1.108678	1.547848	1.581139	1.75	2.677063
Median	71	159	382.5	263.5	318.5
Standard Deviation	2.217356	3.095696	3.162278	3.5	5.354126
Sample Variance	4.916667	9.583333	10	12.25	28.66667
Range	5	7	7	8	11
Minimum	69	154	380	260	312
Maximum	74	161	387	268	323
Sum	285	633	1532	1055	1272
Count	4	4	4	4	4
Largest(1)	74	161	387	268	323
Smallest(1)	69	154	380	260	312
Confidence Level (95.0%)	3.528311	4.925948	5.031894	5.569286	8.519617

Appendix 7: Bulk chemical and physical analyses: methodologies

1. The determination of soil pH

The determination of soil pH was carried out following the standard method of Bascomb (1974). Soil was air-dried in the laboratory for two weeks and then sieved to <2mm. A sub-sample of approximately 10g of this fine earth fraction was then weighed into a clean glass beaker, to which 25ml distilled water was added. This was stirred and left to stand for 30 minutes, after which determination of the pH of the solution was made using a glass electrode pH meter calibrated to pH 4 and 7. The pH meter was switched on and calibrated 1 hour prior to the commencement of measurement. Readings were taken twice to ensure a stable measurement had been reached.

In order to further standardise the conditions of measurement, the pH was also determined in the presence of 0.01M $CaCl_2$. 2ml of calcium chloride was added by pipette to each soil solution and the pH measured again using the method described above.

2. The determination of soil organic matter by Loss on Ignition (LOI)

The air-dried, <2mm fraction derived from the bulk samples was further oven-dried at 105^{o}C to ensure complete dryness. Approximately 10g portions of this were then accurately weighed out into clean, dry crucibles and placed into a muffle furnace and left overnight (16hrs) at 375^{o}C (Ball, 1964). After being left to cool in a dessicator, the samples were then re-weighed to determine the percentage loss of mass resulting from the ignition of the organic fraction. The long-cool burn scheme was chosen out of caution and the possibility of shell, carbonates and clay fractions being affected if a higher temperature had been used.

3. The determination of soil organic matter by Wet Oxidation (WO)

Chemical analysis of the same was undertaken using the Wet Oxidation procedure, wherein the C in the soil is oxidised to CO_2 by excess potassium dichromate. The unused dichromate is titrated against a reducing agent and the dichromate used found by difference.

Sub-samples of the <2mm fraction derived from the bulk samples were further ground to .5mm, dried for four hours at 105^0C and stored in a dessicator. 0.10 - 0.70 g (W1) of oven dry soil was then weighed into a 500ml conical flask, with 0.10-0.20g soil taken for ‘peaty’ horizons, 0.20-0.40g for A horizons and 0.50-0.70g for B horizons. 10ml of potassium dichromate solution was pipetted into the flask, to which was added 20ml concentrated sulphuric acid. This was swirled to mix and left for 30 minutes. 200 ml distilled water was then added along with 10 ml orthophosphoric acid and 2 ml indicator solution (Barium diphenylamine sulphonate). The solution was titrated against ammonium ferrous sulphate, using a burette, to a bright green end-point. Here the titre volume was noted (a).

A reagent blank was then carried out using all reagents as above, and the titre volume noted (b).

The % organic carbon was calculated thus :

$$\frac{4.0 \times (b - a)}{b \times W1}$$

Carbon was then converted to organic matter through the following :

1.72 (OM = 58% C)

4. The determination of soil total phosphate by Sodium Hydroxide Fusion

The sodium hydroxide fusion was undertaken following the procedures of Smith and Bain (1982). Colorimetric determination of total phosphate was then undertaken as follows. A 5ml aliquot of the supernatant liquid was pipetted into a volumetric flask and diluted to 40 ml with distilled water. A drop of p-nitrophenol indicator was then added and the pH adjusted to 6 by dropwise addition of 0.5M H_2SO_4. 4ml of mixed reagent* was added and the solution made to volume with distilled water. This was left to stand for 30 minutes to allow colour development. Relative concentrations of these standard solutions were made ranging from 0-20 mg P. The absorbance of the standards and samples was measured in a 40 mm cell at 880 mm using distilled water to zero the colorimeter. These standards were used to plot a graph of absorbance against relative concentration (mg P). The concentration of samples was calculated from the graph, with total phosphate (mg P/100g) calculated thus:

From calibration graph, conc. of P in 5ml aliquot = χ μg P

$\therefore$ 45ml extract contains 9. χ μg P

$\therefore$ 0.1g soil yields 9. χ μg P

$\therefore$ 100g soil yields $^{9\chi}/_{0.1}$ x 100 = 9000χ μg P = 9.χ mg P

The result is expressed as **mg P/100g** oven dried soil, and the conversion to **P_2O_5** undertaken by multiplying P_2O_5 / P_2 , i.e. $^{141.96}/_{61.96}$ = **2.29**

* Mixed reagent: 125ml 2.5 M sulphuric acid, 37.5 ml ammonium molybdate, 75 ml ascorbic acid, 12.5 ml potassium antimony oxytartrate.

Appendix 8: Thin section descriptive tables - Profiles NA1, NA2

		Coarse mineral material (< 10μm)																					Coarse organic material				Fine organic material					Pedofeatures												
Profile	Thin section sample	Quartz	Feldspar	Biotite	Muscovite	Garnet	Hornblende	Olivine	Compound quartz	Sandstone	Siltstone	Igneous rock fragments	Metamorphics	CaC03	Coal	Clinker-type material	Phytoliths	Diatoms	Bone	Fired material	Rubified mineral	Fine mineral material	Fungal spores	Lignified tissue	Parenchymatic tissue	Charcoal	Cell residue	Amorphous (black)	Amorphous (brown)	Amorphous (yellow-orange)	Amorphous (inclusions)	Limpid clay coatings	Dusty clay coatings	Silt coatings	Organic coatings	Clay infills	Amorphous crypto-crystalline nodules	Amorphous crypto-crystalline infills/coatings	Excremental	Depletion	Microstructure	Coarse material arrangement	Groundmass b-fabric	Related distribution
NA1	NA1AP1	****	*	t	*	t	t	*	**	*	t	*	t		**		**	**			t	Mid/dark brown hetero-geneous organo-mineral Dotted limpidity	**	t	***	*	**	*	t	t	t				t				**		Intergrain microaggregate	Random basic Moderately sorted	Weakly stipple-speckled	Single-spaced porphyric/open enaulic; localised chitonic
	NA1AP2.1	****	**	t	t	t	t	**	*	**	*	*	*				*	*			t	Mid/dark brown hetero-geneous organo-mineral Dotted limpidity	*		**		t	*	*	t					t				***		Intergrain microaggregate	Random basic Well sorted	Weakly stipple-speckled	Single-spaced enaulic; localised chitonic
	NA1AP2.2	****	**	t	t	t	t	*	*	*	*	t	t		**						t	Mid reddish/dark brown hetero-geneous organo-mineral Dotted limpidity	t	t	t	**	t	*	*										***		Intergrain micro-aggregate; localised channel	Random basic Poorly sorted	Weakly stipple-speckled	Single-spaced to open enaulic
	NA1AP2.3	****	**	t	t	t	t	*	**	**	*	*	*				t			t	t	Mid/dark brown heterogeneous organo-mineral Dotted limpidity	t	t		*	t	*	*	t					t				***		Intergrain microaggregate to channel	Random basic Sorted	Weakly stipple-speckled	Single-spaced to open fine enaulic; localised chitonic
	NA1AP3	****	*	t	*	t	t		**	**	t	*	t				t				t	Light/mid brown hetero-geneous organo-mineral Dotted limpidity	t			*	t	*	t	t					t				***		Intergrain microaggregate	Random basic Sorted	Weakly stipple-speckled	Single-spaced to open fine enaulic; localised chitonic
	NA1BS	****	*	t	*		t		**	**	t	*	t								t	Light/mid brown heterogeneous dominantly mineral Dotted limpidity				t	t	*	t						*				***		Pellicular to bridged	Random basic Sorted	Undifferentiated	Chitonic to monic
NA2	NA2P1.1	****	*	t	t	*	*	*	*	**	*	*	*		t		***	***		t	t	Mid reddish brown hetero-geneous organo-mineral Dotted limpidity	**	*	***	t	**	**	***	***						t			***		Intergrain microaggregate	Random basic Sorted	Stipple-speckled	Single-spaced to open enaulic; localised porphyric
	NA2AP1.2	***	*	t	t		t	**	**	**	*	*	t				*	*		t	t	Mid brown heterogeneous organo-mineral Dotted limpidity	*	t	***	t	*	**	**	**	t				*				***		Intergrain microaggregate	Random basic Sorted	Stipple-speckled	Open enaulic; localised chitonic
	NA2AP2	****	**	t	t		t		*	**	t	*	*				*	*			t	Mid/dark brown hetero-geneous organo-mineral Dotted limpidity	*	*	***	*	t	t	*	t					*				***		Intergrain microaggregate	Random basic Poorly sorted	Stipple-speckled	Open enaulic; localised chitonic
	NA2AB	****	*	t	*	t	t		**	***	*	*	**				*	t		t	t	Mid/dark brown hetero-geneous organo-mineral Dotted limpidity	*	t	**	*	*	t	*	t	t				*				****		Intergrain microaggregate to vughy	Random basic Poorly sorted	Stipple-speckled	Enaulic to chitonic
	NA2BS	****	*	*	t	t	t		**	***	*	*	*							*	t	Mid/dark brown hetero-geneous organo-mineral Dotted limpidity	t	t	*	t	t	t	*	t	t				*				***	t	Intergrain microaggregate	Random basic Poorly sorted	Weakly stipple-speckled	Enaulic to chitonic

