# Continuity and Change in Arable Land Management in the Northern Isles: Evidence from anthropogenic soils

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## Abstract

Human activity can affect the soil in ways which are traceable long after the land has been given over to other uses, and past land management practices can be reconstructed by investigation of these relict characteristics. In some regions the addition of fertilising materials to the arable soils has created artificially deepened anthropogenic topsoils which can be over 1 m thick. Such relict soils are found all over the world, and are widespread in north-western Europe. This work focuses on the anthropogenic soils in the Northern Isles, which were formed from the Neolithic period up until the 20$^{th}$ century. Three multi-period sites were investigated using thin section micromorphology, organic/inorganic phosphate analysis, soil magnetism, particle size distribution, loss on ignition and soil pH.

Current views of anthropogenic soil formation, based on pedological investigation and historical documentary sources, are that they are formed as a result of the addition of domestic animal manures and turf used as animal bedding to arable areas. This project sets out to test the hypothesis that in fact anthropogenic soils are the result of a wide range of formation processes which took place over extended periods of time. The hypothesis has been tested by analysing soils and associated middens of different dates, which have been sealed and protected by blown sand deposits. The results have shown that in the Neolithic period arable soils were created by cultivating the settlement's midden heaps as well as by adding midden material to the surrounding soils. In the Bronze Age human manure, ash and domestic waste were spread onto the fields around the settlements to create arable topsoils up to 35 cm thick. In the Iron Age arable agriculture was intensified by selective use of organic manures on one of the sites investigated, but organic waste material was not used as efficiently as it was in later periods, and on both sites it was allowed to accumulate within the settlements. In the Norse period, when the intensive system used in historical times appears to have originated, organic waste may have been used more efficiently. These changes appear to reflect a greater organisation of land resources and manuring strategies and increased demand for arable production over time.

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**Table of Contents**

## List of Figures

## LIST OF PLATES

## LIST OF TABLES

# CHAPTER 1: INTRODUCTION

## 1.1 The Archaeological Landscape

Archaeological research has moved away from the study of sites in isolation and has moved towards the analysis of sites together with their hinterland, so that the archaeological landscape can be considered as a whole. Archaeological landscapes develop and change, so that a number of distinct landscapes may succeed one another over the course of millennia, especially on areas of good agricultural land. Land use will change over time, settlements may disperse or cluster, boundaries move and are re-aligned, and fields take on different functions as the economic base of a group changes. In some regions, such as East Anglia and Wessex, the palimpsest of different landscapes can often be untangled by tracing the different alignments of field boundaries, which survive despite the soils of the arable fields having been reworked by subsequent cultivation. On Mainland Scotland the untangling of palimpsest landscapes has proved to be more difficult, and not only are the arable soils reworked but even the phasing of structures and boundaries is made difficult by their dispersal and by continuity of boundary alignment (Chrystall 1998). The problem of distinguishing landscapes of different periods makes it difficult to investigate changes in land use, resource management and subsistence strategies over time.

The environmental conditions of the Northern and Western Isles provide the archaeologist with a rare opportunity to compare sequences of past landscapes which can sometimes span millennia. Periodic episodes of sand blow cover the settlements and their arable fields, so that in some areas whole landscapes are preserved intact. The settlements often continued to be occupied or were re-occupied, and the arable fields were re-created. Although later settlements were often built on top of the old, the culture and economic bases changed over time, as different cultures responded to the same environment in different ways and as the environment itself changed and resources became scarce. It is to be expected that different cultures will place differing emphasis on marine resources, cereals, animals and animal products, and will have differing preconceptions of how things 'ought' to be done. There will also be differing economic opportunities as societies grow in complexity.

The aim of this project is to investigate a series of archaeological landscapes in order to identify the changes in arable land management practices that took place over time in a region. The investigation spans *c.* 5500 years, from the Neolithic, which in the Northern Isles begins around 3500 BC, until AD 1967, when the traditional pre-industrial manuring system went out of use on the farms of Papa Stour, Shetland. The underpinning theory is that some of the social changes which took place during this time are reflected in the way that land was used, and in particular the intensity with which it was farmed. The links between land management and social organisation will be discussed further in Chapters 2 and 3.

## 1.2 The Northern Isles

The Northern Isles were selected as the study area because of the preservational conditions outlined above. The region is low-lying, windy and exposed with a maritime climate which stabilises the temperatures, so that the summers are cool and the winters are relatively mild. Arable agriculture in this region is limited by the short growing season and by the poor quality of the soils, which derive from drift and sand. In the sandy areas the soils suffer from poor water retention and poor structural stability because of the lack of organic material, while the soils on drift tend to be waterlogged and acidic. In the last few hundred years soil improvement in the Northern Isles was brought about through manuring, which added nutrients and provided cohesion to the sandier soils. The intensive addition of mineral and organic manures has created a distinctive type of soil, in which the topsoil horizon can be up to 1m in depth. The complex method by which most of these soils were created is well documented, having been used in more isolated areas until as recently as the 1960s (Fenton 1978). Turves were cut from areas of rough grazing land which was fenced off from the intensively cultivated arable land. The turves were either burned for fuel and the ash was spread as bedding in the cattle byres, or they were placed directly into the cattle byres. The byres were regularly mucked out and the slurry-soaked bedding was deposited in midden heaps, which were spread onto the arable land in the spring. This system of soil improvement creates a deep, nutrient-rich topsoil which is known in Germany and the Netherlands as a plaggen soil, from the German 'plagge', or sod (Conry 1974). Most of the deepened topsoils in the Northern Isles probably originated in the Norse period and continued to develop until the 19$^{th}$ or 20$^{th}$ centuries (Simpson 1993; Davidson and

Simpson 1994), but amended Neolithic, Bronze Age and Iron Age soils have also been found. Previous work on these soils (Simpson et al 1998a; Simpson et al 1998b) has demonstrated that the prehistoric soils were created by different means than the Norse and later soils.

The analysis which took place prior to this project was concentrated on the arable soils, which are only part of the archaeological landscape. In this project the arable soils were analysed together with the settlement deposits in order to identify the range of material which was produced in the settlements. Control samples were taken from upland areas around the sites in order to identify the possible sources of the turves used as fertilisers, and reference samples were created in order to identify local materials such as peat and peat ash. By analysing material from outlying areas together with the material in the middens and arable soils, the use and re-use of material could be identified. The analysis has provided new insights into continuity and change in land management practices from the Neolithic until the pre-industrial modern period.

## 1.3 Thesis Outline

This work begins with a review of the development of arable agriculture in Britain, and goes on to review the literature on the development and classification of deepened arable soils and manuring (Chapter 3). The review chapters provide the background out of which the hypotheses are developed, and Chapter 4 sets out the research design and the methods by which the hypotheses were tested. The results are presented in three chapters, one chapter for each site which was analysed in the course of the project. The results are drawn together in the final discussion which considers the contribution of the project to wider issues in archaeological research. The concluding chapter summarises the changes which took place over time in the region.

# CHAPTER 2: ARCHAEOLOGICAL BACKGROUND

## 2.1 Introduction

This chapter provides a summary of the archaeological settlement patterns and economy in Britain and the Northern Isles from prehistory to the post-medieval periods. The aim is to produce an overview of the archaeological setting to the research and to introduce the current ideological debates. The emphasis is on arable agriculture and the impact of agriculture on settlement mobility, and the review also considers the social changes that took place after more sedentary lifestyles were adopted.

The terms we use to talk about archaeological concepts are continually changing as we look to answer more complex questions about the past. The chronological terms Mesolithic, Neolithic, Bronze Age and Iron Age originally referred to the technology of the different periods, and while we still use the terms we now use them to refer to particular types of culture rather than to the technology of that culture. For example, the Mesolithic was a time when tiny flint implements were made, but more importantly the Mesolithic peoples were hunter-gatherers, i.e. they had an economic base which meant that they were largely mobile, owned few possessions and used a large area to gather resources.

## 2.2 Arable Agriculture in the European Neolithic

The beginning of the Neolithic was marked by the introduction of agriculture, although there is evidence that arable agriculture was practised on a small scale by the hunter-gatherers of the preceding Mesolithic (Barker 1985; Armit and Finlayson 1996; Zvelebil 1994). The shift from a hunter-gatherer society to an agricultural one would have been a major change, and there has been a great deal of debate over how quickly and how extensively this change took place (e.g. Thomas 1991; Whittle 1996a and b; Barclay 1997). The key issues have been the extent to which Neolithic peoples became sedentary, and how much of their hunter-gatherer lifestyle they maintained (*ibid.*). Ard marks and cereal grains indicate that agriculture took place on a number of Neolithic sites in Britain and Europe, but the cultivation may not have taken place in permanent plots (Barclay 1997). Evidence for sedentism has been based on the survival of field boundaries (e.g. Caulfield 1978; Whittington 1978) and on funerary monuments which appear to mark out territorial boundaries (Barker 1985). Evidence for mobility has rested on the rarity of Neolithic structures and the absence of field boundaries in lowland Britain (Thomas 1991; Whittle 1996a and b). Both sides have drawn on the palaeoecological evidence (discussed below), which has been re-interpreted several times (*ibid*; Mercer 1981).

### 2.2.1 Slash and burn

Neolithic agriculture was initially thought to have taken place in small fields in temporary clearings (Iversen 1941). The model was based on the 'swidden' or slash and burn system which was practised in Scandinavia until the 20th century, which Iversen suggested might have had its origins in the Neolithic. This system, described by Linnaeus in 1751, involved the felling and burning of temperate forest on very poor, stony soils. The ash from the burnt wood enriched the soil with calcium and potassium, creating a fertile agricultural soil for a single year's crop followed by several years of grazing before the forest was allowed to regenerate. The land in this long fallow system required 20-25 years to recover (Boserup 1965). Pollen diagrams produced by Iversen (1941) and Troels-Smith (1953) showed a decline in arboreal pollen with a corresponding increase in plantain, followed by peaks in birch and hazel which were followed by increased arboreal pollen. This succession was interpreted as representing a single episode of clearance or slash and burn, and was thought to have taken place over about 60 years (Iversen 1941). After radiocarbon dating demonstrated that the succession had taken place over 300 years, the diagram was reinterpreted as showing a number of clearances and regenerations (Troels-Smith 1953).

Soil and sedimentary evidence has been used to demonstrate past arable activity and to some degree the scale of the activity. Localised colluvial and alluvial sediments began to accumulate in European valleys and floodplains in the Neolithic, indicating clearance and/or disturbance of land within the catchment (Butzer 1982; Needham and Macklin 1992). More extensive sedimentary deposition in the Middle and Late Bronze Age indicates greater human impact at that time (*ibid.*). The presence of charcoal in soil is sometimes interpreted as representing vegetation clearance by burning (Courty et al. 1989) or for slash and burn agriculture (Romans and Robertson 1975) but it has also been interpreted as representing the addition of ash as fertiliser (Romans 1986). The way in which charcoal is interpreted should probably depend on other lines of evidence such as pollen to corroborate the clearance of vegetation, or the recovery of other midden materials together with the charcoal to suggest the intentional addition of fertilising materials.

The slash and burn model for Neolithic agriculture was widely accepted by archaeologists until the interpretation of the pollen analysis was challenged. The reassessment took into account the filtration effects of forests and the differential distribution of pollen grains of different sizes and weights (Tauber 1965). When the pollen diagrams were redrawn using absolute rather than percentage values, the decline and regeneration of the forest was no longer convincing. Following Tauber's re-interpretation there were a number of attacks on the slash and burn model. Harris (1972) argued that swidden agriculture is not compatible with the keeping of domestic animals, which inhibit the regeneration of the forest and which are known to have been an integral part of the Neolithic economy. Mercer (1981) cited the lack of palynological evidence, the ecological drawbacks of the slash and burn system and the ecological benefits of mixed arable and pastoral farming in permanently cleared land. There has been no such refutation of the soils evidence, in which charcoal in soils continues to be interpreted as indicative of clearance by burning (*c.f.* Simpson et al 1998a) although charcoal in soils could equally well represent the intentional addition of ash from domestic hearths (*c.f.* Romans 1986).

### 2.2.2 Sedentism and mobility

The Neolithic came to be regarded as a time of fully sedentary settlements set in distinct territories, especially after investigations on a landscape scale suggested that funerary monuments marked out territorial boundaries between Neolithic communities with distinct material cultures in Wessex, Somerset, Sussex, East Anglia, the Lincolnshire Wolds, the Yorkshire Wolds and North Yorkshire (Barker 1985). The recognition of such fixed territorial boundaries further supported the belief that the Neolithic population was sedentary.

While funerary monuments marked out conceptual boundaries in some regions, in a few regions field and territorial boundaries were demarcated by physical boundaries. Field boundaries and systems are widespread on the west coast of Ireland, where excavation has produced Neolithic artefacts in association with structures incorporated into the field systems (Caulfield 1978). The base of the peat overlying the field systems also dates to the Neolithic. Neolithic field boundaries are common on Shetland, where they occur in association with settlements comprising one or more stone structures; the systems incorporate major boundaries which commonly follow the hill contours, and smaller walls which demarcate the individual fields (Fojut 1981). Neolithic field boundaries also occur on Orkney, e.g. at Links of Noltland, Westray (Clarke and Sharples 1985). Field boundaries need not have been permanent landscape features, but may in some locations have been redefined annually using lines of small stones (as at the Bronze Age site at Suisgill, Sutherland: Barclay 1985) or using hurdles (Machrie

Moor, Arran: Haggarty 1991); both of these more ephemeral divisions will only show up very exceptionally in the archaeological record (Barclay 1997).

Recently, there has been a reaction against the sedentary Neolithic model, mainly because of the lack of evidence for Neolithic structures in the English lowlands. Thomas (1991) argued that Neolithic settlement and agriculture were shifting and impermanent, and that field systems defined by boundaries did not come into existence until the middle Bronze Age. Whittle (1996a; 1996b) also questioned the sedentism of Neolithic settlement, proposing the term 'tethered mobility' to describe the movement of groups within a certain territory. He emphasised that animals were as important as arable crops, and that arable crops don't necessarily require constant attention and need not tie people to the land year round. He also noted that the weed seed assemblages from Neolithic sites are usually dominated by shade loving species, which might suggest that crops were grown in woodland clearings.

The regions in which most field boundaries survive are unusual because of their preservational conditions. The field systems in western Ireland and in Shetland are preserved under blanket peat which was unsuitable for later agricultural use, and which was disturbed only for peat cutting. The large tracts of fields which survive in western Ireland may be a biased concentration due to the intensive archaeological work undertaken in this area, although there is also a concentration of Neolithic tombs in this region (Caulfield 1978). Similarly in Shetland the Neolithic and Bronze Age homesteads sited above the 40 m contour were not occupied in the Iron Age, and the higher ground was subsequently used for grazing and peat cutting rather than arable agriculture and settlement. The limited survival of Neolithic landscapes begs the question of whether such systems survive because of the marginal nature of the land following abandonment of the settlements, or whether an unusual system developed in these regions because of their marginality or because of other, perhaps social factors.

### 2.2.3 The Neolithic in the Northern Isles

The economy of the Neolithic in the Northern Isles was based on mixed farming (barley, equal numbers of cattle and sheep and a small number of pigs) and marine resources including fish, whales, seals, otters and sea birds (Clark and Sharples 1985). Red deer bones have been found in small quantities on some sites and in large quantities on others (*ibid.*). The settlements were characterised by stone-built houses, which are found either in small clusters (e.g. Skara Brae, Rinyo and Links of Noltland [Clark and Sharples 1985]) or as single houses with ancillary buildings (e.g. Tofts Ness [Dockrill 1993] and Knap of Howar [Ritchie 1983] in Orkney and Scord of Brouster [Whittle et al 1986] in Shetland). The structures were typically built on top of midden heaps, sometimes incorporating the midden material within the wall coring (as at Knap of Howar). The stone built structures and the large accumulation of midden material suggest that these were long-lived, permanent settlements.

## 2.3 Agriculture and the Bronze Age landscape in Britain

Large ditched enclosures began to be constructed on hilltops in southern England in the middle Bronze Age, and in the Late Bronze Age ringwork enclosures were constructed in eastern England while hillforts were built in other regions. It has been suggested that such enclosures were residences of an elite, and some ringworks have produced evidence for specialised activities such as salt production (Mucking, Essex: Jones and Bond 1980) and metalworking (Springfield Lyons: Buckley and Hedges 1987). Differences in the quantity and quality of Bronze Age grave goods accompanying the dead demonstrate differential wealth, but social distinctions are not reflected in the domestic architecture (Wells 1984). As in the Neolithic, trade was predominantly in luxury goods, not in subsistence products (*ibid.*).

In the middle Bronze Age there is extensive evidence for the division of the landscape into field systems, but there is some debate about what the field systems were used for. When they were first discovered it was thought that they delineated arable fields, with droveways between the fields to control stock (e.g. Pryor 1980). The current thinking is that they were arable in some regions, but were used for pasture in others and so cannot be regarded as unequivocal evidence for arable agriculture (Pryor 1996; Bradley et al 1980; Murphy 1993). Bronze Age field systems can extend for hundreds of hectares, with boundaries of stone (e.g. Dartmoor reaves: Fleming 1988), banks and ditches (e.g. Fengate: Pryor 1980) and possibly hedges (*cf* Barber and Brown, 1984). In some regions the settlements associated with the field systems were often set within the fields (e.g. Pryor 1980; Evans 1993) and generally consisted of pairs of structures which were probably occupied by an extended family (Ellison 1980).

It has been suggested that the longevity of the Bronze Age fields (demonstrated by their physical boundaries) was made possible by regular manuring (Fowler 1983). Evidence for extensive manuring in the Bronze Age, Iron Age and Roman periods is drawn from scatters of small, abraded potsherds found on the ploughsoil surface, which are thought to have been dumped after breakage onto organic middens which were subsequently spread onto the fields for fertiliser (Rhodes 1950). It has also been noted (Fowler 1983) that large quantities of waste material in prehistoric settlements were *not* deposited onto arable fields, and domestic waste may have been only accidentally or sporadically incorporated into the dung middens which were used as fertiliser.

### 2.3.1 The Bronze Age in the Northern Isles

An extensive system of earthwork boundaries known as Treb dykes were constructed in Orkney in the Bronze Age (Lamb 1983), and in the early to middle Bronze Age a new form of site, burnt mounds, appeared in the Northern Isles as in other regions. Burnt mounds are crescent shaped mounds, at least one fifth of which contain structures (Øvrevik 1985) which are similar to Neolithic houses but with stone tanks in the centre, rather than hearths. More than 200 burnt mounds have been recorded in Orkney and about the same number are known in Shetland. The mounds are near good agricultural land and ard shares have been recovered from Beaquoy and Liddle (Hedges 1975), but the sites are often situated on low lying, boggy ground and it has been argued that they are not actually occupation sites but fulfilled some special function (Dockrill et al 1998). Very little excavation has taken place on Bronze Age domestic structures in the Northern Isles, although some Neolithic sites continued to be occupied, e.g. Ness of

Gruting, Shetland (Calder 1958) and possibly Hill of Taing and Site 229, South Nesting, Shetland (Dockrill et al 1998). The oval or sub-rectangular structures of the Bronze Age occur at the same height above sea level as the Neolithic structures, and the two phases are not readily distinguished without artefactual or absolute dating evidence.