Frequency class refers to the appropriate area of section (Bullock et al., 1985): t Trace * Very few ** Few *** Frequent/Common **** Dominant/Very dominant
Frequency class for textural pedofeatures (Bullock et al., 1985): t Trace * Rare ** Occasional *** Many

Appendix 8: Thin section descriptive tables - Profiles NA3, TE1

		Coarse mineral material (< 10μm)																					Coarse organic material				Fine organic material					Pedofeatures												
Profile	Thin section sample	Quartz	Feldspar	Biotite	Muscovite	Garnet	Hornblende	Olivine	Compound quartz	Sandstone	Siltstone	Igneous rock fragments	Metamorphics	CaCO3	Coal	Clinker-type material	Phytoliths	Diatoms	Bone	Fired material	Rubified mineral	Fine mineral material	Fungal spores	Lignified tissue	Parenchymatic tissue	Charcoal	Cell residue	Amorphous (black)	Amorphous (brown)	Amorphous (yellow-orange)	Amorphous (inclusions)	Limpid clay coatings	Dusty clay coatings	Silt coatings	Organic coatings	Clay infills	Amorphous crypto-crystalline nodules	Amorphous crypto-crystalline infills/coatings	Excremental	Depletion	Microstructure	Coarse material arrangement	Groundmass b-fabric	Related distribution
NA3	NA3AP1	****	**	t	*	t	t	**	*	*	t	t	*				**	*	t	*	*	Mid brown hetero-geneous organo-mineral Dotted limpidity	*	**	*	*	*	**	*	**	t				t				*		Intergrain microaggregate	Random basic Sorted	Stipple-speckled	Single-spaced enaulic to porphyric
	NA3AP2.1	****	*	t	t	t	*		*	*	*	*	*			*	*	t		t	t	Mid brown hetero-geneous organo-mineral Dotted limpidity	*	*	t	t	t	**	*	*	t				t				*		Intergrain microaggregate	Random basic Sorted	Weakly stipple-speckled	Single-spaced enaulic to porphyric
	NA3AP2.2	****	*	t	t	t	t	*	*	*	t	*	*				t		t	t	t	Mid/dark; occasional light brown heterogeneous organo-mineral Dotted limpidity	t	t	t	t	t	*	*	t					t				**	t	Intergrain microaggregate	Random basic Moderately well sorted	Stipple-speckled	Single-spaced enaulic to porphyric
	NA3AP3	****	*	t	t	t	t	*	*	*	t	*	*				t			t	t	Dark brown hetero-geneous organo-mineral Dotted limpidity	t	*	t	t	t	*	**	t	t				t				**		Intergrain microaggregate occasional channel	Random basic Poorly sorted	Stipple-speckled	Single-spaced enaulic to porphyric
	NA3BW1.1	****	*	t	t	t	t	*	*	t	t	t	*								t	Mid/dark reddish brown hetero-geneous dominantly mineral Dotted limpidity	t	t		t	t	t	t	t					*	t			***		Intergrain microaggregate; occasional channel	Random basic Sorted	Weakly stipple-speckled	Single-spaced enaulic to porphyric
	NA3BW1.2	****	*	t	t	t	t	*	t	t	t	t	*							t	t	Mid/dark reddish brown hetero-geneous dominantly mineral Dotted limpidity	*	t		t	t	*	t	t					*	t			***		Intergrain microaggregate; occasional channel	Random basic Sorted	Weakly stipple-speckled	Single-spaced enaulic to chitonic
	NA3C	****	*	t	t	t	t	*	t	*	t		t				t	t			t	Light brown hetero-geneous dominantly mineral Dotted limpidity	t		t	t	t	t	t						t				**	t	Intergrain microaggregate to single grain	Random basic Sorted	Weakly stipple-speckled	Monic to single-spaced enaulic
TE1	TE1AP1.1	***	*	t	t		t		*	**	t	t	*	*		t	t	t	t	**	*	Dark reddish brown hetero-geneous organo-mineral Dotted limpidity	t	t	t	t	t	**	t	t						t	*	*	t	**	Intergrain microaggregate to subangular blocky	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric
	TE1AP1.2	****	t	t	t	t	t		*	**	*	t	*	**		*	t		t	*	*	Mid/dark reddish-brown hetero-geneous organo-mineral Dotted limpidity	t	t	*	t	t	**	*	t	t					t	*	*		*	Intergrain microaggregate to subangular blocky	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric
	TE1AP2.1	****	*	t	t	t	t	t	t	**	*	*	*	**		t	t	t		*	*	Light/mid brown hetero-geneous organo-mineral Dotted limpidity	t	t	*	t	t	**	t	t	t				*	t	**	t	*	*	Intergrain microaggregate to subangular blocky	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric

Frequency class refers to the appropriate area of section (Bullock et al., 1985): t Trace * Very few ** Few *** Frequent/Common **** Dominant/Very dominant
Frequency class for textural pedofeatures (Bullock et al., 1985): t Trace * Rare ** Occasional *** Many

Appendix 8: Thin section descriptive tables - Profiles TE1, TE2, TE3

Profile	Thin section sample	Coarse mineral material (< 10μm)																				Fine mineral material	Coarse organic material				Fine organic material					Pedofeatures									Microstructure	Coarse material arrangement	Groundmass b-fabric	Related distribution
		Quartz	Feldspar	Biotite	Muscovite	Garnet	Hornblende	Olivine	Compound quartz	Sandstone	Siltstone	Igneous rock fragments	Metamorphics	CaCO3	Coal	Clinker-type material	Phytoliths	Diatoms	Bone	Fired material	Rubified mineral		Fungal spores	Lignified tissue	Parenchymatic tissue	Charcoal	Cell residue	Amorphous (black)	Amorphous (brown)	Amorphous (yellow-orange)	Amorphous (inclusions)	Limpid clay coatings	Dusty clay coatings	Silt coatings	Organic coatings	Clay infills	Amorphous crypto-crystalline nodules	Amorphous crypto-crystalline infills/coatings	Excremental	Depletion				
TE1	TE1AP2.2	***	*	t	t	t	t	*	t	**	t	*	*	**			t		t	*	**	Mid/dark brown hetero-geneous organo-mineral Dotted limpidity	t	t	t	t	t	*	t	t	t				*	t	**	t	*	**	Intergrain microaggregate	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric
	TE1AP3.2	***	t		t	t	t	t	*	*	t	t	*	t			*	t		*	**	Light brown hetero-geneous organo-mineral Dotted limpidity	*	t	t	t	t	t	t	*	t				*	t	**	*	**	**	Intergrain microaggregate	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric
	TE1AB	***	t	t	t	t	t	**	*	*	**	t	t	t			*	t		t	*	Light and mid brown hetero-geneous organo-mineral Dotted limpidity	t	t	t	t	t	*	**	t	*				**		**	*	***	**	Intergrain micro-aggregate to subangular blocky	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric; occasional enaulic
	TE1BS	***	t	t	t	t	t	**	*	*	t	*	t	t			*			*	t	Light and red brown hetero-geneous organo-mineral Dotted limpidity	t	t				t	*	*		**	t	*	**	*	**	**	**	***	Intergrain microaggregate	Random basic Poorly sorted	Stipple-speckled	Single to double-spaced porphyric; occasional enaulic
TE2	TE2AP1.1	***	*	t	t	t	t	t	t	**	*	*	**	t		t	*	t	t	*	t	Mid brown heterogeneous organo-mineral Dotted limpidity	*	t	**	*	*	*	*	t	t				t		*	t	**	*	Intergrain microaggregate	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric to enaulic
	TE2AP1.2	***	t	t	t	t			**	**	*	t	*	t	t	*	*	t	t	*	*	Mid brown heterogeneous organo-mineral Dotted limpidity	*	t	**	t	t	**	*	t	*				t		t	t	*	t	Intergrain microaggregate	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric; occasional enaulic
	TE2AP2.1	****	*	t	t	t	t		*	**	*	*	t	**		t	*		t	*	*	Mid brown heterogeneous organo-mineral Dotted limpidity	*	*	t		t	*	*	t					t		*	t	**	**	Intergrain microaggregate to channel	Random basic Poorly sorted	Weakly stipple-speckled	Sinlgle to double-spaced porphyric
	TE2AP2.2	***	*	t	t	t	t		*	**	*	*	*	t			t				*	Light to reddish brown hetero-geneous organo-mineral Dotted limpidity	t	t	t	t	t	t	t	t				t	t		*	t	**	*	Intergrain microaggregate to channel	Random basic Poorly sorted	Weakly stipple-speckled	Sinlgle to double-spaced porphyric
	TE2AP3	***	t	t	t	t	t		*	*	*	t	*	t						t	*	Mid brown heterogeneous organo-mineral Dotted limpidity	t	t	t	t	t	*	t						t	t	*	t	**	*	Intergrain microaggregate to vughy	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric
	TE2BS	***	*	t	t	t	t		*	**	*	**	*							t	*	Light brown hetero-geneous organo-mineral Dotted limpidity		t	*		t	t	t						t		t		**	t	Intergrain microaggregate	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric
TE3	TE3AP1	***	t		t	t	t	t	*	**	*	*	*	*	t	*	*	*	t	t	**	Mid brown heterogeneous organo-mineral Dotted limpidity	*	t	t	*	t	**	*	t	t				t		t		t		Intergrain microaggregate	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric

Frequency class refers to the appropriate area of section (Bullock et al., 1985): t Trace * Very few ** Few ***Frequent/Common **** Dominant/Very dominant
Frequency class for textural pedofeatures (Bullock et al., 1985): t Trace * Rare ** Occasional *** Many

Appendix 8: Thin section descriptive tables - Profiles TE3, UN1

Coarse mineral material (< 10μm)

Profile	Thin section sample	Quartz	Feldspar	Biotite	Muscovite	Garnet	Hornblende	Olivine	Compound quartz	Sandstone	Siltstone	Igneous rock fragments	Metamorphics	CaCO3	Coal	Clinker-type material	Phytoliths	Diatoms	Bone	Fired material	Rubified mineral
TE3	TE3AP2.1	***	*		t	t	t		*	**	*	*	*	*	t	*			t	t	*
	TE3AP2.2	****	*	t	t	t	t		*	**	*	*	*	*	t	**				*	*
	TE3AP3.1	****	*	t	t	t	t		*	**	*	*	*	t	*	t	t		t	t	*
	TE3AP3.2	****	t	t	t	t	t	t	*	**	*	*	*		t	t	t	t		*	**
	TE3AB1.1	***	t	t	t	t	t	t	t	**	*	*	**				t	t		*	*
	TE3AB1.2	***	t	t	t	t	t		*	**	*	*	*				t			t	t
UN1	UN1AP1	**	t		t	t	t	*	*	*		*	**				t	t		t	t
	UN1AP2.1	**	t	t	t	t	t		**	*	t	*	**				*	t		t	t
	UN1AP2.2	**	t	t	*	t	t		**	*	t	t	**				t				t
	UN1AP2.3	**	t	t	*	t	t		**	*	t		**				t		t		t

Profile	Thin section sample	Fine mineral material	Coarse organic material: Fungal spores	Lignified tissue	Parenchymatic tissue	Charcoal	Fine organic material: Cell residue	Amorphous (black)	Amorphous (brown)	Amorphous (yellow-orange)	Amorphous (inclusions)
TE3	TE3AP2.1	Dark brown hetero-geneous organo-mineral Dotted limpidity	t	t	t	*	t	***	*	t	t
	TE3AP2.2	Mid to dark brown hetero-geneous organo-mineral Dotted limpidity	t	t	t	*	t	**	t	t	t
	TE3AP3.1	Mid to dark brown hetero-geneous organo-mineral Dotted limpidity	t	t	t	*	t	***	t	t	t
	TE3AP3.2	Mid to dark brown hetero-geneous organo-mineral Dotted limpidity	*	t	t	t		***	*	t	*
	TE3AB1.1	Light to mid brown hetero-geneous organo-mineral Dotted limpidity	*	t	t	t	*	*	**	*	
	TE3AB1.2	Mid brown heterogeneous organo-mineral Dotted limpidity	t	t	t	*	t	t	t	t	
UN1	UN1AP1	Dark brown hetero-geneous organo-mineral Dotted limpidity	t	t	t		t	***	**	*	*
	UN1AP2.1	Dark brown hetero-geneous organo-mineral Dotted limpidity	t	t	t		t	***	**	*	*
	UN1AP2.2	Dark brown hetero-geneous organo-mineral Dotted limpidity	*		t	t	t	***	**	**	*
	UN1AP2.3	Dark brown hetero-geneous organo-mineral Dotted limpidity	t	t	t	t	t	***	**	*	*

Pedofeatures

Profile	Thin section sample	Limpid clay coatings	Dusty clay coatings	Silt coatings	Organic coatings	Clay infills	Amorphous crypto-crystalline nodules	Amorphous crypto-crystalline infills/coatings	Excremental	Depletion
TE3	TE3AP2.1				t		*		*	t
	TE3AP2.2				t	t	t		*	
	TE3AP3.1				t	t	*		t	*
	TE3AP3.2				t		*		*	
	TE3AB1.1				*	t	*		**	
	TE3AB1.2				t	t	*	t	*	*
UN1	UN1AP1	t				t			**	
	UN1AP2.1						*		***	t
	UN1AP2.2			t	t		*		***	
	UN1AP2.3				*		**		***	

Profile	Thin section sample	Microstructure	Coarse material arrangement	Groundmass b-fabric	Related distribution
TE3	TE3AP2.1	Intergrain microaggregate	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric
	TE3AP2.2	Intergrain microaggregate	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric
	TE3AP3.1	Intergrain microaggregate to vughy	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric
	TE3AP3.2	Intergrain microaggregate	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric
	TE3AB1.1	Intergrain microaggregate to vughy	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric; some enaulic
	TE3AB1.2	Intergrain microaggregate to vughy	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric; some enaulic
UN1	UN1AP1	Intergrain microaggregate	Random basic Poorly sorted	Stipple-speckled	Single to double-spaced porphyric
	UN1AP2.1	Intergrain microaggregate	Random basic Sorted	Stipple-speckled	Single to double-spaced porphyric
	UN1AP2.2	Intergrain microaggregate to channel	Random basic Poorly sorted	Stipple-speckled	Single to double-spaced to open porphyric
	UN1AP2.3	Intergrain microaggregate	Random basic Poorly sorted	Stipple-speckled	Single to double-spaced to open porphyric

Frequency class refers to the appropriate area of section (Bullock et al., 1985): t Trace * Very few ** Few *** Frequent/Common **** Dominant/Very dominant
Frequency class for textural pedofeatures (Bullock et al., 1985): t Trace * Rare ** Occasional *** Many

Appendix 8: Thin section descriptive tables - Profiles UN1, UN2, UN3

Profile	Thin section sample	Coarse mineral material (< 10μm)																			
		Quartz	Feldspar	Biotite	Muscovite	Garnet	Hornblende	Olivine	Compound quartz	Sandstone	Siltstone	Igneous rock fragments	Metamorphics	CaCO3	Coal	Clinker-type material	Phytoliths	Diatoms	Bone	Fired material	Rubified mineral
UN1	UN1AP3.1	**	t	t	*	*	t		*	t	t		**				t				t
	UN1BS	**	t	t	*	t	t		**	*	t	t	**								t
UN2	UN2AP1	**	t	t	t	*	t		**	t			*				*	*	t		
	UN2AP2.1	***	*	t	t	*	t		**	t			**						t		
	UN2AP.2.2	***	t	t	t	t	t	t	**	*			*						t		t
	UN2AP3.1	***	*	t	*	t	t	*	**	t			**						t		t
	UN2AP3.2	***	t	t	*	*	t	*	**	*	t	t	**				t	t	t		*
	UN2AB1	***	*	t	*	t	t		***		t		**				t				*
	UN2BS	***	t	t	t	t	t		**				**				t	t			t
UN3	UN3AP1	**	*	t	t	*	t	t	t	t	t		*				*	*			t
	UN3AP2.1	***	*	t	t	*	t		t	t			*				*	*			t

Profile	Thin section sample	Fine mineral material	Coarse organic material				Fine organic material				
			Fungal spores	Lignified tissue	Parenchymatic tissue	Charcoal	Cell residue	Amorphous (black)	Amorphous (brown)	Amorphous (yellow-orange)	Amorphous (inclusions)
UN1	UN1AP3.1	Light to red brown hetero-geneous organo-mineral Dotted limpidity	t	t	t	t	t	**	*	t	*
	UN1BS	Mid reddish brown hetero-geneous organo-mineral Dotted limpidity	t	t	t		t	*	*		*
UN2	UN2AP1	Light brown hetero-geneous organo-mineral Dotted limpidity	*	t	*	*	*	*	*	*	
	UN2AP2.1	Mid brown heterogeneous organo-mineral Dotted limpidity	*		t	t	*	*	**	*	t
	UN2AP.2.2	Dark brown hetero-geneous organo-mineral Dotted limpidity	t		t		t	*	*		
	UN2AP3.1	Mid to dark brown hetero-organo-mineral Dotted limpidity	t		t	t	t	*	*	t	
	UN2AP3.2	Mid brown heterogeneous organo-mineral Dotted limpidity	t		t		t	**	t		t
	UN2AB1	Mid to dark brown hetero-organo-mineral Dotted limpidity	t		t	t	t	*	t	t	
	UN2BS	Mid to reddish brown hetero-geneous organo-mineral Dotted limpidity	t			t	t	*	*		
UN3	UN3AP1	Mid to orange brown hetero-geneous organo-mineral Dotted limpidity	*		**	t	**	*	*	**	
	UN3AP2.1	Mid to orange brown hetero-geneous organo-mineral Dotted limpidity	*		**	t	*	*	*	**	

Profile	Thin section sample	Pedofeatures									Microstructure	Coarse material arrangement	Groundmass b-fabric	Related distribution
		Limpid clay coatings	Dusty clay coatings	Silt coatings	Organic coatings	Clay infills	Amorphous crypto-crystalline nodules	Amorphous crypto-crystalline infills/coatings	Excremental	Depletion				
UN1	UN1AP3.1	**	*	t	t	***	**	*	**	**	Intergrain microaggregate to vughy	Random basic Sorted	Stipple-speckled	Single to double-spaced porphyric
	UN1BS	*				*	***	*	**	**	Intergrain microaggregate	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric
UN2	UN2AP1				t	t	*		*	t	Intergrain microaggregate	Random basic Sorted	Stipple-speckled	Single to double-spaced porphyric
	UN2AP2.1						*	t	**	*	Intergrain microaggregate	Random basic Sorted	Stipple-speckled	Single to double-spaced porphyric
	UN2AP.2.2				t		t		*	t	Intergrain microaggregate	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric
	UN2AP3.1				t		*		*	t	Intergrain microaggregate to channel	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric
	UN2AP3.2				t		t		**	*	Intergrain microaggregate	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric; some enaulic
	UN2AB1						*		*		Intergrain microaggregate	Random basic Quite poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric
	UN2BS						***	**	*	**	Intergrain microaggregate	Random basic Poorly sorted	Stipple-speckled	Single to double-spaced porphyric
UN3	UN3AP1				t		*		*		Intergrain microaggregate	Random basic Sorted	Weakly stipple-speckled	Double-spaced to open porphyric
	UN3AP2.1				t		*		**		Intergrain microaggregate	Random basic Sorted	Weakly stipple-speckled	Double-spaced to open porphyric