The excavation of a Bronze Age midden at Birsay Bay produced a seed and bone assemblage so similar to a typical Neolithic midden that the excavators initially thought the midden was Neolithic (Donaldson et al 1981). Over 200 grains of charred barley were recovered, along with fish bone indicative of inshore fishing. The animal bones were dominated by red deer, with two ox bones, wild bird bone and marine mollusc shells (*ibid.*). Six row hulled barley, cattle bones, sheep/goat bones and (less frequently) pig bones were recovered from Tofts Ness, Sanday, Orkney from Neolithic, Bronze Age and Early Iron Age deposits (Bond 1994b). Bronze Age middens at Jarlshof produced large numbers of limpet shells as well as cattle bones, a fish bone and worked cetacean bone. Carbonised barley and saddle querns were also recovered. A similar Bronze Age assemblage was recovered from Clickhimin, where the animal bone included sheep, oxen, pigs and ponies (Hamilton 1956b). The very limited settlement and environmental evidence suggests economic continuity from the Neolithic into the Bronze Age in this region.

## 2.4 The Iron Age

### 2.4.1 Centralisation and hierarchy

The process of dividing up the landscape continued in the Iron Age, but the developments took different forms and took place at different rates in different regions. Extensive territorial boundaries were constructed across central southern Britain, and from 550-400 BC in southern England and as far north as North Wales and the midlands a number of hillforts were constructed, often sited as focal points for territorial boundaries (Cunliffe 1991). Cunliffe suggests that the hillforts were densely occupied, with large numbers of structures and evidence for both storage and exchange (*ibid.*), but it should be noted that only a few hillforts have been subject to extensive open area excavation of the interiors. The economy of the Iron Age in lowland Britain and in Europe became, in certain centres, more specialised as international trade in salt, iron and luxury goods increased (Wells 1984). Several studies have also found evidence for regional trade in subsistence products. An archaeobotanical study of the Iron Age landscape in the region of Danebury suggests that the hillfort was being provided with grain by small settlements and farmsteads in the vicinity (Jones 1985) and a study in the north-east of England found differences in Iron Age manuring practices which suggested differential intensities of arable production (van der Veen 1992). It was suggested in the latter study that some of the farms were producing surpluses for sale to local Roman settlements.

A key feature of the Iron Age in most regions is the development (or further development) of social complexity or hierarchy, which was expressed through differential, 'high status' structures and the development of communities which were larger than the extended family units which made up the typical Bronze Age settlement (Cunliffe 1991). The trade in subsistence products may have supported the Iron Age elite (Dockrill 2000), as the trade in luxury goods supported the Bronze Age elite.

A distinctive characteristic of the Scottish Iron Age is the variety of different structure types. Excavations to date have shown such variation that the structures now tend to be 'lumped' together in broad categories, although the classification is still not universally agreed upon. Stone roundhouses were constructed in the early to mid 1st millennium BC, which unlike most Neolithic and Bronze Age structures stood above ground (Armit and Ralston 1997). These structures have been classed as *Simple Atlantic Roundhouses*, and are characterised by a lack of internal division (Armit 1996). They were usually single structures without ancillary buildings and without serious defences, and they probably housed one extended family (*ibid.*). Simple Atlantic Roundhouses were succeeded by *Complex Atlantic Roundhouses* (Armit 1996) or *Substantial Houses* (Hingley 1992) which had internal divisions, outer enclosures, stairs or ancillary buildings (Armit 1996). The development of Complex Atlantic Roundhouses culminated in the brochs in the final centuries BC (*ibid.*)

### 2.4.2 The Atlantic Iron Age

The Atlantic Iron Age (encompassing the Western and Northern Isles, Caithness and Sutherland) did not develop the elaborate land divisions or large settlements which characterise the Iron Age in the south, but there is nonetheless evidence for larger settlements and for increased hierarchy, if substantial structures such as brochs can be taken as indicators. The brochs on Orkney have associated clusters of stone houses which were built around the broch towers towards the end of the first millennium BC, and the increase in settlement size is notable; the broch complex at Howe was described as a 'heavily fortified village' by the excavator, with a projected population of about 250 (Hedges 1985). The broch settlement at Gurness may have had a population of 30-40 families (*ibid.*). The brochs are usually taken to indicate the development of social differentiation and are thought to be an expression of hierarchy (Armit 1996; Parker Pearson et al 1996; Dockrill 2000) although it has also been suggested that they simply represent centralisation (Hingley 1992).

The function of brochs is still uncertain but it has been suggested that they were defended farmsteads (Harding 1984), signal towers, periodic refuges (MacKie 1975) or high status sites controlling the resources within their territory (Sharples 1985). Childe (1946) suggested that the broch sites were reliant on cereal cultivation, and that agriculture in the Iron Age was intensified. There is evidence to support the suggestion that cereal cultivation was important, although the evidence for intensification is limited and sometimes contradictory. It has been suggested in regional studies of Barra and Harris (Scott 1947), Glen Beag (Harding 1984), Caithness (Fairhurst 1984) and Shetland (Fojut 1982) that brochs and duns (fortified homesteads) were located on good agricultural land. Most of the Scottish crannogs are also located near 'land with arable potential', and excavations of these sites have recovered wooden ploughs and ards in addition to crop remains (Morrison 1985). Excavations at Scalloway uncovered a deposit of charred grain in which 10,000 grains were found in a 200 litre sample (Sharples 1998). The introduction of rotary querns in the Iron Age would have made grain processing more rapid and efficient.

The suggestion that the brochs were the residences of an elite that controlled arable production (Dockrill 2000) is based on evidence for intensification of arable production, but there is evidence for a decline in arable production at the broch sites at Balevullin, Tiree (MacKie 1965) and at Clevigarth, Shetland (Guttmann, unpublished data). A study of 'ring forts' in Glen Lyon found that they were located in areas of good pasture (Stewart 1969), and it has been suggested that trade took place between these sites and the nearby crannog sites, based on good arable land (Morrison 1985).

As in the earlier periods barley was probably the dominant crop in the Northern Isles in the Iron Age, and oats were first introduced at this time (Armit and Ralston 1997). The faunal evidence from Howe shows a decline in red deer throughout the Iron Age (Smith *et al.* 1994). Sheep were the dominant domesticate, and cattle and a large number of pigs were also kept. There were few fish bones in the early broch phase of Howe, but an extensive range of species in the later phases (Locker 1994); a similar pattern was noted at Crosskirk, Caithness (Macartney 1984). Seal bone and cetacean bone, the latter usually worked, have been found at Jarlshof and Crosskirk (Platt 1956; Macartney 1984). Large amount of bird bone, from both coastal and moorland species, have also been recovered, along with domesticated goose, duck and chicken (Macartney 1984; Bramwell 1994). Great Auk has been found in all Iron Age assemblages in the Northern Isles (McCormick and Buckland 1997). A comparison of the animal bone assemblages recovered from brochs and wheelhouses in the Atlantic region showed a significantly higher proportion of pig and wild animal bone, which are thought to indicate high status, on the broch sites (Parker Pearson et al 1996). The faunal evidence therefore supports the argument made on architectural grounds that the brochs were high status sites.

One of the characteristics of broch settlements is the large amount of domestic waste which accumulated in the settlements in mounds and within abandoned buildings. The build-up of domestic waste in settlements in the Northern Isles from the Neolithic to the Late Iron Age is well attested; midden material is used in construction of Neolithic buildings such as Knap of Howar (Ritchie 1983) and Skara Brae (Clarke and Sharples 1985) and structures are often built into mounds of waste material (*ibid.*). The differential disposal of rubbish in the Iron Age was noted by Fowler (1983) and verified in a statistical analysis of the types of material found in pits on Iron Age settlements in Wessex, which demonstrated that the material was specially selected and not dumped arbitrarily (Hill 1995). This study established that what archaeologists had been regarding as rubbish was often deliberately placed.

It has been suggested that midden material in the Atlantic Iron Age may also have had a symbolic significance (Parker Pearson et al 1996). The excavators of a large midden outside the broch at Dun Vulan, South Uist questioned why the midden material was not used as fertiliser when the surrounding machair soils were so poor, and citing Hill

(1995), they concluded that the midden may have had a symbolic meaning, possibly linked with fertility (*ibid.*). A more mundane interpretation of such deposits was made by Smith (1994), who suggested that the accumulation of midden material at Dun Vulan and other Iron Age sites was simply due to less intensive manuring in the Iron Age than in subsequent periods.

It has also been suggested that domestic waste was unused in the Iron Age because a better fertiliser had been found (Simpson et al 1998b). An analysis of the arable soils at Scatness, Shetland identified enhanced phosphate levels and a greater organic component in the Iron Age soils compared to the earlier phases, which may be indicative of manuring with animal dung. The authors suggested that manuring with domestic waste, prevalent in the Neolithic and Bronze Age, had been replaced by manuring with animal dung in the Iron Age, and the midden material accumulated in the settlement simply because it was no longer necessary as a fertiliser (*ibid.*). A similar conclusion was drawn by Davidson et al (1986) to explain the accumulation of midden material in the farm mounds of Sanday and North Ronaldsay; the authors suggested that the fertile soils of these islands rendered intensive fertilising unnecessary.

## 2.5 Later Iron Age: The Picts

Classical sources suggest that in the early 1$^{st}$ millennium AD there was an amalgamation of the numerous tribes living north of the Forth-Clyde divide, which resulted in larger territorial units (Ralston and Armit 1997). One of the consequences of the amalgamations was that clashes occurred on a larger scale, and wars over territory began to replace the traditional cattle raids (*ibid*). Although distinct tribal entities continued to exist, the natives of the region were regarded more or less as a single group (the Picts) by the Romans (*ibid.*). The first mention of the Picts occurs in AD 297, but the Pictish period is generally regarded as beginning with the reign of Bridei in the mid sixth century and ending with the unification of Picts and Scots under Kenneth mac Alpin in AD 843 (Ritchie 1990). At Scatness and Tofts Ness the periods have simply been divided into Early Iron Age (c. 700 BC to 200 BC), the Middle Iron Age (the broch period, c. 200 BC to AD 200) and the Later Iron Age, which includes the Pictish period ( Dockrill 1998).

The construction of brochs and the related roundhouses stopped before the middle of the 1st millennium AD, and Pictish cellular structures were built on top of some of the sites with no evidence for a break in occupation (e.g. Howe [Ballin Smith 1994], Gurness [Hedges 1990] and Scatness [Nicholson and Dockrill 1998). The remains of Pictish structures are rare on both Orkney and Shetland, although a few Pictish place names survive, including the Papa or Papil names which indicate ecclesiastical sites such as the early church sites at Papil, West Burra and St. Ninian's Isle (Fojut 1993). Christian and pre-Christian Pictish symbol stones have been found on Shetland (*ibid.*), and Christian symbol stones have been found in Orkney (Ritchie 1990).

Christianity may have been introduced in southern Scotland in the 5th century, but became established when St. Columba built a monastery on Iona in AD 563 (Foster 1996). The extent of Christian influence at this time is uncertain, but it probably became more pronounced after the Roman church was introduced in c. AD 710 (*ibid.*). Christianity brought a limited amount of literacy, and may have brought with it other new ideas from abroad; new agricultural techniques were often introduced by monasteries, and the deepened topsoils at Iona and at Fearn Abbey, Easter Ross may have resulted from such innovations (Barber 1981).

## 2.6 The Norse period

The Norse period in Scotland is generally divided into the Viking period, from AD 780-1100 or 1158 (the death of Earl Ragnald), and the Late Norse, AD 1100 or 1158-1500. Settlement was on a small scale, with dispersed farmsteads and no large trading centres (Ritchie 1993). The structures introduced by the Norse were sub-rectangular and built of stone and turf, and the farmsteads included byres, barns and stock enclosures (Fojut 1993). The economy in the Viking period was based on cereal agriculture, domestic livestock and fishing on a small scale (Graham-Campbell and Batey 1998). The crops included barley, oats and flax. Rotary querns continued to be used for crop processing, but a Norse water mill was excavated at Orphir, Orkney (Batey and Morris 1992). Stone plough or ard-tips continued to be used, but an iron ploughshare was found in a boat burial at Westness, Rousay (Graham-Campbell and Batey, 1998). Cattle, sheep and pigs were kept, and marine resources included fish, otters, seabirds and shellfish; red and roe deer bones have also been recovered from Viking sites (Ritchie 1993).

In the Late Norse period there was a change in the economy. Between AD 800-1100 the economy at Jarlshof was based primarily on cereal agriculture and stock keeping, and marine resources were of secondary importance (Hamilton 1956a). In AD 1100-1400 there was an increase in the types of line sinkers, which suggests an expansion of fishing (*ibid.*). This trend was also found at Sandwick, Unst (Bigelow 1985) and at Da Biggins, Papa Stour (Crawford and Ballin Smith 1999), where there was an increase in fish bone, line sinkers and imported items in the Late Norse (Bigelow 1992). A recent review of the long-term changes in fishing practice in the Northern Isles has confirmed the intensification of fishing in the Late Norse period, and also demonstrated that deep-water fishing increased at that time (Barrett et al 1999). The increase in fishing may have been to compensate for increased pressure on land (Hunter 1997) or it may have been to support an international trade (Bigelow 1992). The argument for an international trade in fish is supported by historical and archaeological evidence for production dried fish in the 13$^{th}$-14$^{th}$ centuries (Barrett et al 1999).

The increase in fishing in the Late Norse period coincides with a possible increase in dairying (Bigelow 1992) and an intensification of agriculture (Simpson 1993). Areas of artificially deepened, organic-rich soils surround many of the Late Norse farmsteads on Orkney (Simpson 1993) and a survey of the West Mainland identified 41 farmsteads with associated deepened soils which have been stratigraphically and radiocarbon dated to the late 12$^{th}$-early 13$^{th}$ century (Simpson 1993; Davidson and Simpson 1994). The deepened topsoils of Shetland have not been mapped, but areas have been found surrounding Norse farmsteads on Papa Stour (Davidson and Carter 1998), South

Nesting (Simpson, unpublished data) and Scatness (Simpson et al 1998b). It has been suggested (*ibid.*) that the deepened Norse soils represent an expansion of arable agriculture in the Late Norse.

## 2.7 The Highlands and Islands in the Late and post-medieval

In 1472 Orkney and Shetland were annexed by Scotland, but the Northern Isles continued to have close links with Norway and the land was still owned by Norse farmers despite the loss of political control (Shaw 1980). The Norse legal system continued to be used until 1611 (*ibid.*). The economy of Shetland was predominantly based on export fishing and sheep, and in Orkney the economy depended largely on arable farming (Fenton 1978). Little is known about the transition from subsistence fishing and farming to export fishing and farming, but the archaeological evidence outlined above suggests that trade was growing in the Late Norse. By the late 14$^{th}$ century the Shetland fish trade was established and controlled by the Hanseatic League, who maintained control until the 17$^{th}$ century (Nicholson 1998). Records from the 17$^{th}$ century show that Orkney regularly shipped its surplus grain to Shetland, where there was a 'severe and chronic deficiency of grains', and to Norway and Mainland Scotland (Shaw 1980).

The agricultural improvements of the 18$^{th}$ and 19$^{th}$ centuries were brought to Orkney in the mid 19$^{th}$ century by an influx of Scottish farmers who reclaimed areas of moorland through drainage and liming (Fenton 1978). The expansion of agricultural land was such that while in 1808 only 6.3% of Orkney was arable land (including gardens), by

1969 that figure had gone up to 52% (*ibid.*). The reclamation of moorland in Orkney meant that many new farms could be established. Arable production was increased by intensification of production on existing fields as well as by expansion into new areas, and in the 18th century Scottish Highland townships increased their arable production by heavier manuring in order to support a growing population (Dodgshon and Olsson 1988). The more intensive manuring of the post-medieval period was evident in an analysis of the different functional areas of a recently abandoned farm on South Uist (Smith 1994). The materials on this farm were carefully recycled, and any material which could be used as fertiliser was not allowed to accumulate around the farmstead but was spread onto the fields and gardens.

In both Orkney and Shetland the dispersed multitudes of tiny arable fields were re-organised into more practical sized fields in the course of the Improvements (Fenton 1978). In Shetland, the emphasis was on increased grazing as the improvement of the uplands for arable agriculture had only limited success (*ibid.*). The steady increase in meat prices in the later part of the 19th century led to an increase in the number of sheep, and by 1900 nearly 1500 acres of arable land in Shetland had been given over to grazing (Knox 1985). As in other parts of Britain, this resulted in the eviction of tenant farmers, and although the Crofters Holdings Act passed in 1886 gave the tenants security of tenure, the population of Shetland continued to decline (*ibid.*).

## 2.8 Summary

This overview has established that the Neolithic in the Northern Isles was probably fully sedentary. Although very little excavation has been undertaken on Bronze Age settlement sites, the limited economic evidence and the similarity of the houses and field systems to those of the Neolithic suggest that the economic base in the Bronze Age was the same as that of the Neolithic. The centralisation of settlement and the emergence of probable high-status structures in the Iron Age may have been accompanied by the intensification of arable produce, at least on some sites. Analysis of the Norse soils, animal bones, fish bones and artefacts suggests that there was an intensification of arable production, dairying, fishing and trade at that time. A further intensification took place in the post-medieval period, characterised by a more thorough recycling of waste materials and heavier manuring.

## 2.9 Archaeology of the Northern Isles: Hypotheses

The amount of excavation which has been carried out in the Northern Isles is not extensive, and much of it was carried out with only limited environmental sampling. On the basis of the limited excavation which has been done to date, the following hypotheses have been formed:

- The Neolithic in the Northern Isles is characterised by permanent settlements and permanent fields. The fields may not necessarily have physical boundaries but may be identified by the amended soils where they have been preserved by burial.

- The Bronze Age had the same economy and land management system as the Neolithic and should therefore have similar amended soils which reflect a similar landscape.
- There was an intensification in arable production and stock keeping in the Iron Age, which may be reflected by increased animal manures in the soil.
- There was a further intensification of arable production in the late Norse period, which will be reflected by deeper and more extensive anthropogenic soils.

# CHAPTER 3: ANTHROPOGENIC SOILS

## 3.1 Soils as Artefacts

The debate over the development of agriculture in the European Neolithic has focussed on the rapidity and the extent to which arable agriculture was adopted. The evidence is derived from field boundaries, plough marks and the charred remains and pollen of cereals and other crops. Less direct evidence is derived from the seeds and pollen of arable weeds and from alluvial and colluvial sediments which accumulate where land has been destabilised by arable agriculture. Woodland clearance, as indicated by pollen analysis and land molluscs, has also been interpreted as part of the agricultural process. A resource that has been largely overlooked are the arable soils themselves.

The previous chapter provided an overview of the development of arable agriculture in Britain and the Northern Isles. This chapter will review the different methods by which arable soils were modified and fertilised at different times in different regions of western Europe, and will establish that soils hold cultural evidence which can be used to address the issues introduced in the previous chapter. The review will introduce the range of methods which were used to enhance fertility in these soils, providing parallels and contrasts to the methods used in the Northern Isles. The different methods which have been used to study arable soils will also be considered, in order to establish which methods have been most informative.

## 3.2 Classification

The classification of arable soils is problematic, judging by the variation between the different taxonomic systems. The Food and Agricultural Organisation of the United Nations (FAO-Unesco 1974) and the Soil Survey for Scotland (1984) do not provide for man-made soils in their taxonomic system, while the US Soil Taxonomy (Soil Survey Staff 1975) and the Soil Survey for England and Wales (Avery 1980) include a Man-made soils category which is broken down into soils with plaggic epipedons or cultisols (which have been artificially deepened) and disturbed soils (which have not). The German classification system (Mückenhausen 1954) includes a category of 'terrestrial man-made soils' which includes

1) Plaggenesch (plaggen soils)
2) Hortisols (old garden soils)
3) Rigosols (very deep mixed soils)

It is the plaggen or plaggic soils which are of particular interest to this project, as these are created by adding material rather than by deep disturbance, which simply mixes the topsoil with the subsoil.