Frequency class refers to the appropriate area of section (Bullock et al., 1985): t Trace * Very few ** Few *** Frequent/Common **** Dominant/Very dominant
Frequency class for textural pedofeatures (Bullock et al., 1985): t Trace * Rare ** Occasional *** Many

Appendix 8: Thin section descriptive tables - Profiles UN3, UN4

		Coarse mineral material (< 10μm)																					Coarse organic material				Fine organic material					Pedofeatures												
Profile	Thin section sample	Quartz	Feldspar	Biotite	Muscovite	Garnet	Hornblende	Olivine	Compound quartz	Sandstone	Siltstone	Igneous rock fragments	Metamorphics	CaCO3	Coal	Clinker-type material	Phytoliths	Diatoms	Bone	Heated manufactured material	Rubified mineral	Fine mineral material	Fungal spores	Lignified tissue	Parenchymatic tissue	Charcoal	Cell residue	Amorphous (black)	Amorphous (brown)	Amorphous (yellow-orange)	Amorphous (inclusions)	Limpid clay coatings	Dusty clay coatings	Silt coatings	Organic coatings	Clay infills	Amorphous crypto-crystalline nodules	Amorphous crypto-crystalline infills/coatings	Excremental	Depletion	Microstructure	Coarse material arrangement	Groundmass b-fabric	Related distribution
UN3	UN3AP2.2	***	*	t	*	*	t		*	t			**				t	t	t		t	Mid brown heterogeneous organo-mineral Dotted limpidity	t		t		t	*	*	t	t						*		**	t	Intergrain microaggregate	Random basic Sorted	Weakly stipple-speckled	Single to double-spaced porphyric
	UN3AP3.1	***	*	t	t	*	t	*	*	*	t		**				t	t	t		t	Dark brown hetero-geneous organo-mineral Dotted limpidity	t		t		t	**	*	t					t		*		**	t	Intergrain microaggregate	Random basic Sorted	Weakly stipple-speckled	Single to double-spaced porphyric
	UN3AP3.2	***	t	t	t	t	t		*	t			**				t		t		t	Dark brown hetero-geneous organo-mineral Dotted limpidity	t	t	t	t	t	**	*	t					t		*		**	t	Intergrain microaggregate to channel	Random basic Sorted	Weakly stipple-speckled	Single to double-spaced to open porphyric
	UN3AB1	**	t	t	t	t	t		*	t			*						t		t	Dark to reddish brown hetero-geneous organo-mineral Dotted limpidity	t		t		t	**	*	t			t				***		*		Intergrain microaggregate	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric
	UN3BS1	**	t	t	t	t	t	t	*	t	t		*								t	Light/mid to reddish-brown hetero-geneous organo-mineral Dotted limpidity				t	t	*	t	t							***			*	Intergrain microaggregate to channel	Random basic Poorly sorted	Weakly stipple-speckled Occasional granostriation	Single to double-spaced porphyric; occasional enaulic
UN4	UN4AP1	**	*	t	*	*	t	*	**	t			**				*	**	t		*	Light/mid reddish brown hetero-geneous organo-mineral Dotted limpidity	*		**	t	t	**	**	*		t		t	t	*	*	*	*		Intergrain microaggregate	Random basic Poorly sorted	Stipple-speckled	Single to double-spaced porphyric
	UN4AP2.1	**	*	t	t	*	t		**	t			**				t	*	t		t	Mid brown heterogeneous organo-mineral Dotted limpidity	*	t	t	t	t	**	*	t	t	*	*		t	*	*	t	*	t	Intergrain microaggregate to channel	Random basic Poorly sorted	Stipple-speckled	Single to double-spaced porphyric
	UN4AP2.2	**	t	t	t	*	*		**	t			**				t	t	t		t	Dark brown hetero-geneous organo-mineral Dotted limpidity	*	t	t	t	t	**	**	t	t				t	t	*		*		Intergrain microaggregate	Random basic Quite poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric
	UN4AP2.3	**	t	t	*	*	t	*	**	t			**				t	t	t		t	Dark brown hetero-geneous organo-mineral Dotted limpidity	t		t	t	t	**	*	t	*						*		t	t	Intergrain microaggregate	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric
	UN4AP3	***	t	t	t	*	t		**				**				t	t	t		t	Mid brown heterogeneous organo-mineral Dotted limpidity	t		t	t	t	**	*	*	t	t			t	*	*		t	t	Intergrain microaggregate to channel	Random basic Poorly sorted	Stipple-speckled	Single to double-spaced porphyric
	UN4AB	**	t	t	t	*	t		**	t			**					t			t	Mid reddish brown hetero-geneous organo-mineral Dotted limpidity	t		t	t	t	*	*	t		t			t	*	**	*	*	*	Intergrain microaggregate to channel	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric; occasional enaulic

Frequency class refers to the appropriate area of section (Bullock et al., 1985): t Trace * Very few ** Few *** Frequent/Common **** Dominant/Very dominant
Frequency class for textural pedofeatures (Bullock et al., 1985): t Trace * Rare ** Occasional *** Many

Appendix 8: Thin section descriptive tables - Profile UN4

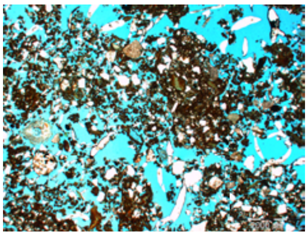
		Coarse mineral material (< 10μm)																			
Profile	Thin section sample	Quartz	Feldspar	Biotite	Muscovite	Garnet	Hornblende	Olivine	Compound quartz	Sandstone	Siltstone	Igneous rock fragments	Metamorphics	CaCO3	Coal	Clinker-type material	Phytoliths	Diatoms	Bone	Fired material	Rubified mineral
UN4	UN4BS1.1	**	t		t	t	t	**	**	*			**				t				t
	UN4BS1.2	***	*		t	*	t	*	**	*			**				t	t			t

		Coarse organic material				Fine organic material				
Thin section sample	Fine mineral material	Fungal spores	Lignified tissue	Parenchymatic tissue	Charcoal	Cell residue	Amorphous (black)	Amorphous (brown)	Amorphous (yellow-orange)	Amorphous (inclusions)
UN4BS1.1	Light reddish brown hetero-geneous organo-mineral Dotted limpidity	t		t	t	t	*	t	t	
UN4BS1.2	Light reddish brown hetero-geneous organo-mineral Dotted limpidity				t	t	*	t	t	

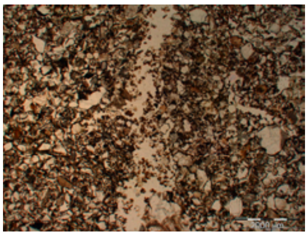
	Pedofeatures												
Thin section sample	Limpid clay coatings	Dusty clay coatings	Silt coatings	Organic coatings	Clay infills	Amorphous crypto-crystalline nodules	Amorphous crypto-crystalline infills/coatings	Excremental	Depletion	Microstructure	Coarse material arrangement	Groundmass b-fabric	Related distribution
UN4BS1.1	*	*		t	*	**	**	*	*	Intergrain microaggregate	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric; some enaulic
UN4BS1.2		*			t	**	**	t	*	Intergrain microaggregate	Random basic Poorly sorted	Weakly stipple-speckled	Single to double-spaced porphyric; some enaulic

Frequency class refers to the appropriate area of section (Bullock et al., 1985): t Trace * Very few ** Few *** Frequent/Common **** Dominant/Very dominant
Frequency class for textural pedofeatures (Bullock et al., 1985): t Trace * Rare ** Occasional *** Many

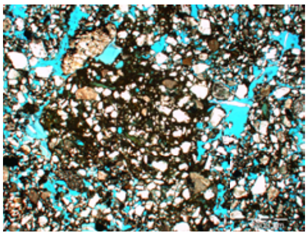
Appendix 9: Thin section digital photomicrograph library: Image thumbnails