The term 'plaggen' initially referred only to the system of manuring fields with peat turves after they had been used as animal bedding, and has subsequently been broadened to include soils raised up to >50cm by the addition of other materials. Conry and Diamond (1971) suggested that the definition should be a 'deep man-made surface layer, which has been raised up by the continued application of manures containing mineral material.' This would include the Dutch 'Tuin' soils which are aggraded by the addition of peat litter and sand (Pape 1970), and soils fertilised with transported dune sand and mud from ditches (de Bakker and Shelling

1966), clayey subsoil (Snacken 1971) and kitchen waste (Foss et al 1970). It would also include the addition of grass sods (Geilman 1924; Niemeier and Taschenmacher 1939; Pape 1970), forest litter (Edelman 1950) and calcareous sea sand (Conry 1969). Under the classification system of the Soil Survey of England and Wales, plaggen soils fall into the category of '*Man-made Humus Soils with a thick man-made A horizon*'. This type of soil is:

> artificially thickened by regular use of manure containing mineral matter, unusually deep cultivation accompanied by addition of organic manure only, or incorporation of human occupation residues. It is at least 40 cm thick or overlies bedrock at a lesser depth, has a moist colour value of 4 or less and chroma of 3 or less throughout its depth, and generally contains artefacts such as pieces of brick or pottery. Humified organic matter is intimately mixed with the mineral fraction in all subhorizons.

Under the United States Department of Agriculture system such soils would usually be classified as plaggepts, i.e. soils with a plaggen epipedon (A horizon) of >50 cm which has been produced over time through the deposition of manure containing relatively insoluble mineral grains (USDA 1960).

Soil classification is based upon the observable properties of soils supplemented by laboratory data, and although the soil type may be indicative of certain environmental processes, the aim of most classifications is not to understand the soil history but to characterise the soil as it is today. The term 'plaggen' originally referred to the soils which were derived from a particular land use in a particular part of the world. The definition of plaggen soils has expanded to include deepened topsoils derived from a range of different materials, and consequently the classification no longer reflects the system by which the soils were created. In archaeological research and for this project in particular it is these land use systems which are of particular interest, and therefore soils created by different types of fertilising materials are considered separately.

## 3.3 Fertilisers in Prehistory and the Roman period

### 3.3.1 Domestic waste

The use of fuel ash and kitchen waste as fertilisers is known to have taken place as early as the Neolithic. A late Neolithic site and two areas of middle and late Bronze Age fields have been recorded in the Netherlands, all on sandy ridges (Bakels 1997). The Neolithic soil, located at Bornwird in the northern Netherlands, contained domestic waste including pottery, flint and charred seeds. The soil was sealed below a layer of peat, the base of which was dated to between 2470 BC and 2330 BC (Fokkens 1982). The topsoil was 58 cm in depth, and the soil could therefore be classed as a prehistoric plaggen soil (Bakels 1997). Cultivated Neolithic soils containing abundant charcoal but with very low levels of organic material were found beneath the Hazleton North long cairn in Gloucestershire (Macphail 1990). The cultivation took place in shifting plots, the last of which was located on top of an earlier midden heap. Thin section and chemical analyses were undertaken on a Neolithic arable soil sealed below a barrow at Strathallan; the soil contained only *c.* 1% organic material, compared with *c.* 8% in the present day cultivated soil (Romans and Robertson 1983). The soil was well sealed, and the evidence suggests that it was not fertilised with organic materials (*ibid.*).

Bronze Age fields have been identified in the Netherlands near Haarlem and in West Friesland. The fields near Haarlem were interleaved with wind-blown sand, and the latest soil was sealed by peat dated to 700 BC (Poldermans 1987; Bakels 1997). Pottery dating to the Middle and Late Bronze Ages (1500-800 BC) was recovered from stratified pits associated with the soil, which was aggraded to a depth of 40 cm, possibly with lake mud. A Middle and Late Bronze Age soil found in West-Friesland contained stratified pottery in the field boundaries and in the ard marks; the recovery of animal bone and plant remains together with the pottery suggests that the soil was manured with domestic waste (in addition to animal manure; see below)(Buurman 1988). An Early Bronze Age ploughsoil at Phoenix Wharf, London also contained domestic waste (Macphail et al 1990).

The practice of manuring with domestic waste also took place in the prehistoric period on the Western Isles. The Western Isles are covered predominantly in blanket peat and moorland, but wind-blown carbonate sands accumulated over most of the Holocene to form the machair landscape along the western shores. Interleaved between the machair sands are soil horizons which were initially thought to represent periods of environmental stability and a cessation of the winds. Research by Gilbertson et al (1999) has established that buried soils in the machair at Cill Donain were in fact anthropogenic, and rather than representing environmental stability they were probably created to consolidate the sandy soil. At Cill Donain the Bronze Age and Iron Age soils were separated by a sand horizon at one exposure, but where they developed continuously the soil was up to 1m deep. Within the soil were shell, bone and ash, with large quantities of phytoliths indicating added plant material.

There is evidence for a beaker-period ploughsoil (identified by the ard marks) containing midden material at Rosinish, Benbecula (Shepherd and Tuckwell 1977). The horizon was sealed by blown sand, which was cut by a later phase of ard ploughing. The later ard marks indicate that cultivation continued despite the sand blow, and midden material found above the cultivated sand may have been deposited in order to consolidate the unstable soil (*ibid.*). Anthropogenic agricultural soils of the Late Bronze Age at Baleshare were created by the addition of domestic waste and peat to the sandy natural soils (Barber, forthcoming). The cultivated plot was at least 3 ha, and ard marks were found throughout the soil indicating continuous cultivation (*ibid.*). At Hornish Point, South Uist, the deepened Iron Age soils may have been cultivated middens rather than soils with added midden material (*ibid.*). A buried Bronze Age soil on Jura, described above, contained (in addition to bracken) charcoal which was interpreted by the excavator as representing the remains of midden material added as fertiliser (Stevenson 1984).

Deepened or manured prehistoric soils have been discovered at a number of locations in Orkney, including Spur Ness, Tofts Ness and the Bay of Stove on Sanday (Dockrill 1993), Links of Noltland (Clarke et al 1978) and Quoygrew (Simpson et al in prep.) on Westray, Knap of Howar on Papa Westray (Ritchie 1983) and Skaill, Deerness on the Orkney Mainland (Gelling 1985; Limrey 1975). On Mainland Shetland deepened prehistoric soils are known from South Nesting Hall (Dockrill et al 1998), Hill of Taing (*ibid.*), Scourd of Brouster (Whittle et al 1986), Sumburgh (Lamb 1985) and Scatness (Simpson et al 1998b). There is little published work done on most of these soils, and the methods by which they have been recorded or analysed are varied, but the presence of domestic waste in the soils seems to be a common factor. Charcoal was present in soils at South Nesting (Dockrill 1993) and at Scord of Brouster, where peat ash was found in the soil near one of the houses (Romans 1986). 'Domestic refuse' including animal bone, fish bone and shell was present in considerable quantities in the ploughsoil at Links of Noltland, and at Knap of Howar soils rich in midden material were spread out over an area of c. 500m$^2$, possibly for cultivation (Clarke and Sharples 1985; Ritchie 1983). At Skaill, Deerness there were several phases of ploughsoil with horizons dating to the early and middle Bronze Age. The soil was a cultivated podzol which may have been manured (Limbrey 1975), but if so the fertiliser contained little or no organic material (Limbrey 1997). Burnt bone was recovered from the basal horizon.

### 3.3.2 Bracken

Two prehistoric sites on the Western Isles may have been fertilised with bracken, possibly as a plaggen system in which it was initially used as animal bedding. A Neolithic ploughsoil with ard marks was excavated between two stone circles at Machrie Moor, Arran (Haggarty 1991). Analysis of the ard mark fills provided pollen from *Hordeum* (barley) and the remains of bracken fronds without roots or rhizomes (Moffat, in Haggarty 1991), suggesting that the bracken was not growing in the field and subsequently ploughed in. The authors suggest that the fronds may have been animal bedding which was reused as manure. The second site is a Bronze Age structure within an enclosure at Cùl a'Bhaile, Jura, which had cultivated soils with associated ard marks (Stevenson 1984). The soils within the enclosure contained cereal pollen and a large concentration of spores of *Pteridium aquilinum* (bracken) and *Lycopodium clavatum* (common club moss) whereas outside the enclosure the spores were sparse or absent from the soil samples (Whittington 1984). Whittington noted that bracken and club-moss make ideal bedding for animals and could well have been spread onto the field as manure after such a use.

### 3.3.3 Seaweed

Seaweed adds nitrogen and potassium to the soil (Fenton 1978) and increases the soil aggregate stability (Haslam and Hopkins 1996). These characteristics make it an especially valuable fertiliser on sandy soils, which are often deficient in potassium (Fenton 1978) and which are physically unstable. The addition of seaweed to arable soils is attested in Jersey, the west coast of Britain (including the Northern and Western Isles) and the west coast of France (Bell 1981). There is evidence for the prehistoric use of seaweed manure at Gwithian, Cornwall, where a buried Late Bronze Age soil was found which contained shells of species which grow on seaweed (Bakels 1997). The Neolithic soil at Machrie Moor, described above, also contained large amounts of algal spores which the author linked with the use of seaweed as manure (Haggarty 1991). Burnt seaweed was identified in the Bronze Age soils at Tofts Ness, Sanday, Orkney, along with burnt marine shells which may have been associated with the material (Milles 1994). Burnt seaweed and molluscs commonly associated with seaweed were also found in a Norse or pre-Norse soil at the Brough of Birsay, Orkney (Donaldson et al 1981). Molluscs associated with seaweed were also found at Buckquoy, Orkney (*ibid.*) and at the $12^{th}$-$13^{th}$ century Norse site of Da Biggins on Papa Stour (Bell 1981). There are many historical records referring to rights to collect seaweed from particular areas of shoreline in Scotland, the earliest dating to 1491 (Shaw 1994).

### 3.3.4 Animal manures

The use of animal manures as fertilisers also originated in the Neolithic. A waterlogged Neolithic field in Weier, Swizerland was found to contain housefly pupae, indicating the addition of stable manure (Bakels 1997). A deepened, phosphate-enriched soil with charred plant remains was found sealed under a Middle Bronze Age barrow in Germany on the Island of Sylt, and may have been manured with animal dung (Blume and Kalk 1986). The soil had a humic topsoil 58 cm thick and can therefore be classed as a prehistoric plaggen soil. A soil in West Friesland contained seeds of nitrophilous weeds which may indicate manuring with dung in addition to the domestic waste which was noted above (Buurman 1988). A cultivated soil in Lithuania produced seeds of *Polygonum convolvolus*, which the author suggests would have grown in permanent, manured fields (Rimantienė 1994). A Bronze Age soil in West Jutland, Denmark was enhanced in organic phosphates and organic matter, indicative of manuring with organic material; the author linked this soil signature with manuring with animal dung (Linderholm 1997).

By the Roman period animal manure was used extensively (Fenton 1981) and the agricultural treatises written by classical authors remained in use until the 18$^{th}$ century (Woodward 1994). The classical authors wrote in great detail on the best types of animal manures and which parts of the farm ought to be manured, and meadows and olive trees were fertilised as well as the arable fields (Fenton 1981). Roman manuring has been demonstrated through phosphate analysis at Scole, Suffolk, where the organically manured arable fields with enhanced organic phosphates were distinguished from the town deposits which had enhanced inorganic phosphates (Macphail et al in press). Manuring inferred by the spread of Roman potsherds is widespread (Rhodes 1950; Fowler 1983).

### 3.3.5 Human manure (nightsoil)

At present, human faeces cannot be distinguished from animal manure in the soil except by analysis of the soil lipids. A Bronze Age soil at Tofts Ness, Sanday, Orkney has been shown to contain large quantities of nightsoil (Simpson et al 1998a), which may have been a common method of manuring in prehistory but this cannot be established until lipid analysis is more widely applied. In the 19th century nightsoil in the Northern Isles (Fenton, pers. comm.) and other parts of rural Scotland (Shaw 1994) was routinely incorporated into the middens and spread onto the fields along with the animal dung.

## 3.4 Fertilisers in the Middle Ages: Turf-based plaggen soils

Plaggen soils created by the addition of turves of peat or peaty soil are extensive in north-west Europe, from the Jutland peninsula to Northern Belgium (Conry 1974). They may also extend further east, to around Luneburg Heath, East Prussia and the Havelland area near Berlin (Niemeier and Taschenmacher 1939). Areas of plaggen soils have also been recorded in Scotland in Aberdeenshire (Glentworth 1944; Walton 1950), Orkney (Soil Survey for Scotland 1979; Davidson and Simpson 1984) and Shetland (Davidson and Carter 1998; Simpson et al 1998b). The plaggen soils of NW Europe will be considered first.

### 3.4.1 Plaggen soils in NW Europe

The European plaggen soils generally date to the medieval period (Spek 1992) although some earlier soils have been recorded. Pollen analysis suggests that the majority of Dutch plaggen soils began to develop in the 10th century (*ibid.*). Radiocarbon dating of the soils initially appeared to suggest an origin in the 6th-11th century, however the radiocarbon dates were recalibrated to produce a refined date range of 8th-12th century, with one anomalous 1st century date (*ibid.*). Following a review of the sample locations and a consideration of the problems of contamination with earlier soils and the problem of the differential rates of decay of different humus fractions, Spek (1992) suggested that the radiocarbon dates were unreliable and that archaeological dating of plaggen soils is the most reliable method. Spek's stratigraphic analysis of the finds and structures above, within and below the plaggen soils produced a 12th-13th century *terminus post quem.*

The Dutch plaggen soils are predominantly located on Pleistocene sands, but have also been found on loess, peat, alluvial clay and marine clay (Conry 1974). The oldest plaggens are usually positioned between the drier high ground (which is used for turf cutting) and the more waterlogged lower ground (used for grazing and hay-cutting) (Pape 1970). The soils later expanded onto the humus podzols and sandy soils of the more marginal areas, and decrease with depth as they decrease in age away from the centres of settlement, i.e. the older soils are on the better land and were built up to greater depth. There are >221,000 ha of true plaggen soils (with a topsoil or plaggen layer of 50 cm or more) in the Netherlands and >196,000 ha of incipient plaggens (which are only 30-50 cm in depth) (Pape 1970). These two groups of soils cover *c.* 30% of the sandy areas of the Netherlands (Conry 1974).

The plaggen system was carried out using peat turves which were cut once every 5-8 years, or every 12-15 years where deeper, thicker sods were removed (Pape 1970). Given this rate of peat cutting, it has been estimated that a farm with 4 ha of arable land required 3 ha of heath per year; if the average recovery time was 10 years, then 30 ha of heathland were required for every 4 ha of arable (Oosting 1942). In some districts 10% of the land was arable while 90% was used for grazing and turf cutting (Pape 1970).

Plaggens in the Netherlands are low in pH, and all plaggen soils in NW Europe are characterised by a high phosphate content. Although the physical properties are excellent for water retention, oxygenation and root penetration (the porosity of plaggens is c. 50%), the soils are low in nutrients, and by the end of the 19th century the yields were so low that in many areas arable agriculture was abandoned and plaggen soils were afforested (Conry 1974). At around this time chemical fertilisers were introduced, and also the deep stables in which cattle had been kept were no longer regarded as sufficiently hygienic by the dairy industry (Pape 1970). The reclamation of heathlands meant that there was less available grazing for sheep, which had anyway become less profitable due to competition from other countries (*ibid.*). The combination of these factors meant that plaggening was no longer carried out in the Netherlands after *c.* 1900 (*ibid.*).

Pollen analysis has been used to establish the soil history, settlement history and land use of the Dutch plaggens (Groenman-van Waateringe and Luijten 1995). The increased cereal production associated with expanded plaggening has been linked with the growth of the market economy in the late Middle Ages (*ibid.*) and production has even been shown to rise and fall with the major market fluctuations (Mücher et al 1990). Behre (1976; 1980) suggested that there was a link between the introduction of plaggening and the rapid increase of winter rye at the end of the early Middle Ages, on the basis that a winter crop of rye is only possible with intensive manuring. A rapid rise in rye production took place in the 10th-12th centuries, but the rise was accompanied by increased production of other cereals as well, and may simply represent an increase in land reclamation rather than a change in agricultural methods (Spek 1992).

### 3.4.2 Plaggen soils in Orkney

The Soil Survey for Scotland has mapped 7km$^2$ of deep topsoils in Orkney. The soils are usually over 75 cm in depth and are developed on freely or imperfectly drained podzols over stony drift derived from sandstones and flagstones (Simpson 1997; Dry and Robertson 1982). The areas of deep topsoil surround farmsteads with Norse place-names (Davidson and Simpson 1984), and $C^{14}$ dating has shown the soils to have originated in the Late Norse period, around the 12$^{th}$ or early 13$^{th}$ centuries (Simpson 1993). The deep topsoils occur almost exclusively in areas where there is a scarcity of seaweed, confirming the historical records which state that seaweed was the preferred fertiliser (Simpson 1994). The value of the deep topsoils is nevertheless demonstrated by the fact that townships with larger areas of anthropogenic deep topsoils had higher tax values (*ibid.*).

There is extensive historical and ethnographic evidence to show that the processes by which the deep topsoils in Orkney were fertilised in the 18$^{th}$-20$^{th}$ centuries were much the same as those of north-western Europe (Fenton 1978), and analyses of the total soil phosphates confirms that, like the European soils, they are strongly enhanced (Simpson 1997). Spatial analyses of the phosphate content and $\delta^{13}C$ have shown that, like the European plaggens, the Orkney plaggens were most heavily fertilised nearest the farmsteads (Simpson 1997). Textural pedofeatures identified in thin section analysis suggest that cultivation as well as manuring was at its most intense in proximity to the farms (*ibid.*). The thickness of the clay textural pedofeatures was indicative of a moderate amount of disturbance, which may be linked with historical documentation of the use of the Orkney one-stilted plough (*ibid.*).

Thin section analysis and particle size distribution was further used to identify the source of the turf in a plaggen soil at Marwick (Simpson 1997). The lithology of the mineral component of the plaggen soil at Marwick linked the material to the unenclosed hill land beyond the area of enclosed grazing, and the identification of iron depleted stone rims in thin section suggest that the source was acidic. A truncated soil profile from the podzolised hill land confirmed that turf was removed from this area.

The instigation of the plaggening system in Orkney coincided roughly with an improvement in the climate and a growth of population in the 1100s to early 1300s (Simpson 1993). The agricultural intensification could have been a response to the increased population and/or greater economic opportunities (*ibid.*). The increased arable production coincides with increased fishing and an increase in the bones of very young calves, which suggests an intensification of dairying; these changes have been interpreted as a response to increased opportunity for trade in an economy which was based on subsistence with exchange of the surplus (Bigelow 1992).

Monasteries throughout medieval Europe and Scotland were responsible for the introduction of a number of agricultural innovations, and it has been suggested that deepened arable soils were introduced by monks in the later phases of some of the ecclesiastical sites; both Iona and Fearn Abbey have associated deepened anthropogenic soils (Barber 1981). It has also been noted that Birsay Monastery on Mainland Orkney is part of the Hamburg-Bremen archbishropic, which is located in an area with a history of plaggening which predates that of Orkney. The plaggen system may have been introduced by the German monks who would have been familiar with the system (Simpson 1993).