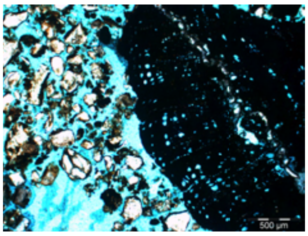
001 NA2AP1.1 Excremental fabric



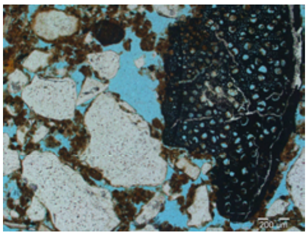
002 NA3AP3 Excremental channel



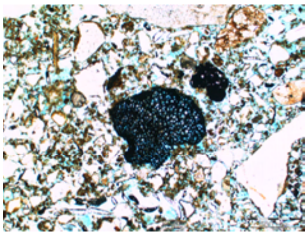
003 NA1AP1 Groundmass patch



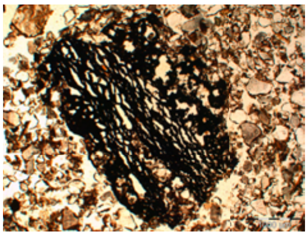
004 NA1AP2.2 Charcoal



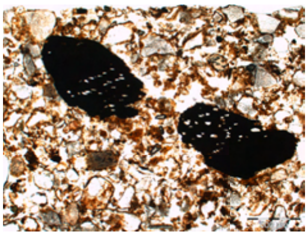
005 NA1AP3 Charcoal



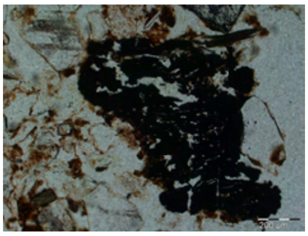
006 NA2AB Charcoal



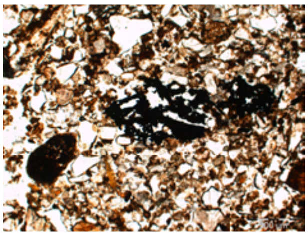
007 NA3AP1 Charcoal



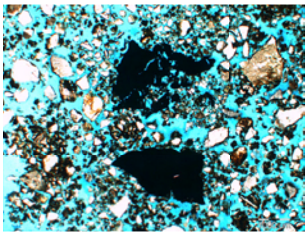
008 NA3BW1.2 Charcoal



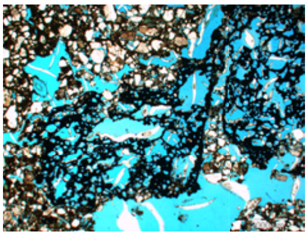
009 NA3AP2.2 Peat-like amorphous



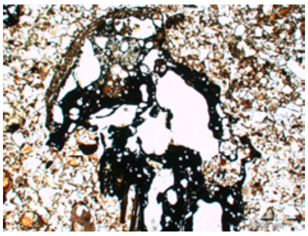
010 NA3AP3 Peat-like amorphous



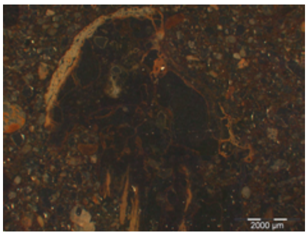
011 NA2AP1.2 Degrading peaty amorphous



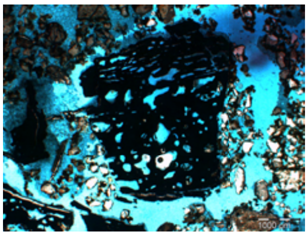
012 NA1AP1 Coal



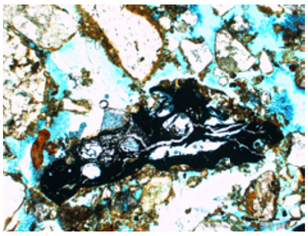
013 NA3AP2.1 Clinker



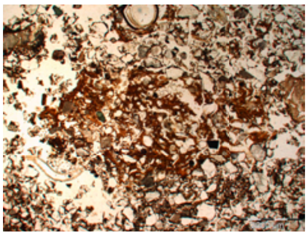
014 NA3AP2.1 Clinker (OIL)



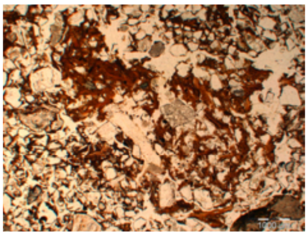
015 NA1AP2.2 Charcoal - coal



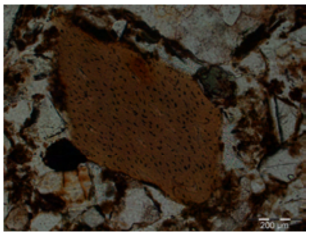
016 NA2AB Charcoal - peat



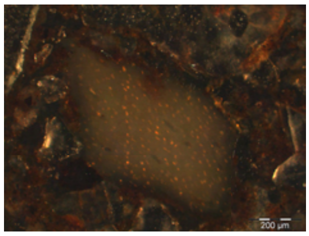
017 NA3AP1 Peaty turf



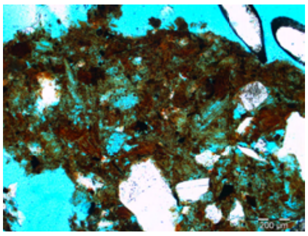
018 NA3AP2.1 Degrading peaty turf



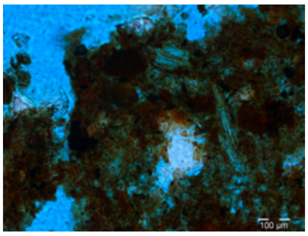
019 NA3AP2.2 Burnt bone



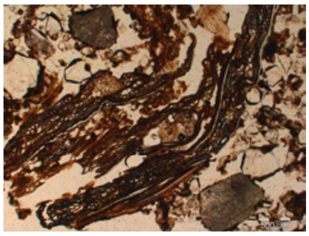
020 NA3AP2.2 Burnt bone (OIL)



021 NA2AP1.1 Possible herbivore dung1

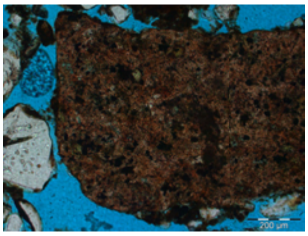


022 NA2AP1.1 Possible herbivore dung2

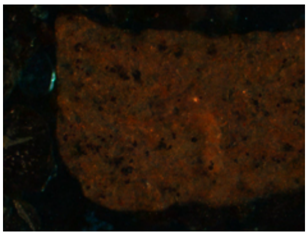


023 NA3AP1 Lignfied tissue

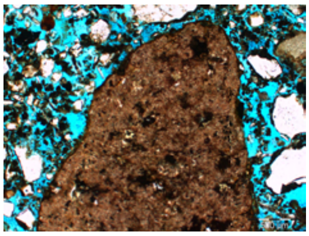
024 NA3AP1 Degrading lignfied tissue and cell residue



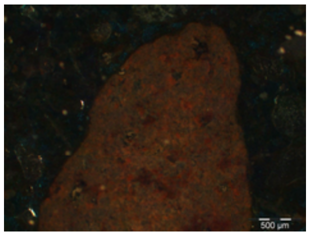
025 NA1AP2.3 Fired material



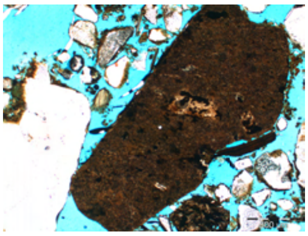
026 NA1AP2.3 Fired material (OIL)



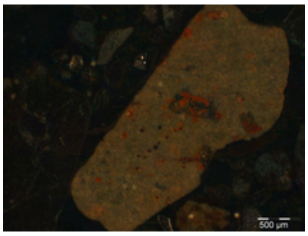
027 NA2AB Fired material



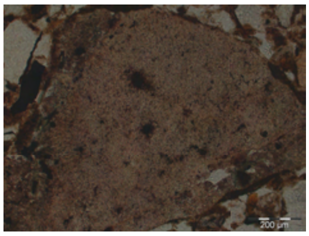
028 NA2AB Fired material (OIL)



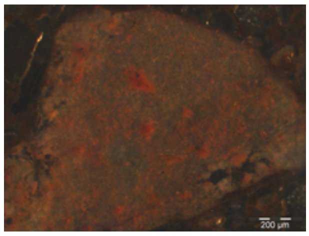
029 NA2BS Fired material



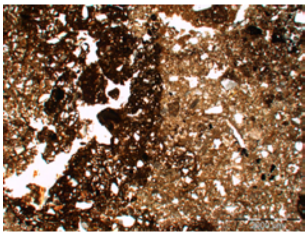
030 NA2BS Fired material (OIL)



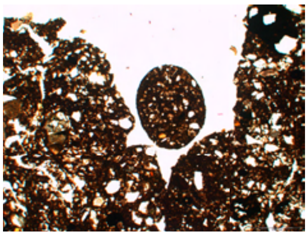
031 NA3AP1 Fired material



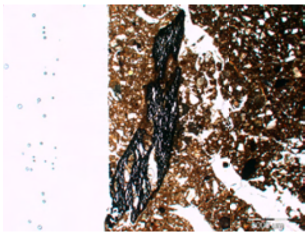
032 NA3AP1 Fired material (OIL)



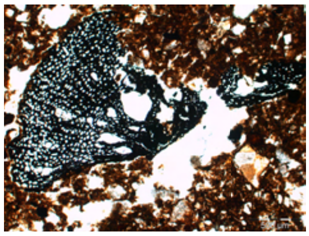
033 TE1AB Mixed groundmass



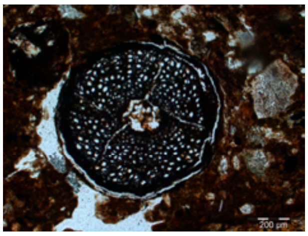
034 TE3AP3.2 Excremental material



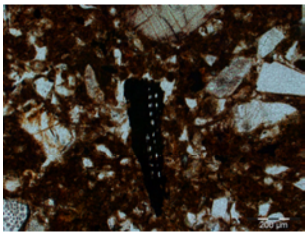
035 TE1AP1.2 Charcoal



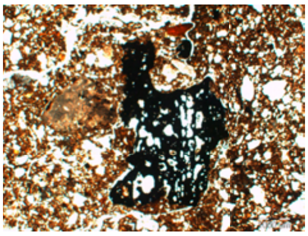
036 TE3AB1.2 Charcoal



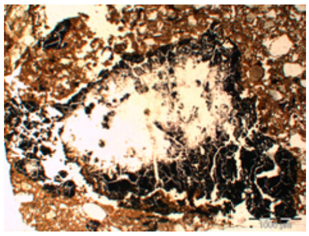
037 TE3AP3.1 Carbonised root



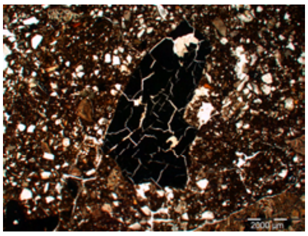
038 TE3AP3.2 Small surviving charcoal



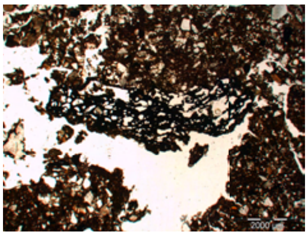
039 TE1AP1.2 Well preserved carbonised peat