### 3.4.3 Plaggen soils in Shetland

The soils of Shetland have not been mapped with the same degree of detail as those of Orkney, but the turf plaggening system is known from historical times and on the more remote islands it was still in operation in the 1960s (Fenton 1978). The boundaries which divided the enriched arable land from the rough grazing areas can still be seen in places. As in Orkney, the system is believed to date to the Norse period (Davidson and Carter 1998). The deep topsoils are characterised by high phosphate values and by burnt and unburnt peat fragments identified in thin section (*ibid.*).

## 3.5 Fertilisers in the post-medieval: shell sand

The use of calcareous sea sand to neutralise acid soils was widespread in the coastal regions of Europe, Ireland and Britain in the medieval and post-medieval periods. It was often composted together with seaweed and animal dung. The addition of sea sand to soils may have taken place in the early 1st millennium AD in Ireland, but mostly the practice appears to date to the post-medieval period, often being introduced as part of the agricultural improvements of the 18th and 19th centuries. Several of the regions that employed this practice are described below.

### 3.5.1 Shell sand in Ireland

Deep topsoils which have been aggraded by the addition of calcareous sea sand have been extensively mapped in the coastal regions of Ireland, in particular in the three southern counties of Cork, Kerry and Wexford, where it is estimated that thousands of hectares are located (Conry 1974). The vast majority of the deepened, sand-enriched Irish soils were created in the post-medieval period (Conry and Mitchell 1971). The earliest reference to manuring in Ireland is in the Irish law tract *Folda Tire*, or 'Divisions (or types) of land', which was first transcribed in the 7th century but which probably originated as an oral tradition before 500 AD (*ibid.*). The tract describes the best agricultural land as that 'which does not require the application of manure or shells; in which there are no sticking plants'. In a review of the historical literature on plaggen soils, Conry and Mitchell (1971) suggest that although Irish plaggens probably began to develop sometime before 500 AD, plaggening did not become common until the population explosion which began around 1780. The authors found a strong correlation between field size, population and the intensity of plaggening, and suggest that the increase in population led directly to a decrease in the size of fields, which were more intensively manured in order to increase their productivity. The paper also suggests that the greater value of agricultural produce in relation to pastoral products may also have been a factor in the intensification of arable farming.

### 3.5.2 Shell sand in Devon and Cornwall

Areas of deep sanded topsoils have also been mapped in Devon and Cornwall, where they date from the medieval until the present (Staines 1979). Only two 100 square kilometre areas of Cornwall have been subject to detailed soil mapping to date. Sheet SW53 (Hayle) shows c. 1200 ha of deep topsoils, *i.e.* one eighth of the mapped area. The development of the deep topsoils is attributed to the addition of calcareous sands (in the case of the Highweek Deep Series, one third of which (*c.* 741 ha) are deepened) or to the addition of a combination of seaweed, organic manure and calcareous sea sand (this includes the man-made topsoil phases of the Highweek, Ivybridge, Conway, Trusham and Dartington phases and the Ludgvan gleyed and ungleyed phases) (Staines 1979). The A horizons of these soils are >40 cm thick, and are comparable to the Irish plaggens in both their thickness and in their composition, which in both regions derives largely from calcareous sea sand.

Dispensations for the collection of sea sand were granted to farmers by Richard I (1189-1199), and were confirmed by Henry III (1216-1272) (Staines 1979). An Act of Parliament in 1609 also granted farmers the right to remove sea sand (*ibid.*). Borlase (1758) describes different types of sand which could be used to improve agricultural yields: the sand from Mounts Bay was described as 'a fine, light opening sand, good for corn and grass'. Coral sand from Mounts Bay was recovered along with 'oreweed' and was spread on 'old shelfy earth and covered with sand' until it was required. Since the 18th-19th century compost heaps 20-30 m long have been prepared in Cornwall in the autumn and winter. 'Lugg' sand was placed on top of layers of seaweed, dung and calcareous sea sand from Hayle; lugg sand is low in calcium carbonate but is enriched by large amounts of rotted seaweed. One or two farmers were still using a seaweed and sand compost at the time of the soil survey (1979), and Hayle sea sand was still widely used (*ibid.*).

### 3.5.3 The Northern and Western Isles

The practice of adding calcareous sand to acidic topsoils appears to have been introduced to Orkney (Schrank 1995) and Shetland (Knox 1985) during the course of the agricultural improvements of the 18th and 19th centuries, and the practice is still carried out in places today. An observer on the Western Isles in 1764 and 1771 noted that although shell sand was widely available, it was not used to fertilise the arable soil, which remained unmanured 'as it was left at the Creation' (McKay 1980).

## 3.6 Discussion

The changes in land management over time reflect changes in the environment and in society, in population growth and decline and in expansion and contraction of trade in agricultural surpluses. In Ireland, for example, the post-medieval expansion of plaggening coincided with an increase in population, whereas in Norse Orkney and the medieval Netherlands it appears to be linked with the economic opportunities introduced by a growing trade in agricultural surpluses. In the Western

Isles and possibly in the fields near Haarlem in the Netherlands manuring was used in prehistory to stabilise the sandy soils.

Domestic waste, including fuel ash residues and kitchen refuse, is the most commonly cited material identified in early prehistoric arable soils. This may be because charcoal, bone and peat ash are easily identified in the field, unlike organic manures which can only be identified using geochemical or thin section analysis. Stable manure was used as a fertiliser as early as the Neolithic in Switzerland (Bakels 1997) and probably also in the Bronze age in Denmark (Linderholm 1997), Germany (Blume and Kalk 1986) and the Netherlands (Buurman 1988); Fokkens (1982) notes that 'on the sandy soils of northern Friesland permanent cultivation without manuring is out of the question.' By contrast, at Hazleton North (Macphail 1990), Strathallen (Romans and Robertson 1983) and Sumburgh (Limbrey 1975) the absence of organic manures has also been suggested. The difference may be regional, with stable manure coming into use earlier on the continent than in Britain. More evidence and more systematic work on arable soils is required to test this.

This review has highlighted a number of different methods used to extract evidence for arable activity and land management. Arable soils have largely been identified by archaeological features such as ard and spade marks, and from the charred remains of cultigens. Arable weeds provide information about the soil ecology, some species requiring more nutrient rich soil which can be indicative of manuring. Pollen analysis has been used to identify clearance of woodland and the introduction of arable and pastoral weeds, as well as cereal pollen. Geochemical analysis (especially phosphate analysis) and soil micromorphology have been used to identify areas of arable land use, and have also been used to obtain more detailed information about the particular materials which were added to the soil. The application of seaweed has been identified by the survival of algal spores and of the shells which adhere to it, or by fragments recovered from the soil.

Fuel ash and charcoal are produced as a part of everyday living and no special land management practices can be inferred from their presence, although the type of fuel used provides information about the local environment. Animal dung in small quantities is added to the soil by grazing animals, but the intensive use of animal dung implies stabling or corralling of the animals in order to concentrate the manure in one place for collection (Bakels 1997). The presence of large amounts of animal dung in the soil therefore suggests a regulated system of stock keeping. The medieval practice of plaggen manuring with turves is a further intensification of manuring practice, and is also a method which makes systematic use of a wider area of land. The medieval and (predominantly) post-medieval reclamation of acid heathlands using shell sand is a further step towards a more sophisticated land management system.

## 3.7 Hypotheses

The hypotheses that arise out of this review are:

- Methods of manuring have changed over time, and although deep topsoil horizons may appear similar in the field, they were created by different means at different times.
- Soils can retain evidence for manuring, and some of the materials used can be identified using thin section and chemical analysis.

- Sources of manuring materials can be suggested using reference and control samples.
- Links between local soils, settlement deposits and arable fields can be established by identifying the sources of the manures.

# CHAPTER 4: RESEARCH DESIGN AND METHODS

## 4.1 Theoretical basis

The previous chapter demonstrated that materials which have been added to a soil may survive the destructive effects of tillage and decomposition. Some of the materials can be identified in thin section, while others can be detected by chemical analysis. These materials, like the artefacts in midden deposits on archaeological sites, can provide information about the economy of the associated settlement, and the deposition of this material onto arable fields can be regarded as another form of rubbish disposal. The cultural material which survives in the soil is often overlooked, and analysis of most sites (apart from surface artefact surveys) is concentrated on the midden deposits in and around archaeological settlements.

In Chapter Two it was established that midden material on prehistoric sites was used for different purposes, e.g. for construction (Ritchie 1983; Clarke and Sharples 1985), for ritual purposes (Hill 1995) and for fertiliser (Rhodes 1950; Simpson et al 1998 a and b). Chapter Three established that different types of materials were used for fertiliser in different archaeological periods and in different regions. The types of material which were used reflect both the local environment (e.g. the use of peat or wood as fuel) and the economy of a settlement (e.g. the use of animal dung as fertiliser, which suggests fairly intensive animal husbandry [Bakels 1997]). The choice of fertilisers may also reflect local custom or even ignorance of the benefits of certain fertilisers, e.g. the failure of the Western Islanders to apply shell sand to their acidic soils (McKay 1980).

In this project the cultural material in the archaeological middens of two multi-period prehistoric sites is compared with the cultural material held in the soils, in order to identify the full range of materials produced by the settlements under study. The comparison of the soils and middens was expected to show differential use of waste materials, with some materials selected as fertilisers and other materials accumulating in middens or used for other purposes. The spatial analysis of the individual phases was followed by a comparison of the arable soils and middens of the different periods, in order to identify changes in arable land management practices and changes in the ways that midden material was used over time.

## 4.2 Hypotheses

The following hypotheses were established in Chapters 2 and 3:

- The Neolithic in the Northern Isles is characterised by permanent settlements and permanent fields. The fields may not necessarily have physical boundaries but may be identified by the amended soils where they have been preserved by burial.
- The Bronze Age had the same economy and land management system as the Neolithic and should therefore have similar amended soils which reflect a similar landscape.
- There was an intensification in arable production and stock keeping in the Iron Age, which may be reflected by increased animal manures in the soil.

- There was a further intensification of arable production in the late Norse period, which will be reflected by deeper and more extensive anthropogenic soils.
- Methods of manuring have changed over time, and although deep topsoil horizons may appear similar in the field, they were created by different means at different times.
- Soils can retain evidence for manuring, and some of the materials used can be identified using thin section and chemical analysis.
- Sources of manuring materials can be suggested using reference and control samples.
- Links between local soils, settlement deposits and arable fields can be established by identifying the sources of the manures.

## 4.3 Selection of methods

The evidence for the types of materials used as fertilisers in the different archaeological and historical periods was summarised in Chapter 3, which also demonstrated that some of the materials were more readily identified than others. The use of domestic waste was a common occurrence in the Neolithic and Bronze Age soils, but it was noted that there is a bias towards recognition of this material. Charcoal, animal bone and artefacts are recognisable in the field whereas many other manuring material can only be identified microscopically or chemically. Thin section analysis is therefore an important method for identifying the materials that have been added to soils, and the use of micromorphology in conjunction with geochemical analysis has been shown to be particularly informative. Micromorphology has been undertaken together with phosphate analysis, magnetic susceptibility, loss on ignition (LOI) and pollen analysis (Macphail et al in press), with energy dispersive x-ray analysis, microprobe and diatom analysis (Macphail et al 1998), with stable isotope, particle size distribution and phosphate analysis (Simpson 1997) and with stable isotopes and lipids (Simpson et al 1998a), to give a few examples. On large multidisciplinary excavations a whole range of archaeological specialisms can be integrated, e.g. on the excavation of a Hebridean farmhouse on South Uist where charred macrobotanical remains, molluscs, phytoliths, particle size distribution, magnetic susceptibility, pH, loss on ignition and phosphates were studied (Smith 1994; 1996).

Soil micromorphology was used in this study in order to identify the components of the soil that would otherwise be missed in the field. It was also used to identify soil processes which can be indicative of land use and management, taking on board the caveats discussed below. Phosphate analysis was considered to be one of the most informative geochemical methods for a study of manuring practice because it can be used to quantify organic waste in the soil. The organic/inorganic fractionation method (described below) was undertaken in order to quantify the amount of animal manure and bone in the different areas and deposits. Loss on ignition was a further method of quantifying the organic material in the soils. A range of magnetic tests were undertaken in order to identify and compare the amount of ash in the soil, which on many sites in the literature review is quantified only by the presence or absence of charcoal. The quantifications obtained from thin section analysis and those obtained from allied methods were then correlated in order to ensure that the chemical and geophysical methods were reflecting the same materials as those identified in thin section. Each method has shortcomings when used on its own, but used together the different methods can corroborate one another in identifying concentrations and anomalies, and also micromorphology can be used to identify where in the soil the particular concentrations are located. Particle size distribution was undertaken in conjunction with thin section analysis in order to compare deposits and trace possible common origins. This combination of methods has been used successfully to trace the origins of added mineral manures on Papa Stour, Shetland (Davidson and Carter 1998) and West Mainland, Orkney (Simpson 1997). The methods are discussed in more detail below.

## 4.4 Validation of methods

The investigative methods were tested on a site which was farmed by pre-industrial methods until 1967. There is documented evidence for the types of manures which were used on this farm, and the owner was able to describe the land management system which operated before arable farming was abandoned in favour of sheep farming. The arable land on the farm was subject to the plaggen manuring system, and the thin section, geochemical and soil magnetic analyses were aimed at finding distinctive indicators for this system. The different areas of the farm were subject to different treatments, so analysis was undertaken of each of the different functional areas so that the different management techniques could be identified. Having established that the added materials could be identified in the soil, and having identified a group of indicators for plaggen manuring, the methods were then applied to the prehistoric sites.

## 4.5 Review of Methods

### 4.5.1 Soil micromorphology

Soil micromorphology is used in archaeology for both site-specific problems, such as identifying the formation processes and constituents of particular deposits, and for landscape studies, which focus on past climate, soil development and land use. This project aims to link the two approaches by studying the agricultural landscape (using samples from arable soils) together with on-site deposits (using samples from archaeological middens) to trace how materials were used and re-used in the past.

Arable soils are usually identified by archaeological features such as ploughmarks, rig and furrow, lynchets, the presence of rounded and abraded potsherds or by the homogenisation of the topsoil horizon, which distinguishes it from the local uncultivated soils. There are also a number of indicators which can be identified in thin section, *e.g.* coarse textural pedofeatures (Jongerius 1983), the presence of charcoal and other cultural material (Romans 1986), enhanced numbers of phytoliths (Courty et al 1989), the presence of planar voids (Macphail et al 1990), plough and ard pans at the base of the ploughsoil (Jongerius 1983; Gebhardt 1992) and the presence of lenses of fine material along ard or plough cuts (Lewis 1998). The problem with using micromorphological indicators is that biological reworking of soils can eradicate many of these features. A further problem is that textural pedofeatures, a key indicator, can also result from disturbance other than cultivation (Carter and Davidson 1998). It has been suggested that where several of the cultivation indicators occur together they can usually be interpreted as indicators of past cultivation (Courty et al 1989; Macphail

1998), but due to biological reworking the absence of such indicators does not indicate that cultivation did not take place.

*Micromorphology Reference Slides*

While there is an extensive body of literature pertaining to the description of soil thin sections, the literature on interpretation of features has not kept pace. In the words of FitzPatrick (1993), interpretation is still largely 'a combination of experience, intuition and guess-work'. In order to bring objectivity to the micromorphological interpretations in this project, reference slides were made of the different types of fertilising materials which were described in the ethnographic and historical literature, and which could therefore be expected to appear in the modern and possibly the prehistoric soils. Samples were taken from the Shetland Croft Museum, which functioned as a traditional farm until the 1930s, and from the Corrigall Farm Museum on Mainland Orkney. These samples include:

- Dried peat from the peat stack at the Shetland Croft Museum.
- Samples from the packed earth between the stone flags of the Croft Museum's byre floor and drain.
- Peat ash from a peat fire in an open hearth from the Corrigall Farm Museum.
- Sheep dung (Corrigall)
- Cattle dung and straw bedding from a modern muckheap at Sumburgh Farm, near Scatness.

A reference slide for coal ash was kindly provided by M. Canti of English Heritage. Some processing was also undertaken in order to create further reference slides for peat ash. Peaty turf samples were taken alongside the controls on Papa Stour and Scatness, which were taken from areas of differing geology. These samples were burned at 400°C and 800°C in a furnace. The flow of air through the furnace (for extraction of smoke and fumes) is believed to be similar to the flow of air through an open fire (Johan Linderholm, pers. comm.).

*Thin section processing*

The micromorphology samples were processed using standard methods of the Department of Environmental Science, University of Stirling:

1) The soil moisture was removed from the samples by acetone replacement.
2) Crystic resin was added to the samples (CRYSTIC 17449 with catalyst MEKP LA3) which were then placed under vacuum to eliminate the air.
3) The samples were left to cure for c. 3 weeks in the fume cupboard, followed by a week in the drying oven.
4) The cured blocks were cut using a diamond blade circular saw and bonded to slides.
5) The slides were lapped on a Logitech LP40 auto lapping plate using silicon carbide grit as an abrasive. The slides were hand lapped where irregularities occurred.
6) When the soil reached a thickness of 30 µm the samples were polished on a Logitech polishing pad using 3 µm diamond powder in ethanediol.
7) The slides were cleaned and cover slipped.

### 4.5.2 Phosphates

Phosphate analysis has been widely used in archaeology as a method of prospection, mainly to identify the extent of settlements and arable fields but also, with varying degrees of success, to try to distinguish the two. Phosphorus has a strong affinity for oxygen, and is therefore usually found in soils as phosphate, which occurs in organic and inorganic forms. In the organic form the phosphate is bonded to an organic compound, and in the inorganic form it is bonded to a metallic ion, either iron or aluminium in acid soils and calcium in calcareous soils. In some studies the different phosphate fractions appear to distinguish the different parts of the settlement, and it has been suggested that the fractions may even indicate the type of crop which was formerly grown in a field (Eidt 1977). The fractionation method seems to work on some sites but does not work consistently and is strongly affected by changes in pH. For this project a different type of fractionation has been used, which differentiates levels of organic and inorganic phosphates in the soil.

Organic phosphorus typically makes up 20-80% of the total P in surface soil horizons (Brady and Weil 1999). Organic P is found in vegetation, and consequently high levels of organic phosphorus coincide with high levels of soil organic matter (Hesse 1971). Soil microbes transform organic P into soluble phosphate ($H_2PO_4$), which is either taken up by plants or fixed as inorganic phosphate by reaction with Fe, Al, Mn or Ca (Brady and Weil 1999). Organic P changes into inorganic P under the same conditions as organic matter decomposes, and the rate of change is dependent on the same factors, mainly temperature, oxygen and moisture (*ibid.*). Organic P is also found in human and animal excrement, and therefore the addition of farmyard manure to agricultural soils raises levels of organic P in the soil (Linderholm 1997).

Although there is an increase in organic P in manured agricultural soils, there is an accompanying increase in the rate of mineralisation which can counter the effect. In a study of eight agricultural soils in North America, Sharpley and Smith (1983) found that the organic P in all but one of the soils was *lower* than on uncultivated analogue sites, although the total P content in all had increased. In a study of a cultivated soil in Nigeria, Adepetu and Corey (1977; cited in Sharpley and Smith 1983) found that 25% of the organic P had mineralised in the first two cropping periods after cultivation.

By contrast, an analysis of the organic/inorganic P proportions in podzolic soils in Sweden has shown that both the total P and the organic P in the cultivated soils were higher than in the uncultivated analogues (Linderholm 1997). The cultivated soils also had higher levels of soil organic matter, which showed a positive correlation with the organic P. A similar analysis was then applied to a cultivated soil and an uncultivated analogue from a medieval farm abandoned in 1350, with similar results. A study of a buried early Bronze Age agricultural soil in West Jutland, Denmark also had higher organic P than the uncultivated analogue soil. These studies also found that the dwelling areas had increased levels of inorganic P, a finding which was also demonstrated by Eidt (1984) on sites in South America.

The organic/inorganic fractionation method was applied successfully to a Roman site on podzolic soils on the border of Norfolk and Suffolk. Levels of inorganic P within the Roman town boundaries were higher than in the undisturbed podzol, while raised levels of organic P were found in the surrounding buried agricultural soils which were associated with the settlement (Macphail et al., in press).

The survival of organic P in the Swedish, Danish and East Anglian agricultural soils may be related to the inherent infertility of podzolic soils. These soils could only be successfully cultivated after the addition of farmyard manure, due to their acidity and the low levels of soil organic matter. After the additions of farmyard manure ceased, the soil microbes which change organic P into inorganic P must have declined.

High levels of organic P may also be preserved in soils which have been deeply buried, in which anaerobic conditions have killed off the bacteria which transform the organic into inorganic P. Work by Ottaway (1984) on a Yugoslavian tell site has identified a higher level of organic P (12% of the total) in a buried Neolithic soil as compared with the undisturbed soil below. The organic P levels were still higher (34%) in the buried Iron Age and Roman soils, when the site was more densely settled.

Linderholm (1997) and Macphail et al (in press) calculate the proportion of organic P by dividing the total P by the inorganic P to get the Ptot/Pinorganic ratio, so that a P ratio of 1 indicates 100% inorganic P. Their work has established that in podzolic soils P ratios of 1.5 to 10 are indicative of manuring. An analysis of a stable floor at Butser experimental farm produced P ratios of around 1, and investigation of thin sections from the floor show the trampled bedding and dung cemented by mineralised phosphate. Inorganic phosphate had also penetrated into the chalk floor of the stable.

*Phosphate sample processing*

The samples were ground into a powder and 1g (Bragasetter and Scatness) or 0.5g (Tofts Ness) was placed in a crucible. 5ml of 12N $H_2SO_4$ was added to each sample, which was then placed in a 70°C sand bath for 10 minutes. The samples were removed and a further 5ml of 12N $H_2SO_4$ was added. The samples were filtered after cooling for an hour. Colorimetry was carried out using ammonium molybdate and ascorbic acid (see Appendix 6). One sample from each of the three sites was subdivided and the ten sub-samples were processed in order to establish the amount of variation in the sampling. The coefficient of variation in the replicates for Bragasetter was 7.49, for Scatness it was 10.50 and for Tofts Ness it was 6.69.

### 4.5.3 Soil magnetism

The magnetic materials in soils derive from minerals which are natural components of the parent materials, or from their secondary products. The only soil minerals to strongly affect soil magnetism are the oxides and hydroxides of iron, and in most soils there are only two strong magnetic minerals of any importance, magnetite and maghemite (Mullins 1977). Magnetite occurs in sand-size grains in basalt, andesite and (in smaller quantities) other igneous rocks. It is also formed by magnetotatic bacteria which produce small chains of magnetite crystals in their cells, which build up in the soil (Thompson and Oldfield 1986). Secondary iron minerals are created by several processes (Mullins 1977):

1) Oxidation at low temperatures (which only works in conjunction with other processes) transforms magnetite into maghemite.
2) Burning at 150-259°C also transforms magnetite into maghemite.
3) Dehydration of lepidocrocite (which occurs mostly in gley soils) at 275-410°C transforms this mineral into maghemite.
4) Maghemite is formed in the soil by reduction-oxidation cycles under normal pedogenic conditions; soil biota may play some part in this process.

Soils and sediments can be characterised and distinguished from one another by the composition of magnetic materials, the concentration of the dominant mineral and the grain size (i.e. the number and size of magnetic domains within the crystals). The composition, concentration and grain size can act as indicators for different parent materials, different environmental processes, and as indicators for burning.

Table 1: Size range classes of magnetic crystals (magnetite)

| | | |
|---|---|---|
| Superparamagnetic | SP | < 0.03 μm |
| Viscous | | Around SP-SD boundary |
| Single domain | SD | 0.03-0.1μm |
| Pseudo-single domain | PSD | 0.1-20μm |
| Multi-domain | MD | 20μm + |

Materials which retain magnetism after they have been removed from the magnetic field are called ferromagnetic or ferrimagnetic. Primary ferrimagnetic crystals in the soil are usually multi-domain (MD), and secondary iron minerals are usually single domain (SD) or smaller (Thompson and Oldfield 1986). Secondary magnetic minerals in cultivated soils are in the range of superparamagnetic (SP), viscous and SD (*ibid.*). Magnetotatic bacteria produce superparamagnetic and single domain size grains (Maher 1998; Dalan and Banerjee 1998), and the very fine grained superparamagnetic grains are produced by burning (Peters and Thompson 1999).

Magnetic properties of soils and sediments have been used to correlate strata, to establish past climates and to trace erosion and sedimentation patterns (Maher 1998). In archaeology the analysis of soil magnetism is commonly used to define the limits of archaeological sites, areas or features by identifying areas of magnetic enhancement. The technique was used in America on a Mississippian mound site where the sources of the different deposits were traced by identifying the signatures of the different 'natural' soils, the archaeological feature fills and the midden deposits (Dalan and Banerjee 1998). Current research is also underway to trace the sources of ash in archaeological deposits by characterising the magnetic properties and comparing them with the properties of reference samples from wood ash and different types of peat ash (C Peters, pers.com.).

All of the magnetic tests were carried out at Edinburgh University, with the help of Dr. Clare Peters. Four magnetic tests were used for this project. *Mass susceptibility* measures the concentration of ferromagnetic and ferrimagnetic crystals of all sizes, but is more sensitive to larger grains (Dalan and Banerjee 1998). *Frequency dependent* *susceptibility* measures magnetic susceptibility at two different frequencies, so that the proportion of superparamagnetic grains (which have a higher frequency) can be quantified (*ibid.*). *Anhysteretic Remanent Magnetisation* (ARM) measures the remanence after the application of a strong alternating magnetic field in the presence of a weak, steady field (i.e. it measures how well the material retains the magnetisation under this particular type of treatment); this is another way of measuring SD and PSD grains (*ibid.*). *Saturation Isothermal Remanent Magnetisation* (SIRM) measures the magnetisation persisting after a saturating field has been removed (*ibid.*), and is another way of measuring the concentration of all of the magnetic grains in the sample.

### 4.5.4 Particle size distribution

The particle size distribution (PSD) in the soils and middens was estimated in order to trace the sources of the different materials and to distinguish soils with an anthropogenic input from the controls. PSD has been used together with thin section analysis to trace the origins of the added turf material on Papa Stour (Davidson and Carter 1998).

The particle size was estimated using a Coulter Counter. The samples were prepared by sieving to 500 μm, which by the definition of Bullock et al (1985) removes the coarse sand, or by the definition of the Soil Survey of England and Wales removes the coarse sand fraction and part of the medium sand fraction. The samples were subject to loss on ignition in a furnace at 425° C before dispersion and sampling in the Coulter Counter. The particle size curves were plotted and overlain using the Coulter Counter software, which shows the degree of variation between samples by plotting the standard deviation when any two or more samples are overlain.

### 4.5.5 Soil organic matter

The percentage of soil organic matter in the archaeological soils, middens and controls was estimated and compared using loss on ignition. Soil organic matter accumulates where large amounts of organics such as stable manure are added to the soil (*c.f.* Rothamsted experiments, Catt 1994), and peat and the addition of peat can be expected to have the same effect. A high proportion of soil organic matter was expected to correlate with a high organic P content, as recorded by Linderholm (1997), thus providing further control to the analysis. The samples were oven dried at 105°C for 4 hours. 10g of each sample was measured out into a crucible and burned in a furnace at 850°C for 45 minutes, and the LOI was determined by the weight before and after the organics were burnt off.

### 4.5.6 pH

Soil pH is a measure of acidity/alkalinity and is a key factor in plant nutrient availability and microbial activity (Brady and Weil 1999). It was shown in Chapter 3 that efforts to regulate soil activity do not appear to predate the medieval period, leading in the Netherlands to diminished productivity of the acidic plaggen soils. In some regions, e.g. the Northern and Western Isles, the addition of calcareous material to acidic soils was not carried out until the Improvements in the $18^{th}$ and $19^{th}$ centuries.

The pH of the archaeological soils and middens was compared with the pH of the local soils in each of the study areas in order to determine the effects of the soil amendments.

### 4.5.7 Historical sources

- First and second edition Ordnance Survey map sheet XXXV.13 (1880 & 1901), Papa Stour
- The Head Dykes around Scatness were plotted from the first edition Ordnance Survey by Brian Smith at the Shetland Archive in Lerwick.

## 4.6 The sites (Fig. 4.1)

Bragasetter Farm, on Papa Stour, Shetland, was selected as the modern comparative site on which to validate the methods because of the detailed ethnographic and historical information which was collected on the island while the traditional system was still in use; the resident of the farm was also able to provide information on how the agricultural system had functioned before the land was given over to sheep grazing. The field boundaries, kaleyard (walled garden) and planticrues (small enclosures built to protect seedlings) are still intact, and the ridges and furrows of the arable fields are still visible as earthworks (Plate 1). The different areas could therefore be sampled in an attempt to establish the characteristic signatures of the different areas of the farm where distinct manuring practices were carried out.


Figure 4.1: Site Location

Plate 1: Bragasetter Farm, Papa Stour

Plate 2: The Early Iron Age roundhouse at Tofts Ness

The multi-period sites of Tofts Ness, Sanday, Orkney (Plate 2) and Scatness, Shetland (Plate 3) were selected as the prehistoric study sites because both had distinct, multiple phases of activity including multiple buried arable soils. Preliminary archaeological excavation had already established the chronology of some of the soils and midden deposits, so a sampling strategy could be planned which would include a representative range of soils and contemporary middens. The published analysis of charred seed remains and molluscs at Tofts Ness and the preliminary specialist investigations at Scatness added to the understanding of the environment and economies of the sites.

Plate 3: Scatness under excavation, August 2000

## 4.7 Excavation, Sampling and Controls

Micromorphology and bulk samples were taken from soil profiles and section faces in test pits, which were excavated in order to record and sample the sequence of soil horizons, buried soils and archaeological deposits so that different areas and different phases could be compared. The test pits were excavated in spits in order to distinguish strata which might otherwise appear homogenous in the field, and in order to recover material for dating. Micromorphology samples were taken in Kubiena tins, and bulk samples were taken from individual contexts adjacent to the tins. The bulk samples were taken for analysis of phosphates, soil magnetism, particle size, loss on ignition and pH (which were analysed at Stirling University, by the author) and for lipids, isotopes ($\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$) and elemental analysis (to be analysed at the Bristol University Department of Chemistry). All of the bulk samples were air dried and sieved at 2mm, and the samples for lipids, isotopes and elemental analysis were sent to Bristol. All soil horizons and archaeological deposits were described using standard archaeological recording methods, including descriptions of Munsell colour, texture, stoniness and quantity of cultural material.

Control samples were taken in order to compare the agricultural soils and midden deposits with relatively unaltered, non-agricultural soils. Because of the intensity of land use over the millennia none of the 'natural' soils can be regarded as unaltered, but samples were taken from local pasture (which has been enriched by the dung of grazing animals) and moorland (which was subject to peat cutting and grazing). The micromorphology control samples provided information on the lithology of the different local soils and the pedogenic processes such as iron and clay movement. Bulk samples from the control areas provided background levels of phosphorus and soil magnetism from areas of differing geology against which the samples from the agricultural soils could be compared in order to determine the degree of enhancement.

### 4.7.1 Fieldwork: Bragasetter

The fieldwork at Bragasetter comprised the excavation of 16 test pits, four in each of the different functional areas (rig land, infield grazing, kaleyard and planticrues). Samples were taken at consistent depths (15-23 cm, 30-38 cm, 45-53 cm and 60-68 cm) in each of the test pits, so that replicates could be taken and compared. The test pits with the deepest profiles in each area were selected for analysis, and a replicate profile from the rig land (the area with the most variation, according to the historical literature) was also analysed. Further replicates were taken at 15 cm depths from the kaleyard, rig and planticrues. The 15 cm samples were considered to be of particular importance because the uppermost part of the profile will contain the most recent additives to the soil. This supposition was confirmed for the kaleyard by the recovery of modern pottery from depths of 31 cm and 34 cm (Test Pit 4) and 38 cm (Test Pit 1). A total of 16 micromorphology samples were analysed, including the replicate samples.

### 4.7.2 Fieldwork: Tofts Ness

Tofts Ness was excavated by S.J. Dockrill in the 1980s. For the current project two of the excavation trenches from Mound 11 were partially re-opened in order to obtain samples from midden deposits and soils for which the function and chronology had already been established. A 2m x 1m section was excavated along the north facing, north-west corner of Area J, and a 3m x 1m north facing section was opened in Area A. An auger survey was carried out to the east of Area J in order to add detail to the initial survey, which showed the extent of anthropogenic soil but did not distinguish between the different phases. The aim of this survey was to trace the extent of both the upper, LBA-EIA sand-based soil and the lower, Neolithic to Bronze Age soils, and to identify any other phases which had not been recorded in earlier phases of the research programme. The auger survey (10 m intervals on two transects) was undertaken in advance of test pitting, so that the information from the survey could be used to plan the test pit location. A total of 30 micromorphology samples were taken from Tofts Ness, including a control sample from the modern pasture soil.

### 4.7.3 Fieldwork: Scatness

Excavation at Scatness was carried out by a team from Bradford University and was directed by S.J. Dockrill. Sampling was carried out on the exposed section face of Area H, a 2.5m deep test pit through the archaeological soils and deposits down to the basal sand, and from midden deposits within an Iron Age structure (Structure 12) and a Pictish structure (Structure 5). The midden deposits dated to the middle Iron Age (Structure 12) and the Norse period (Structure 5). A total of 23 micromorphology samples were taken, including three control samples which were taken from pasture land to the north (from Toab and Hestingott) and moorland to the south of the site (from the Scat Ness peninsula).

## 4.8 Statistical analysis

The differences between the different areas and phases were tested using analysis of variance (ANOVA) in SPSS. A range of different post-hoc tests were applied; post-hoc tests identify which variables differ significantly from which, with differing degrees of rigorousness. The test for Least Significant Difference (LSD) was found to be the most effective in distinguishing the different areas. The data were normalised using log scales to transform positively skewed data or by squaring or cubing to transform negatively skewed data. Normality was tested using the normality test in Minitab or by checking that the skewness/standard error and kurtosis/standard error were <2. Discriminant analysis was carried out in SPSS on the normalised magnetic data, in order to determine which tests were successful in distinguishing the different materials and causing them to cluster. Correlations were carried out using Pearson's correlation on normalised data in SPSS. P values are given in the text.

# CHAPTER 5: VALIDATION OF METHODS: Bragasetter, Papa Stour

## 5.1 Introduction

Before the prehistoric sites were excavated, the methods were tested on a control site, a farm on the island of Papa Stour which was cultivated using pre-industrial methods until 1967 and subsequently used only for grazing. There are a number of abandoned crofts on Papa Stour, but Bragasetter (NGR HU 1723 5945) was chosen because of the survival of the rigs in the surrounding arable fields, which indicate that the land was not seriously disturbed after abandonment of the traditional farming methods. The site was also chosen because of the isolation of the farm. In the central area of the Papa Stour township it was unclear which fields were associated with which farm, and Bragasetter had the advantage of being relatively isolated in the southern part of the township, so that the associated fields could be easily identified. Bragasetter also had a particularly deep soil in the kaleyard, which indicated that large amounts of material had been added; this was ideal for a project which is focussed on identifying materials added to arable soils.

The soils on Papa Stour were analysed by Davidson and Carter (1998) in a study which was carried out in order to investigate the micromorphological indicators for tillage in a soil which had been cultivated by traditional, non-mechanical methods. The indicators for tillage have been researched in modern soils (Jongerius 1970; 1983) and in soils which have been cultivated using prehistoric implements (Gebhardt 1992; Macphail et al 1990) and a number of features have been identified. Arable soils tend to be biologically active, however, and many of the indicators produced by cultivation are eradicated by biological reworking and will therefore only survive in soils which have been rapidly buried or waterlogged. When the study was carried out the soils on Papa Stour had not been cultivated in *c.* 30 years, and had been neither buried or waterlogged. There were no surviving textural pedofeatures or structural characteristics indicative of cultivation, but enhanced phosphates, the particle size and lithology (indicative of the addition of extraneous material) and fragments of burnt and unburnt peat could be clearly correlated with the historical information regarding the local manuring practices (*ibid.*).

Davidson and Carter's study was successful in identifying the manuring practices on Papa Stour using soil micromorphology in conjunction with total phosphate analysis and particle size distribution, and the site was therefore selected as an appropriate place to test the new suite of methods which were used for this project. Organic/inorganic phosphate fractionation has been used to assess the quantities of animal dung in soil (Linderholm 1997; Macphail et al in press) and is therefore a particularly appropriate test for analysis of manuring practice. Soil magnetism was selected as the best way of assessing the ash content in the soil, which was also known to have been used as fertiliser. The excavation on Papa Stour ran in conjunction with a project which is currently being carried out by the Department of Environmental Science at Stirling University which will include analysis of lipids (to identify the type of animal dung and possibly to find an indicator for seaweed), stable isotopes (to identify the marine, i.e. seaweed component) and elemental analysis of the arable soils; the results of this have unfortunately not been forthcoming in time to incorporate into this project, but it was originally one of the aims.

### 5.1.1 The Study Area (Figures 5.1 and 5.2)

The solid geology of Papa Stour is predominantly acid igneous rock, with some sandstone and basalt. A shallow, stony till overlies most of the island, which is covered by windblown shell sand in areas of the eastern end of the island, where settlement is now confined. The windblown sand is covered by calcareous regosols, brown calcareous soils and calcareous gleys of the Fraserburgh Association (Dry and Robertson 1982). The soils on the till are gleys, peaty gleys, peaty podzols and rankers of the Walls Association (*ibid.*).

Prehistoric remains are distributed across the island irrespective of the soils; sites are found on both the calcareous eastern part and on the more acidic and poorly draining soils of the western part. The prehistoric remains on Papa Stour include burnt mounds, chambered cairns, house foundations, enclosures and fields systems with clearance cairns. In the Norse period settlement was confined to the calcareous eastern part of the island. This settlement pattern has remained to the present day, with all the modern farms situated on the eastern side of the head dyke, a major turf and stone boundary which divides the township from the rough, common grazing land to the west. All of the modern farms are thought to have Norse origins, the place name evidence indicating secondary, probably Late Norse origins (AD 1158-1263/66), although one early Norse place name is known to have formerly existed (Crawford 1984).