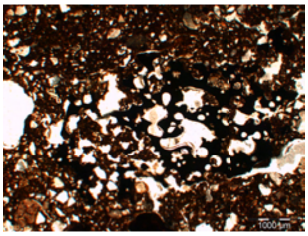
040 TE1AP2.1 Degraded carbonised peat



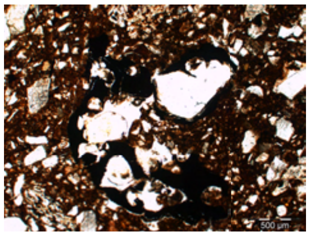
041 TE3AP1 Amorphous carbonised material



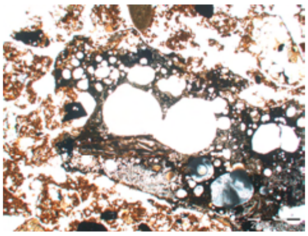
042 TE3AP2.2 Coal



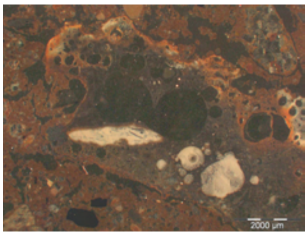
043 TE3AP3.1 Probable disaggregated coal



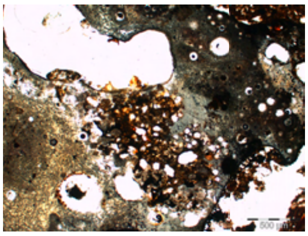
044 TE3AP3.1 Possible disaggregated coal



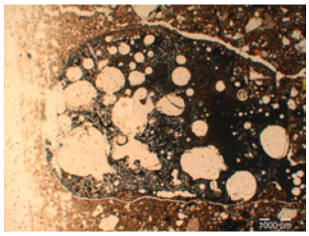
045 TE2AP1.2 Clinker



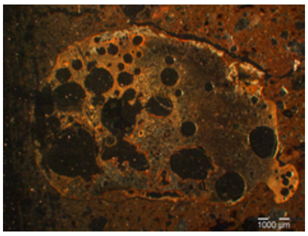
046 TE2AP1.2 Clinker (OIL)



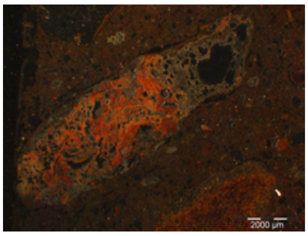
047 TE3AP3.2 Clinker and amorphous material



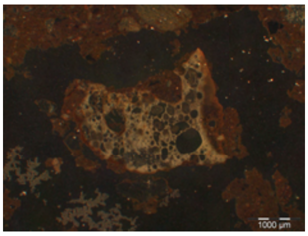
048 TE3AP1 Clinker



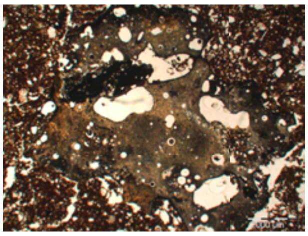
049 TE3AP1 Clinker (OIL)



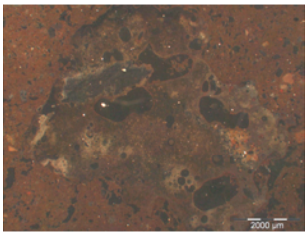
050 TE1AP1.2 Clinker (OIL)



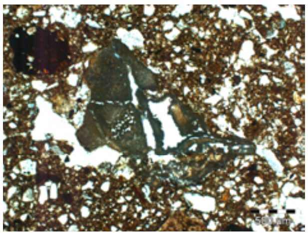
051 TE3AP2.1 Clinker (OIL)



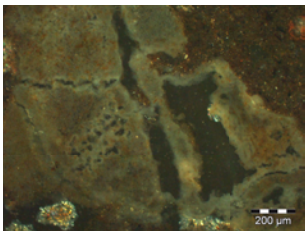
052 TE3AP3.2 Clinker



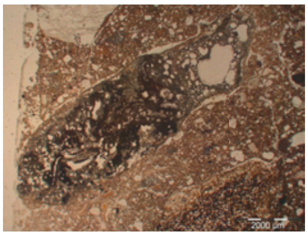
053 TE3AP3.2 Clinker (OIL)



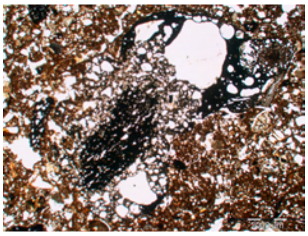
054 TE1AP1.1 Ashed material



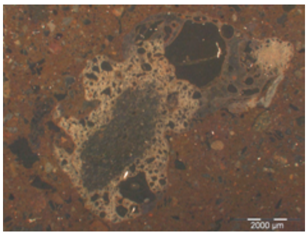
055 TE1AP1.1 Ashed material (OIL)



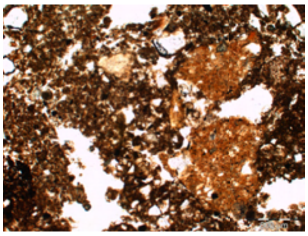
056 TE1AP1.2 Ash-type clinker



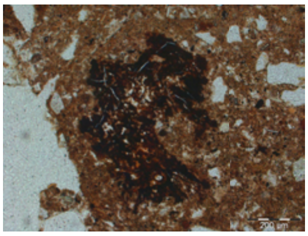
057 TE3AP2.2 Clinker-type charcoal



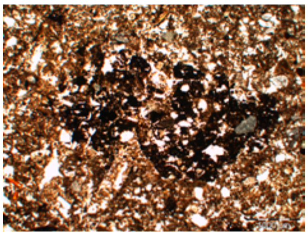
058 TE3AP2.2 CLinker-type charcoal (OIL)



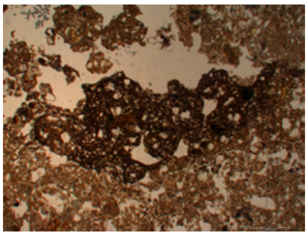
059 TE1AP3.2 Unburnt peaty material



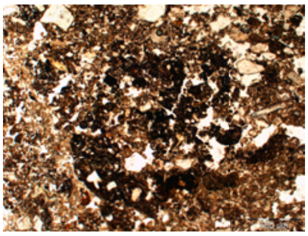
060 TE3AB1.1 Unburnt peaty material



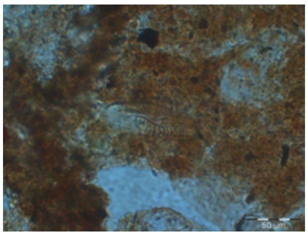
061 TE1AB Turf material



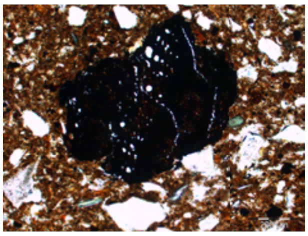
062 TE1AB Turf material



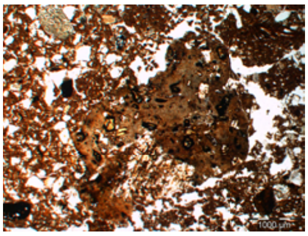
063 TE1AB Disaggregated peaty turf



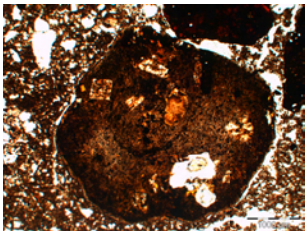
064 TE1AP3.2 Diatom



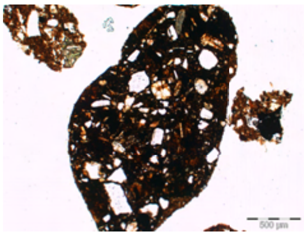
065 TE3AP2.2 Charred lignified tissue



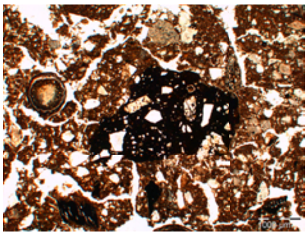
066 TE2AP1.1 Mortar with calcite-type matrix



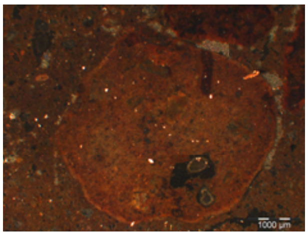
067 TE1AP2.1 Mortar



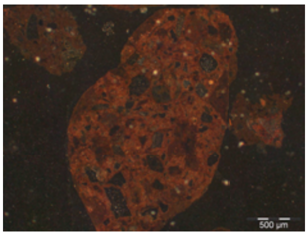
068 TE2AP1.2 Mortar



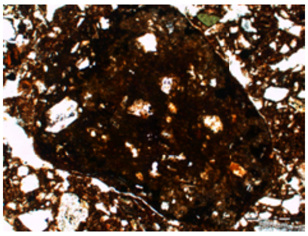
069 TE2AP1.2 Mortar



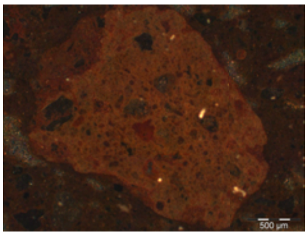
070 TE1AP2.1 Mortar (OIL)



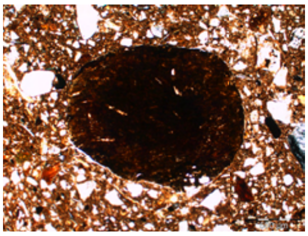
071 TE2AP1.2 Mortar (OIL)