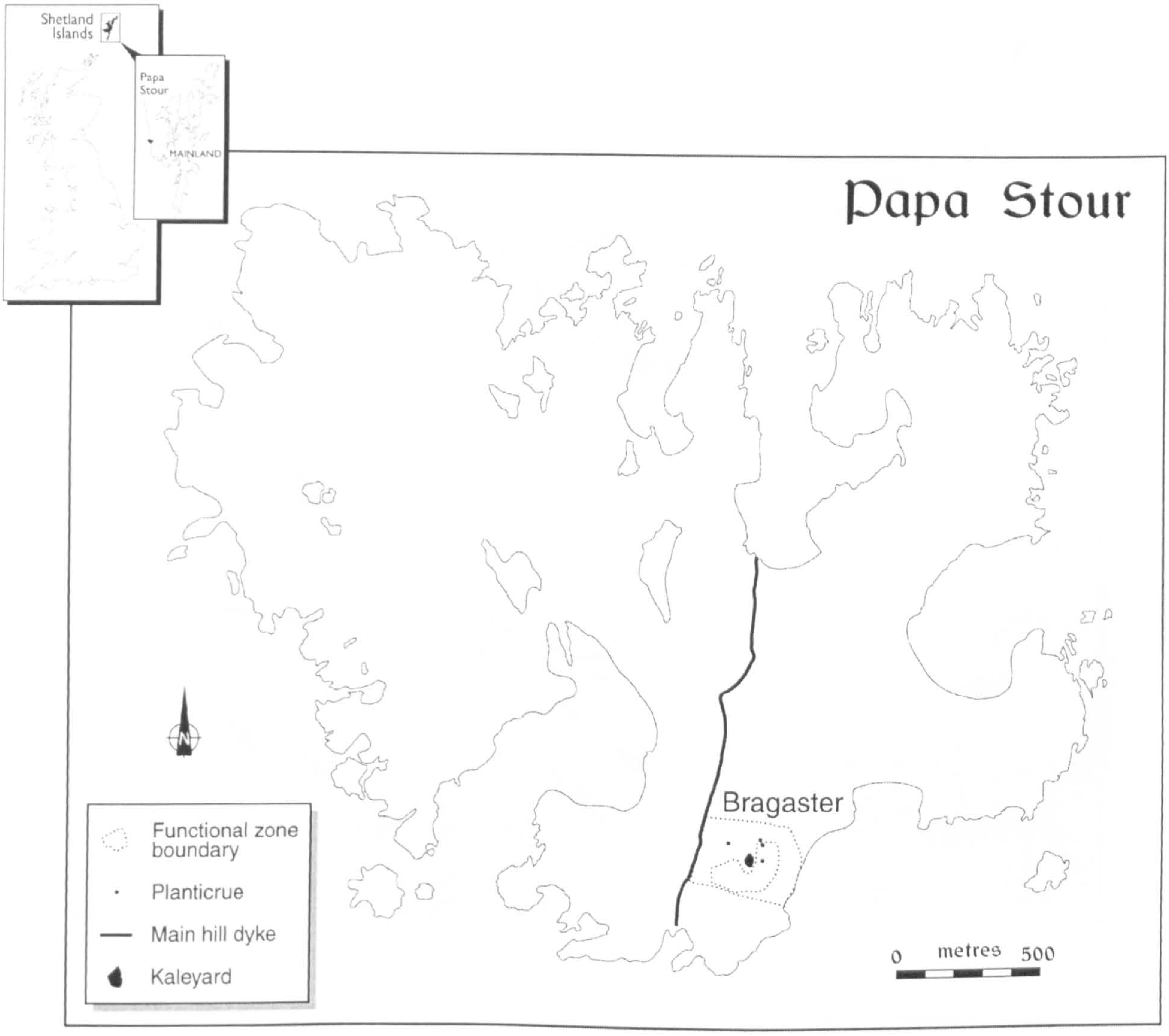



Figure 5.1: Papa Stour, showing Bragasetter (Bragaster) fields

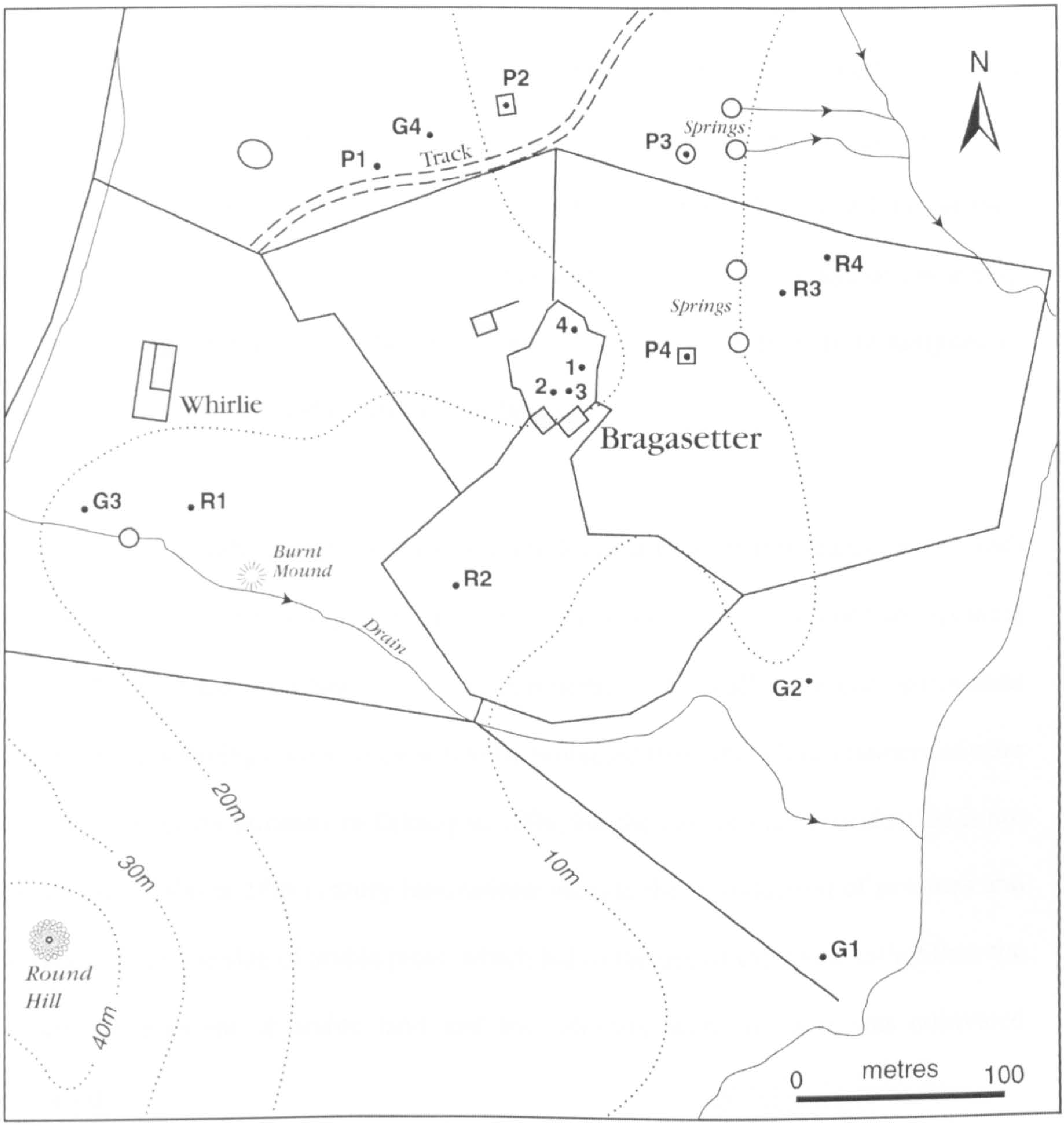



Figure 5.2: Bragasetter, showing test pit locations

Prior to the Enclosures of the 19th century, the township land was divided into rigged agricultural fields and grazing land. Although the rigs may have changed ownership from time to time, they were not regularly re-allocated in the Northern Isles as they were in the rest of Scotland (Fenton 1978). The most recent major change of ownership took place during Enclosure in the 1840s, when the scattered rigs were re-assigned to create blocks of land around the individual farms.

Each farm had a kaleyard or enclosed garden; kaleyards were introduced in the 18th century, although kale was grown at least as early as the 15th century in Scotland (Fenton 1978). Each farm had one or two planticrues, i.e. small stone enclosures used for setting out seedlings where they would be protected from the wind. Planticrues were first documented on Stronsay in Orkney in 1804, but the date of their introduction is not known (*ibid.*). Other 18th century innovations include the introduction of potatoes and the reduction in the size of arable plots, which led to the use of the spade rather than the plough. The extent of arable land and the intensity with which it was cultivated increased.

Each farm had peat and turf cutting rights in a particular area of the common grazing land to the west of the head dyke. The peat was dried and burnt, and the ashes were deposited on the rigged land and sometimes in the planticrues (Fenton 1978). Peat ash was also used to line the cattle byres and was spread on the fields when the byres were cleaned out in the spring. Unburnt turves were also used to line the cattle byres, and were afterwards spread on the rigged land. According to Fenton, unburnt turves were used to add depth and nutrients to the planticrues. The townland grazing was not fertilised. Each farm also had rights to collect seaweed on particular beaches and areas of coastline; seaweed was deposited on the rig land (Fenton 1978), in the planticrues and on the midden (Peterson, pers. comm.).

The farm at Bragasetter had different functional areas including rig land, a kaleyard, planticrues and infield grazing (i.e. grazing land within the head dyke). The rig land and the kaleyard are known to have been heavily manured, but sources conflict regarding the nature of the manure which was added. Fenton (pers.comm.) states that rigs and kaleyards in the Northern Isles were fertilised with different materials, with domestic waste generally going into the kaleyard and byre waste going into the fields. The resident of the farm states that all waste material was deposited in the midden, which was applied to both the kaleyard and the rig land, but that the kaleyard was manured with midden material every year, whereas the rigged land was manured every two years. The fields closer to the farmsteads were used for barley and were fertilised more intensively than the outer fields (Fenton, pers. comm.), which may mean that they were fertilised every year. The planticrues were lightly manured, and the grazing land was untreated. Peterson stated that seaweed was added to the rig land on occasion and was also composted in the middens for application to both kaleyard and rig land.

## 5.2 Results

### 5.2.1 Field Observations

A complete description of the soil profiles is located in Appendix 1, but a brief description is included here. The Kaleyard soils were between 44 and 70 cm deep, with topsoil (A horizon) depths between 26 and 48 cm. In Test Pit Kaleyard 4 (K4) the 48 cm topsoil overlay a subsoil (B horizon) with translocated humus, iron and/or aluminium (Fig. 5.3). The A and Bh horizons overlay a dense, compact horizon (Bx) which overlay the drift.

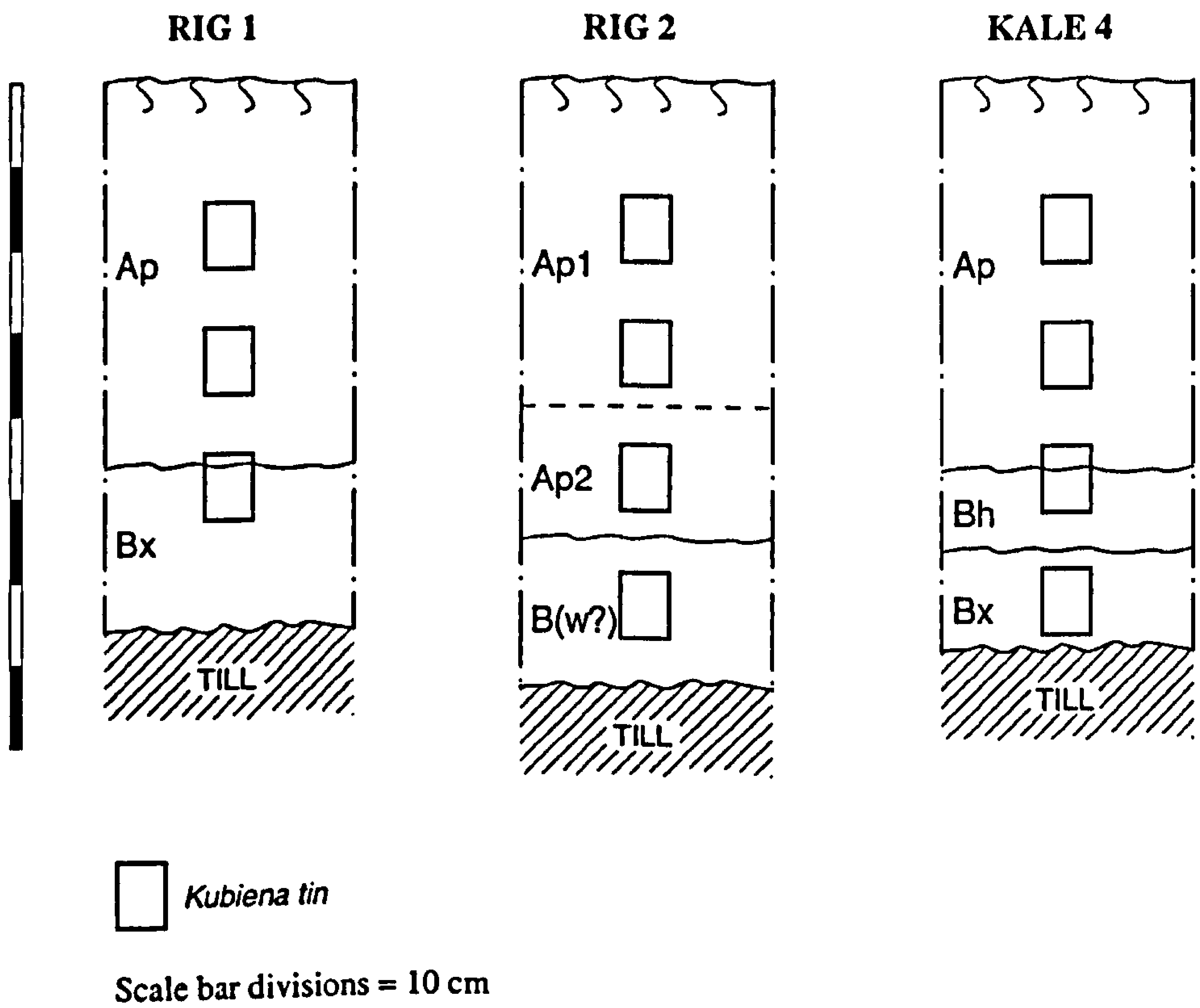



Figure 5.3: Soil Profiles

The Rig soils were between 34 and 74 cm deep, with topsoil depths between 18 and 56 cm. Two distinct horizons were distinguished in the topsoil of the deepest profile, in

Test Pit 2 (R2). The A horizons overlay a Bx horizon in Pits 1, 3 and 4; in Test Pit 2 the A horizon overlay a possible Bw horizon, i.e. one which showed evidence for weathering or leaching under aerated conditions. The Rig profiles overlay drift material.

The Planticrue soils were between 24 and 30 cm deep. The topsoil was between 16 and 20 cm in depth and overlay A/C horizons, i.e. dark subsurface horizons without the illuvial or alteration characteristics of a B horizon.

The Grazing area soils were between 25 and 42 cm deep. The topsoils were between 16 and 29 cm deep and overlay Bx (compacted), BC (in early stages of weathering, but past the earliest C horizon stage) and AC ( dark subsoil) horizons.

### 5.2.2 Reference material

*Soil Micromorphology*

Reference samples were taken from a range of different materials which were known through historical and ethnographic sources to have been added to the soils. The distinctive characteristics of these materials were as follows:

- The dried, unburned peat had a dark red colour in thin section and had a distinctive, fibrous texture (Plate 4).
- The sample from the byre floor was made up of *c.* 5% red fibrous material identical the unburned peat sample (Plate 5). This is in accordance with the historical and

Plate 4: Peat from South Mainland, Shetland (Magnification x 40, PPL)

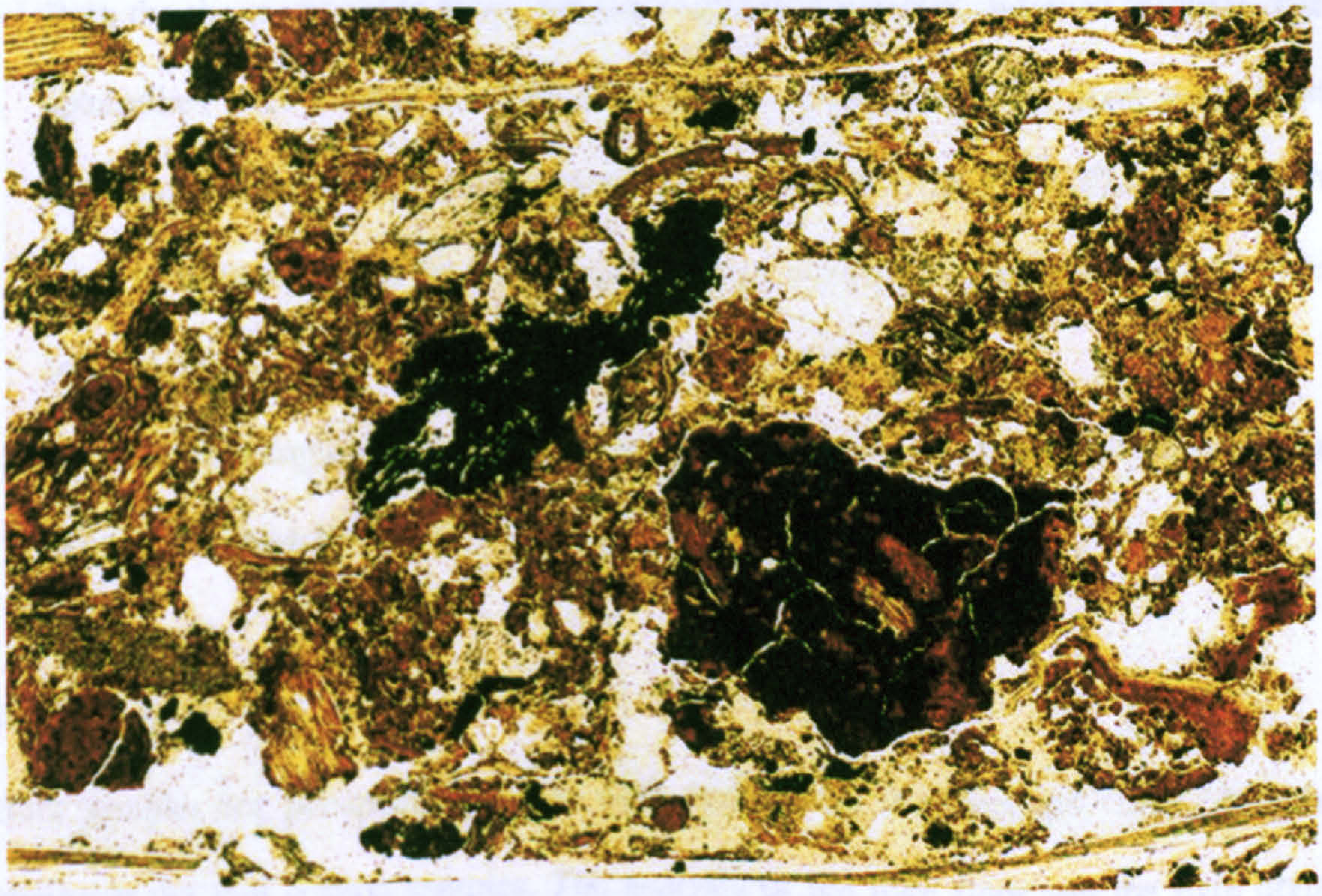


Plate 5: Peat in the byre floor, Corrigall Farm Museum (Magnification x 25, PPL)

ethnographic information which states that peat and turf from the rough grazing areas was used to line the cattle byres. 5-10% of the fabric was organic material either from dung or bedding.

- The peat and coal ash samples were bright red and orange under OIL. The Munsell colours of the reference ash under OIL were yellow (Plate 6), reddish yellow and light red, with a value/chroma of 7/8 and higher, but some of the material was a bright orange which was beyond the scale of the chart (Plate 7). The charred peat fragments contained mineral grains and the larger fragments had a pedological void structure (Plate 8), unlike the cellular structure of wood charcoal. Charred coal fragments were also distinctive, having a uniform black colour and circular, smooth walled voids.
- Both the sheep and cattle dung contained calcitic spherulites and plant material. The spherulites were evident at x500 magnification under XPL. The plant material in the dung contained large numbers of well preserved phytoliths (Plate 9), which were identified as such by their shape and (to distinguish them from micas) their isotropism.
- The control samples from the rough grazing area on Papa Stour contained diatoms (Plate 10), which live in water or on wet ground.

*Phosphates*

Bulk samples for phosphate analysis were taken from the Shetland Croft Museum alongside the thin section samples. The analysis of the byre floor and the byre drain

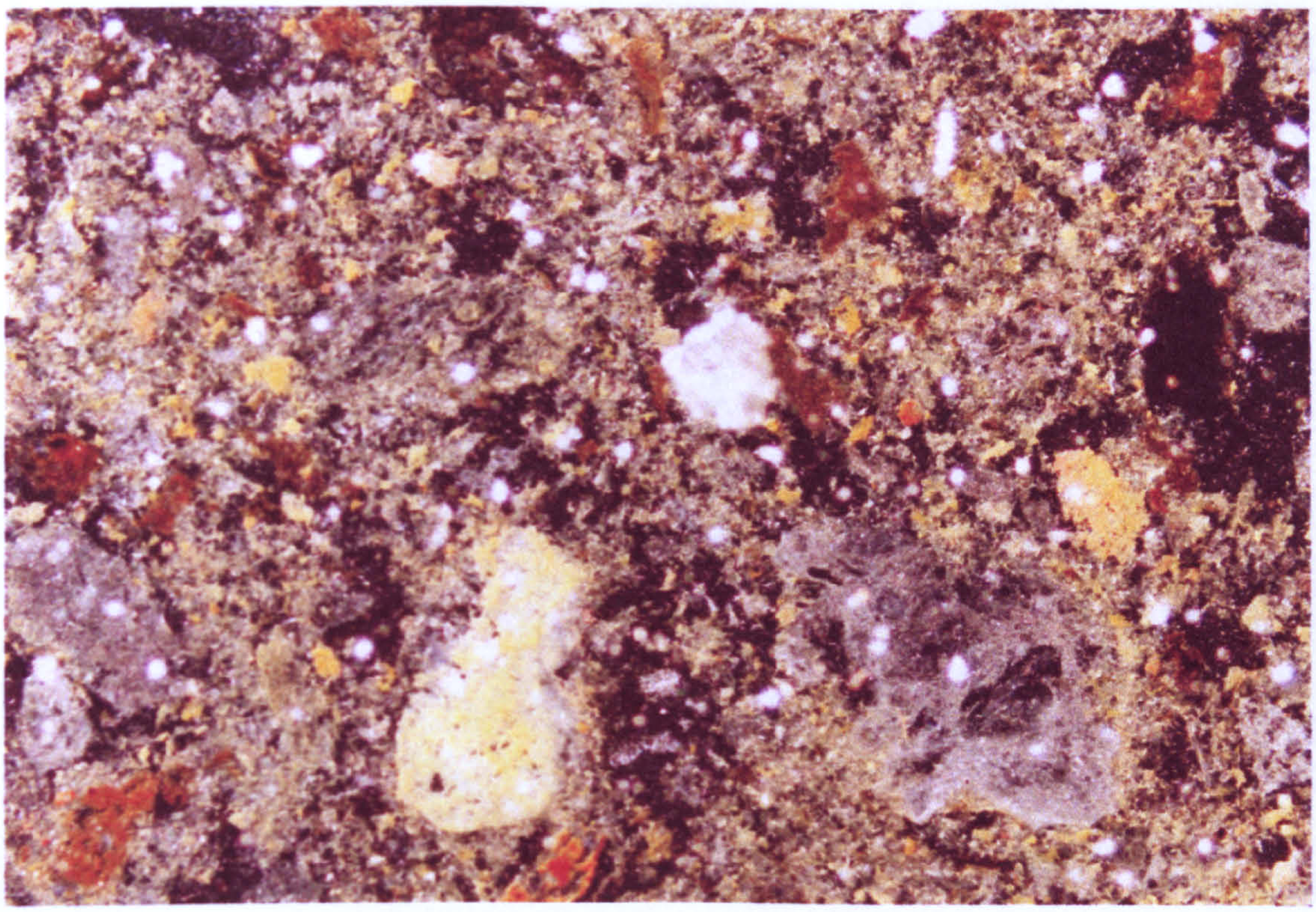


Plate 6: Peat ash, Corrigall Farm Museum (Magnification x 40, OIL)

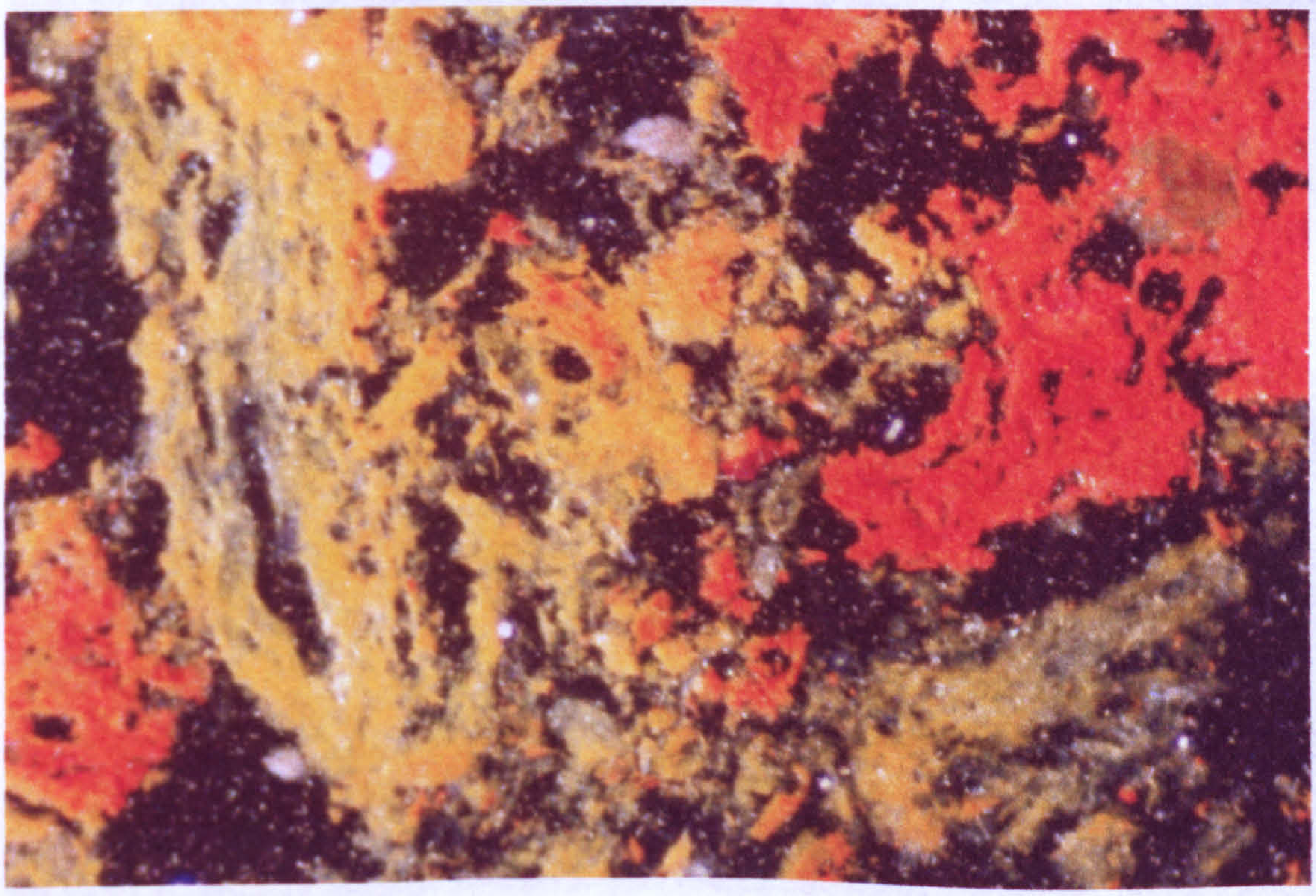


Plate 7: Peat ash, Papa Stour (Magnification x 50, OIL)

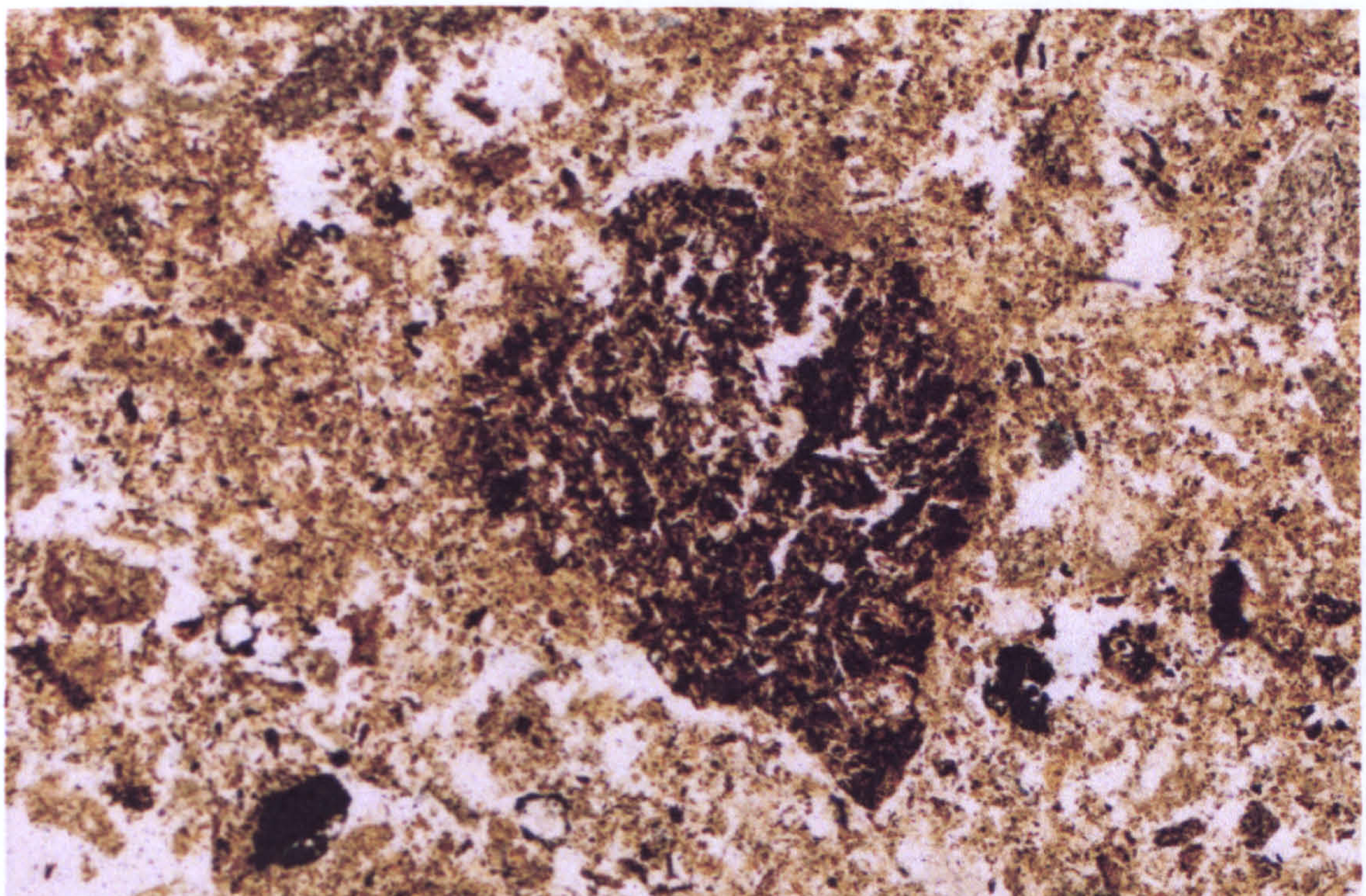


Plate 8: Charred peat fragment, Corrigall Farm Museum (Magnification x 25, PPL)

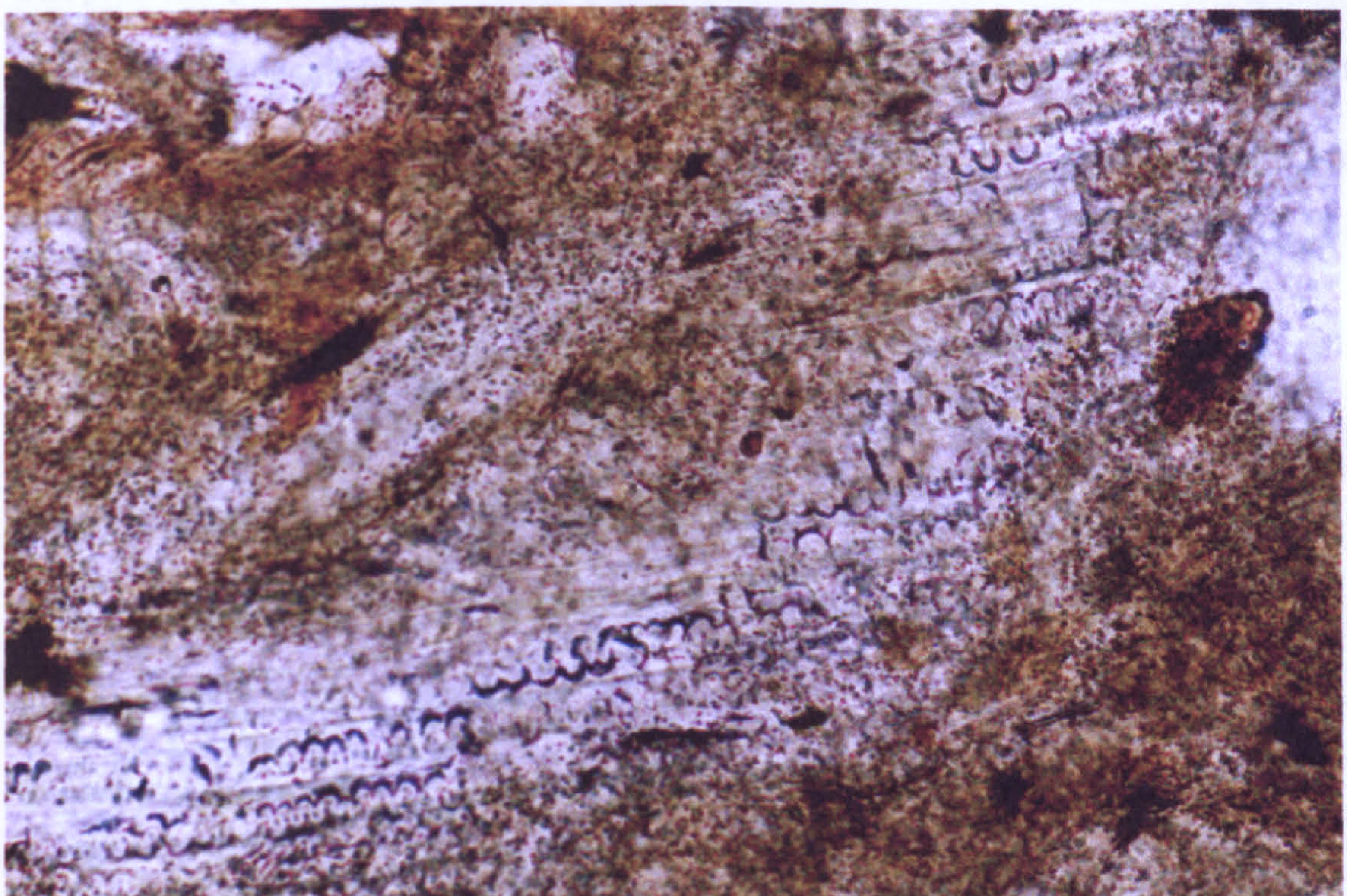


Plate 9: Phytoliths in sheep dung (Magnification x 400, PPL)

established P ratios of 1.04 and 1.12, i.e. the total phosphates were 96.55% and 89.22% inorganic P. The total P levels were extremely high, at 1172 and 1046 mgP/100g soil.

### 5.2.3 Soil Micromorphology

*Results*

The thin section descriptions of the Bragasetter slides are summarised in Table 5.1; for detailed descriptions and interpretations see Appendix 1. Descriptions follow Bullock et al (1985).

Diatoms were found in all areas and at all depths (Plate 11). Charred peat was present in all areas apart from the grazing area, forming up to 10% of the soil fabric in the kaleyard test pit 4, at a depth of 30 cm (K4.30). The material was black and reflective in oblique incident light (OIL) and usually contained mineral grains. Coal fragments were found in the uppermost (15cm) sample in K4 and Rig 2. Fibrous red material occurred in all contexts apart from the grazing sample, and was particularly frequent in the kaleyard samples where it formed up to 15% of the soil fabric (at the base of the topsoil, K4.45). Fungal spores were found in all of the areas at all depths, excepting K4.60; in some samples fungal spores were found within the fragments of unburned peat (Plate 12). Bone fragments occurred throughout the soil profile of Rig 2, where they formed up to 2% of the sample, but were absent from Rigs 1 and 4. Very rare bone fragments were found in K4.15 and K4.30.