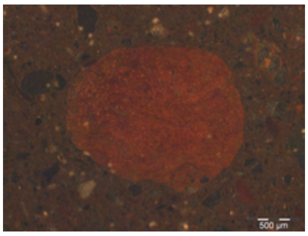
072 TE1AP1.1 Mortar



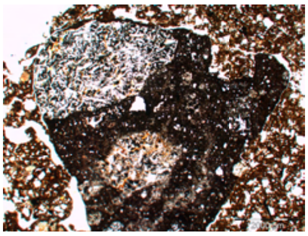
073 TE1AP1.1 Mortar (OIL)



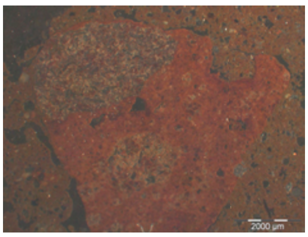
074 TE1AP1.1 Fine mortar



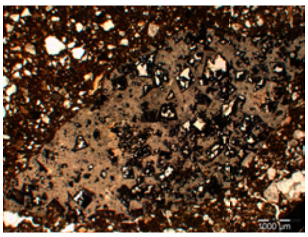
075 TE1AP1.1 Fine mortar (OIL)



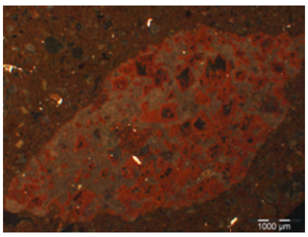
076 TE3AP3 Coarse mortar



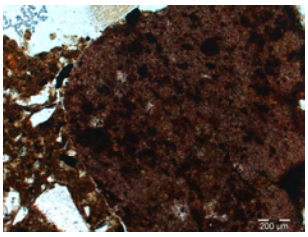
077 TE3AP3 Coarse mortar (OIL)



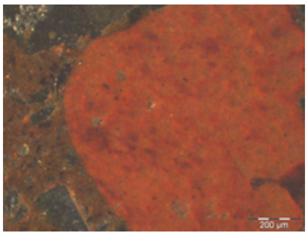
078 TE3AP2.2 Fired material



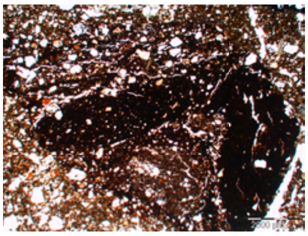
079 TE3AP2.2 Fired material (OIL)



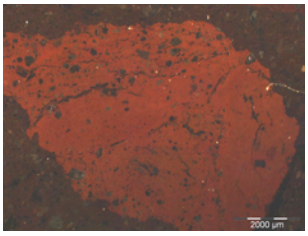
080 TE3AP1 Pot



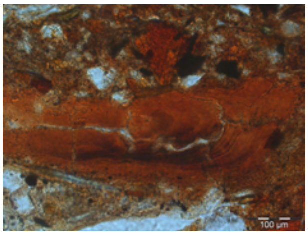
081 TE3AP1 Pot (OIL)l



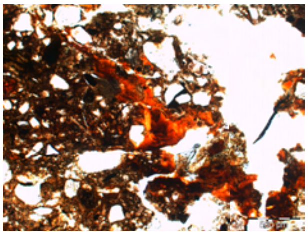
082 TE3AP2.2 Pot



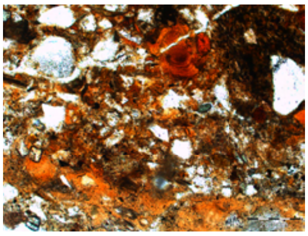
083 TE3AP2.2 Pot (OIL)



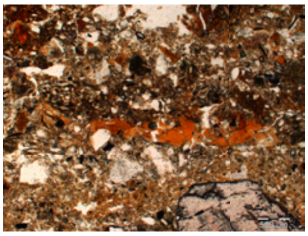
084 TE1BS Laminated clay infill



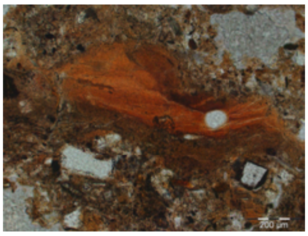
085 TE1BS Laminated clay pedofeature



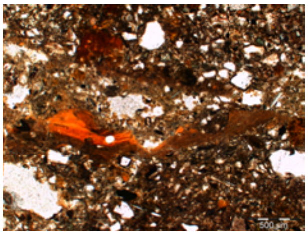
086 TE1BS Laminated, cracked clay infill



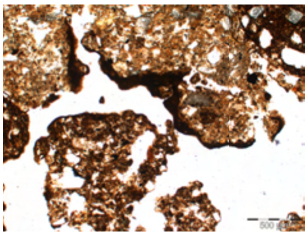
087 TE1BS Limpid clay



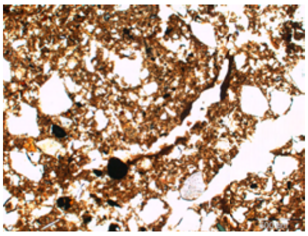
088 TE1BS Compound pedofeature



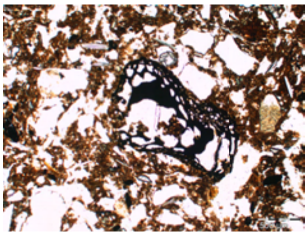
089 TE1BS Compound pedofeature



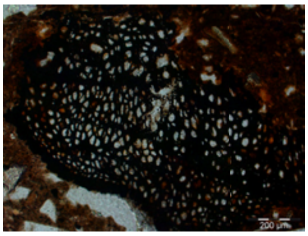
090 TE1AB Organic coatings



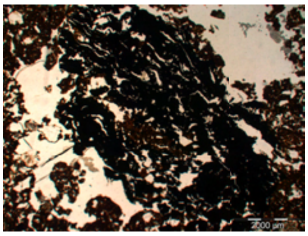
091 TE1AP3.2 Organic channel infill



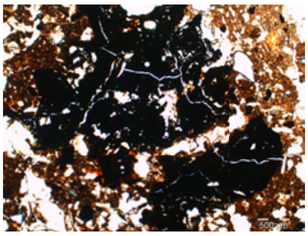
092 UN2AB Charcoal



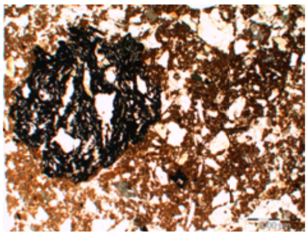
093 UN4AP3 Charcoal



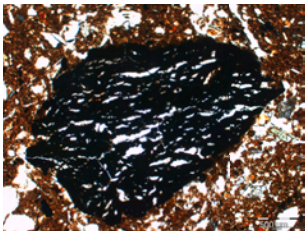
094 UN1AP2.2 Burnt peat



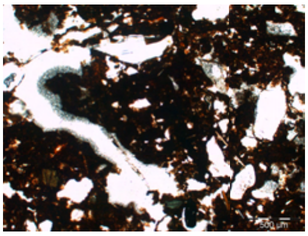
095 UN4AP2.1 Burnt peat



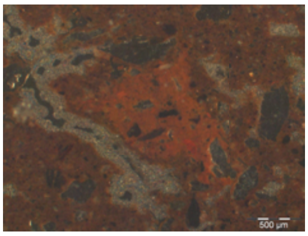
096 UN2AP2.2 Burnt peat



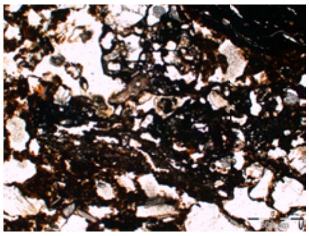
097 UN4AP2.1 Burnt peat



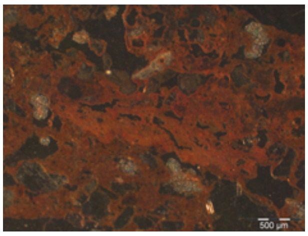
098 UN4AP2.2 Burnt peat



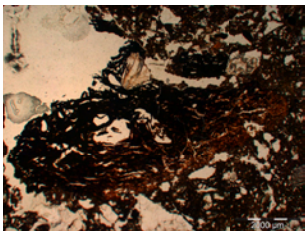
099 UN4AP2.2 Burnt peat (OIL)



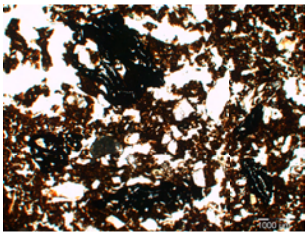
100 UN2AP3.2 Burnt peat



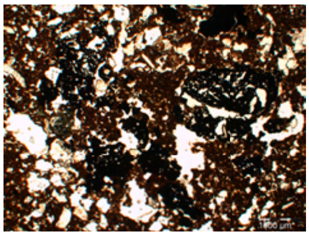
101 UN2AP3.2 Burnt peat (OIL)



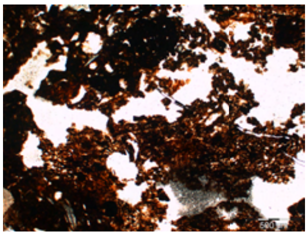
102 UN1AP2.3 Part burned peat



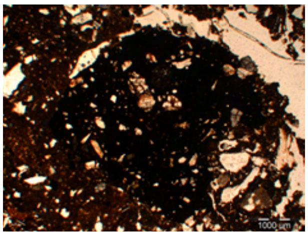
103 UN1AP2.1 Diasaggregated burnt peat



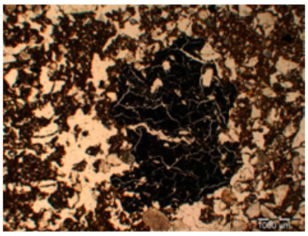
104 UN1AP2.2 Disaggregated burnt peat



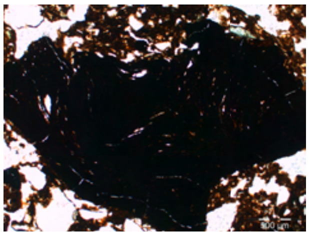
105 UN4AP2.2 Groundmass showing fragmentary ...



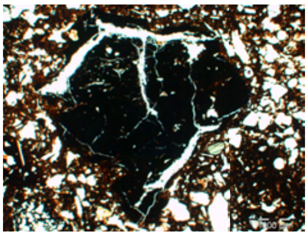
106 UN1AP2.3 Burnt turf



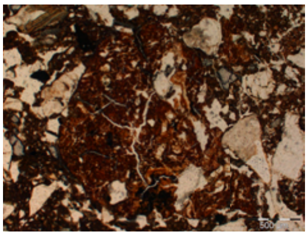
107 UN2AP2.1 Burnt amorphous organic material



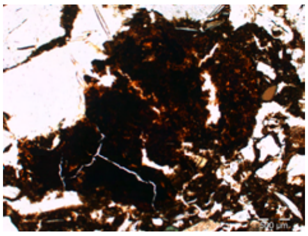
108 UN3AP3.2 Burnt amorphous organic material



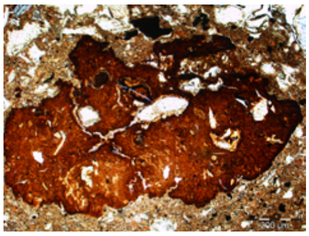
109 UN3AB Burnt amorphous organic material



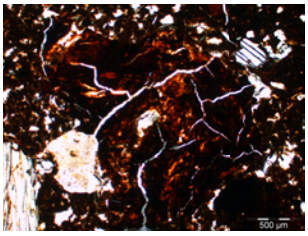
110 UN2AP2.1 Peat or turf fragment



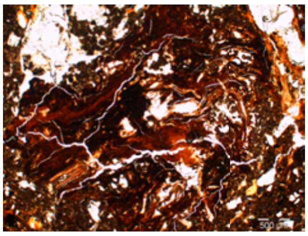
111 UN2AB Peat fragment



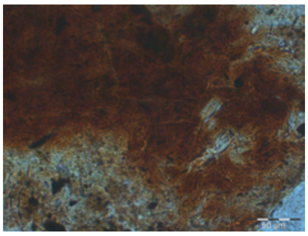
112 UN4AP2.1 Peaty turf



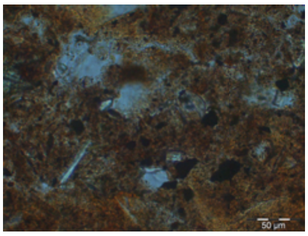
113 UN1AP1 Peaty turf



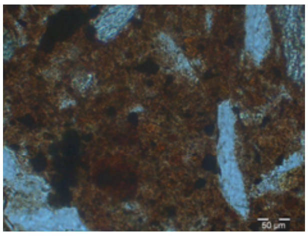
114 UN4AP1.1 Peaty turf



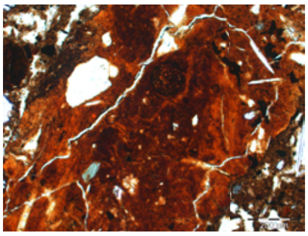
115 UN4AP1.1 Diatom in peat



116 UN4AP1.1 Diatom in peat

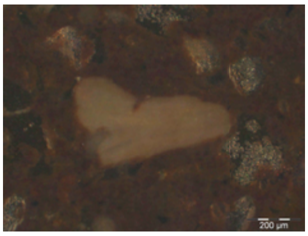


117 UN4AP2.1 Diatom in peat

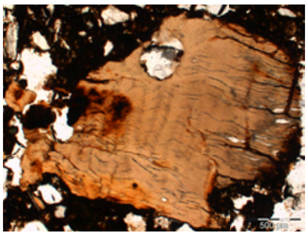


118 UN4AP2.1 Peaty turf containing sclerotia

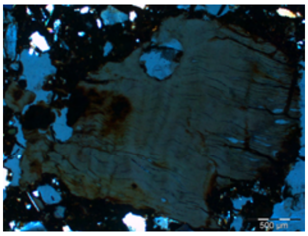
119 UN3AP3.2 Burnt bone



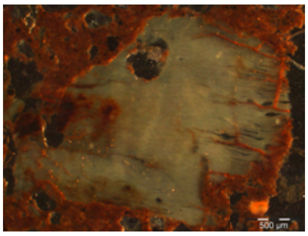
120 UN3AP3.1 Burnt bone (OIL)



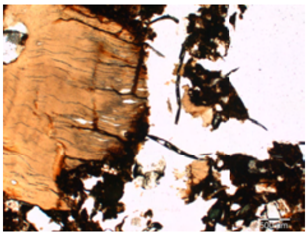
121 UN2AP3.1 Charred bone



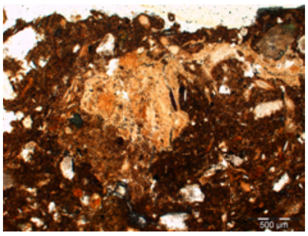
122 UN2AP3.1 Charred bone (XPL)



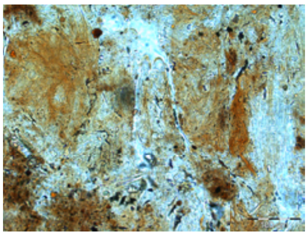
123 UN2AP3.1 Charred bone (OIL)



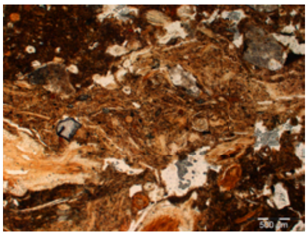
124 UN2AP3.1 Degrading bone



125 UN3AP1 Possible herbivore dung

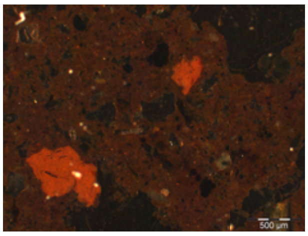


126 UN3AP1 Possible herbivore dung

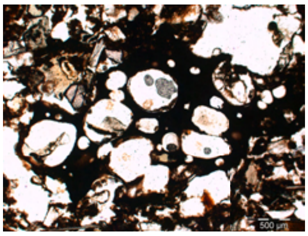


127 UN3AP2.1 Possible herbivore dung

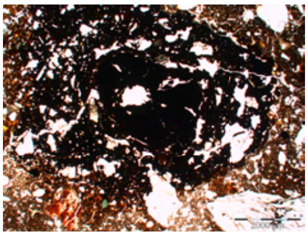
128 UN3AP1 Plant residues



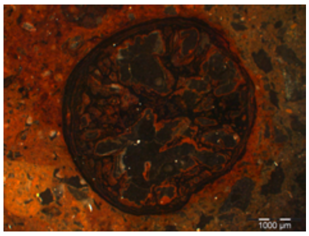
129 UN1AP1 Pottery fragments



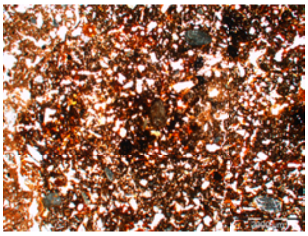
130 UN2AP3.2 Possible pumice



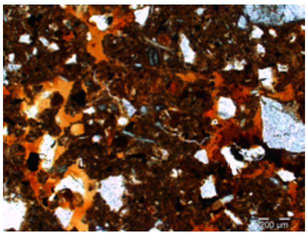
131 UN4AP1.1 Iron concreted root



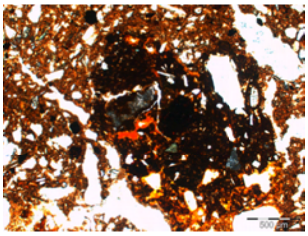
132 UN1BS Iron impregnated root pseudomorph



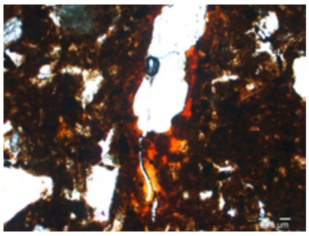
133 UN1AP3.1 Limpid clay infills



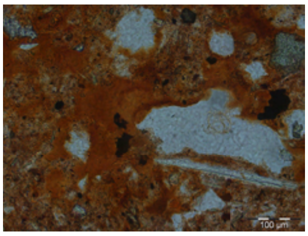
134 UN4AP2.1 Limpid clay infills



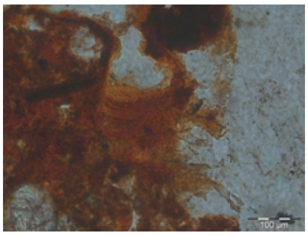
135 UN1AP3.1 Limpid infill in peaty fragment



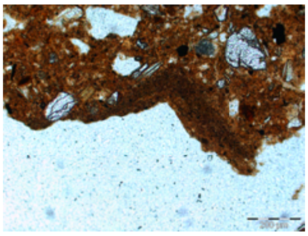
136 UN1AP1 Limpid clay channel infill



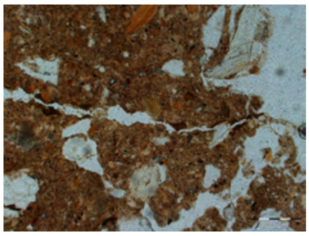
137 UN1AP3.1 Laminated clay infill and coating



138 UN4BS1.1 Laminated clay coating



139 UN1AP3.1 Silt coating



140 UN2AP1 Small organic coatings