Table 5.1: Thin section analysis

| Section And horizon | Depth | Birefringence (low, M, H) | Fine Fabric (PPL) | OIL | Charcoal (peat/turf) | Charcoal (woody) | Coal | Red-brown fibrous material | Bone | Phytoliths | Diatoms | Fungal spores | Textural (silt) | Textural (clay coatings) | Fe accumulations | Excremental (porous) | Depletion (Fe) | Amorphous organo-mineral | Organo-mineral nodules | Microstructure | Related Distribution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R1 (A) | 15 | L | Dark reddish brown and pale brown | Reddish brown | +++ | | | ++ | | + | | + | | + | | ++ | | | | Channel & chamber, weakly developed aggregates | Close porphyric |
| R1 (A) | 30 | L | Dark reddish brown | Reddish brown | +++ | | | + | | + | + | + | | + | | +++ | + | | | Channel & chamber, weakly developed aggregates | Close porphyric |
| R1 (Bx) | 45 | L | Multiple fabrics. | Yellow-brown, orange brown, reddish brown | ++ | | | + | | + | + | + | + | + | + | +++ | | +++ | + | Channel and chamber | Porphyric |
| R2 (A) | 15 | L | Reddish brown | Yellowish red | +++ | ++ | + | ++ | + | + | + | + | | + | | • | | | | Spongy, w/ micro-aggregates. Poorly developed blocky. | Close porphyric |
| R2 (A) | 30 | L | Dark red | Reddish brown | +++ | | | ++ | ++ | | | + | | + | + | +++ | | | | Sub-angular blocky, with channels and chambers | Close porphyric |
| R2 (Ap2) | 45 | L | Reddish brown-yellowish-red | Reddish brown | +++ | + | | + | ++ | ? | + | + | + | + | | • | + | | | Crumb/ sub-angular blocky | Close porphyric |
| R2 B(w?) | 60 | M | Reddish yellow and dark brown; multiple fabrics | Reddish yellow and yellowish red | + | + | | + | + | + | ? | + | ++ | + | + | +++ | + | | | Channel and chamber | Close porphyric |

KEY: + Very Rare (<0.5%), ++ Rare (0.05-2%), +++Very Few (2-5%), • Few (5-15%), •• Frequent (15-30%), ••• Common (30-50%), •••• Dominant/Very Dominant

Table 5.1: Thin section analysis

| Section And horizon | Depth | Birefringence (low, M, H) | Fine Fabric (PPL) | OIL | Charcoal (peat/turf) | Charcoal (woody) | Coal | Red-brown fibrous material | Bone | Phytoliths | Diatoms | Fungal spores | Textural (silt) | Textural (clay coatings) | Fe accumulations | Excremental (porous) | Depletion (Fe) | Amorphous organo-mineral | Organo-mineral nodules | Microstructure | Related Distribution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R4 (A) | 15 | L | Yellowish red and red-brown | Yellowish red | + | | | ++ | | + | | + | | + | | +++ | + | | | Channel & chamber, poorly developed sub-angular blocky | Porphyric |
| K3 (A) | 15 | L | Dark red | Reddish brown | +++ | | | + | | ++ | | + | | | | + | | +++ | | Angular blocky | Porphyric |
| K4 (A) | 15 | L | Red | Reddish brown | +++ | + | + | +++ | + | + | + | | | + | + | • | + | | | Crumb, w/ slight sub-angular blockiness at base | Close porphyric |
| K4 (A) | 30 | L | Reddish brown | Reddish brown | • | + | | +++ | + | + | + | + | | + | | +++ | | | | Poorly developed sub-angular blocky | Porphyric |
| K4 A(3cm) (Bh) | 45 | L | Reddish yellow and yellowish red | Reddish brown | +++ | | | • | | ++ | + | + | | + | | +++ | | | | Poorly developed sub-angular blocky | Porphyric |
| K4 (Bx) | 60 | H | Yellowish red | Yellowish red | + | | | •? | | | | | | ++ | •? | | | | | Channel & chamber with cracks | Close porphyric |
| G1 (Ah) | 15 | L | Red | Reddish brown | | | | | | + | | ++ | | | | •• •• | | | | Intergrain microaggregate | Enaulic |
| P1 Ap/AC | 15 | L | Reddish-brown, yellowish red | Yellowish red | +++ | | | ++ | | + | + | + | | + | | •• | + | ++ | ++ | Crumb/sub-angular blocky | Porphyric |
| P2 Ap/AC | 15 | L | Reddish brown, yellowish red | Yellowish red | ++ | | | ++ | | ++ | | + | + | + | + | ++ | | ++ | | Angular blocky with chambers | Porphyric |

KEY: + Very Rare (<0.5%), ++ Rare (0.05-2%), +++Very Few (2-5%), • Few (5-15%), •• Frequent (15-30%), ••• Common (30-50%), •••• Dominant/Very Dominant

Plate 10: Diatom from Control Sample 1, Papa Stour (Magnification x 500, PPL)

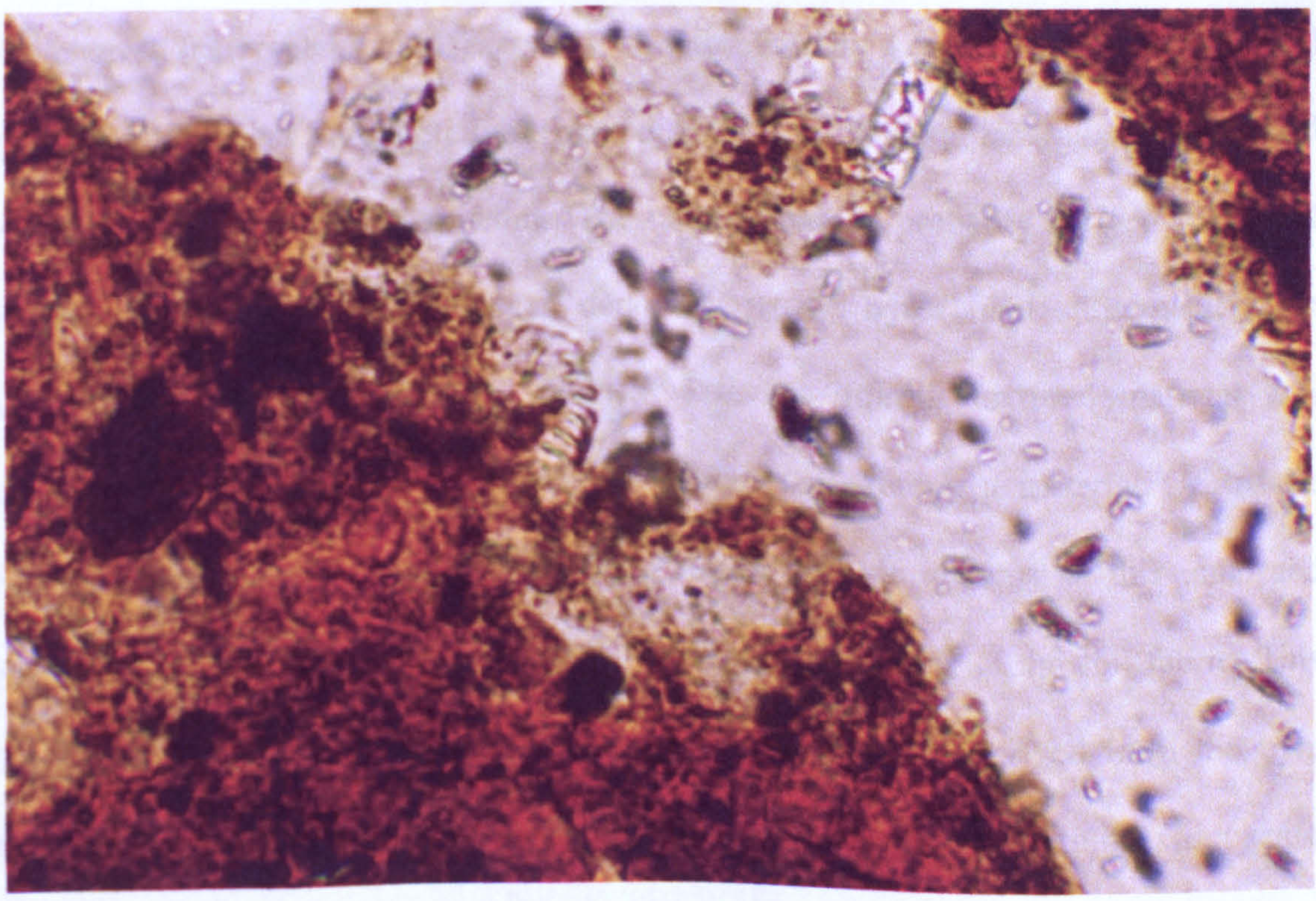


Plate 11: Diatom in peat fragment, Bragasetter kaleyard (Magnification x 500, PPL)

The movement of iron in the soil was evident in the rig, kaleyard and planticrue samples, both as accumulations (segregations and hypocoatings) and depletions (bleached stone rims). Thin clay coatings occurred on mineral grains in all of the samples apart from the grazing area. In R2.60 clay coatings occurred in voids, both before and after the silt accumulation. Silt pedofeatures were evident as void linings (Plate 13), mineral grain coatings and aggregate cappings at depths of 45 and 60 cm in the rig samples and at 15 cm in one of the planticrues. The birefringence of the fine fabric was low apart from in the two 60 cm samples. Porous excremental aggregates were present in all slides apart from K4.60, where organo-mineral nodules gave a crumb structure to the soil.

*Interpretation*

The charred (carbonised) peat fragments, characterised by a crack void pattern, mineral grain inclusions and irregular edges, were distinct from the angular fragments of wood charcoal with their cellular structure. The charred peat is probably derived from fuel ash, which is known to have been deposited in the byres (and subsequently the midden), the planticrues and the midden. The red, fibrous textured material was identical to the unburned peat fragments identified in the reference material. One of the most striking features in the thin section analysis was the quantity of this unburned peat, especially in the kaleyard where it comprised up to 15% of the soil fabric. This material was distinct from the carbonised peat and probably derived from the byre bedding; it might be considered as an indicator for plaggen manuring in the strict sense (i.e. using peat/turf as animal bedding before use as fertiliser). Fungal spores were

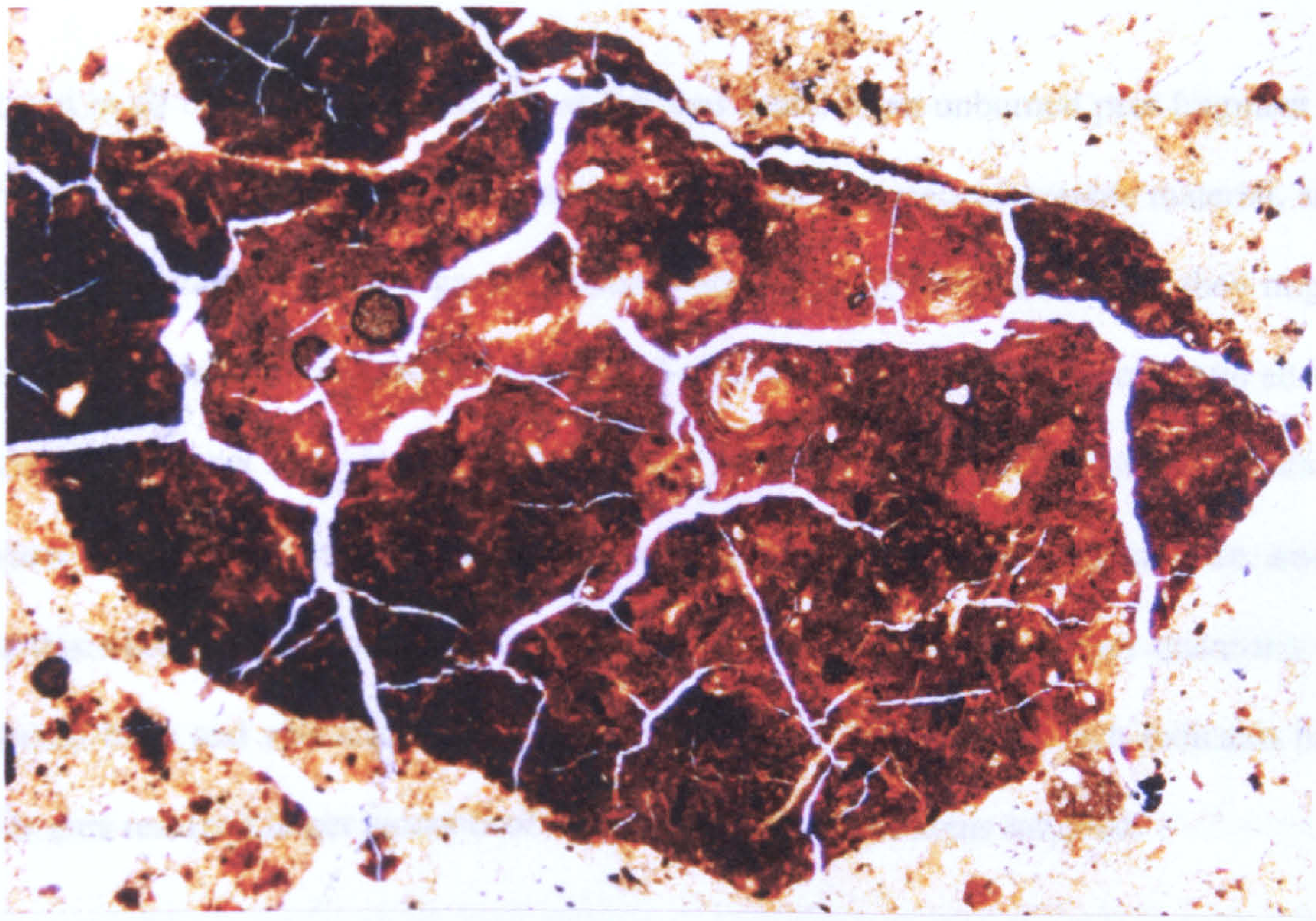


Plate 12: Peat with fungal sclerotia (dark rimmed circular features, near top left) (Magnification x 40 PPL)

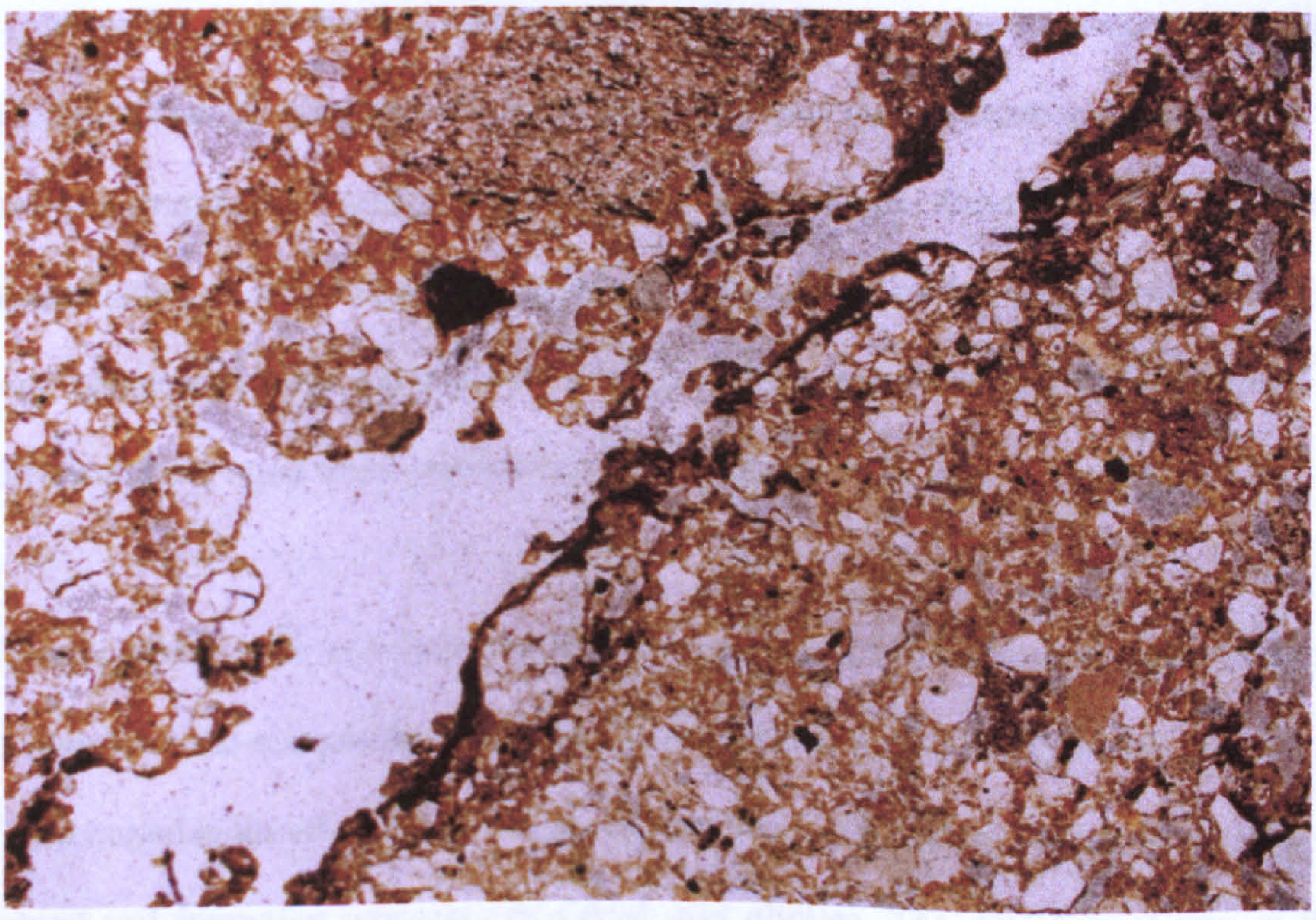


Plate 13: Silt lining in void, Rig 1 at 45 cm depth (Magnification x 20, PPL)

found in all of the different areas, and one was found in an unburned peat fragment in Rig 2, 45 cm depth (R2.45). Fungi are important decomposers of organic material, and the sclerotia are found in organic horizons and in peat (FitzPatrick 1993); they might therefore be taken as indicators for manured agricultural topsoils or for soils with added peat. The animal bone found in the rigs and kaleyard probably derived from kitchen waste which was dumped in the midden and subsequently used to fertilise these areas, as described by Peterson (pers. comm.). Rig 2 contained slightly larger quantities of animal bone and was also the deepest test pit in the arable land, which indicates that this area received larger amounts of manure than the others areas sampled.

The birefringence of the fabric was low in most of the samples, apart from those at 60 cm in Kaleyard Pit 4 (the Bx horizon) and Rig 2 (the Bw horizon). High birefringence, i.e. anistrophism of the fine fabric, is generally due to a high clay content or a high calcium carbonate fraction. Although both clays and calcium carbonate are prone to leaching from surface horizons and accumulating at depth, there was not any notable accumulation of either material apart from this higher birefringence. The Bx (i.e. the very compact sub-surface horizon) in Rig 1 was characterised by the number of different fabric types and in particular the accumulation of iron.

There is evidence for both depletion and accumulation of iron in the soil. The leaching of iron down the soil profile is an effect of weathering, and is mainly linked to rainfall. The accumulations of iron as nodules, segregations and hypocoatings is the result of natural soil formation processes in a cool, wet climate. The depletion of iron in the mineral grains is evident as a bleached area around the rim, and is an indication of acidification, i.e. fairly advanced weathering (Romans 1986). The very rare, very thin clay coatings on the mineral grains could have formed by several processes. Clay is mobilised in the soil in wet, acid conditions and the coatings therefore could have formed in the acid, peaty conditions to the west of the head dyke and could have subsequently been transported within the turves used for animal bedding. Clay is also mobilised by disturbance to the soil, and the coatings could have developed due to cultivation. If clay were moving down the soil profile it would also form linings in the soil voids, and the lack of clay coatings in the voids suggests that this was probably not the formation process, unless such features developed and were reworked. Clay infills would probably have formed below the active ploughzone, but slaking can be countered by a large earthworm population (Limbrey 1975).

The soils at Bragasetter have fabric and structural characteristics which indicate high levels of biological activity. Rounded and mammilated aggregates are interpreted as porous and very porous excrement; this material becomes compacted over time, eventually forming a dense excremental fabric in which only a few small vughs remain. Eventually the aggregates become so compacted that the excremental origin of the fabric is only evident around the edges of the voids, where the mammilated and rounded edges of the aggregates are still evident. All of these forms are evident in the slides. The crumb structure and the presence of channels and chambers are also indicative of earthworm activity; the subangular blocky structure of some of the soils is indicative of subsequent wetting and drying of the soil.

Coarse textural pedofeatures were identified at depths of 15 cm in Planticrue 2 and at 45 cm in Rig test pits 1 and 2 and 60 cm in Rig 2. The material was a coarse brown silt which formed cappings on aggregates and filled or lined some of the voids. The material was very rare (<0.05%), apart from R2.60, where it formed 0.05-2% of the slide. Whereas fine clay can be mobilised under natural conditions, such coarse, silty material would have been mobilised by disturbance such as cultivation (Jongerius 1970; Macphail et al 1987). The survival of the features is attributed to the aggradation of the ploughsoil, which would have raised the level of the active ploughzone over the years. The coarse textural pedofeatures are interpreted therefore as the result of later ploughing, which caused slaking of the material down into the voids of the earlier ploughzone. The silt pedofeatures cannot be dated and may have formed after the site was last cultivated, but the fact that the land was subsequently used as pasture suggests that the features relate to agricultural disturbance. Also of interest is the chronology of the clay coatings, which occur both before and after the silt pedofeatures, indicating that minor disturbance continued after the major episode which caused the silt translocation.

### 5.2.4 Phosphates

*Results*

Figure 5.4 shows the range of phosphorus values at a depth of 15 cm ('N=' shows the number of samples processed). The rig values show too much variation to consider as one group, and therefore the outlier, Rig 2, is considered separately. Figure 5.5 shows

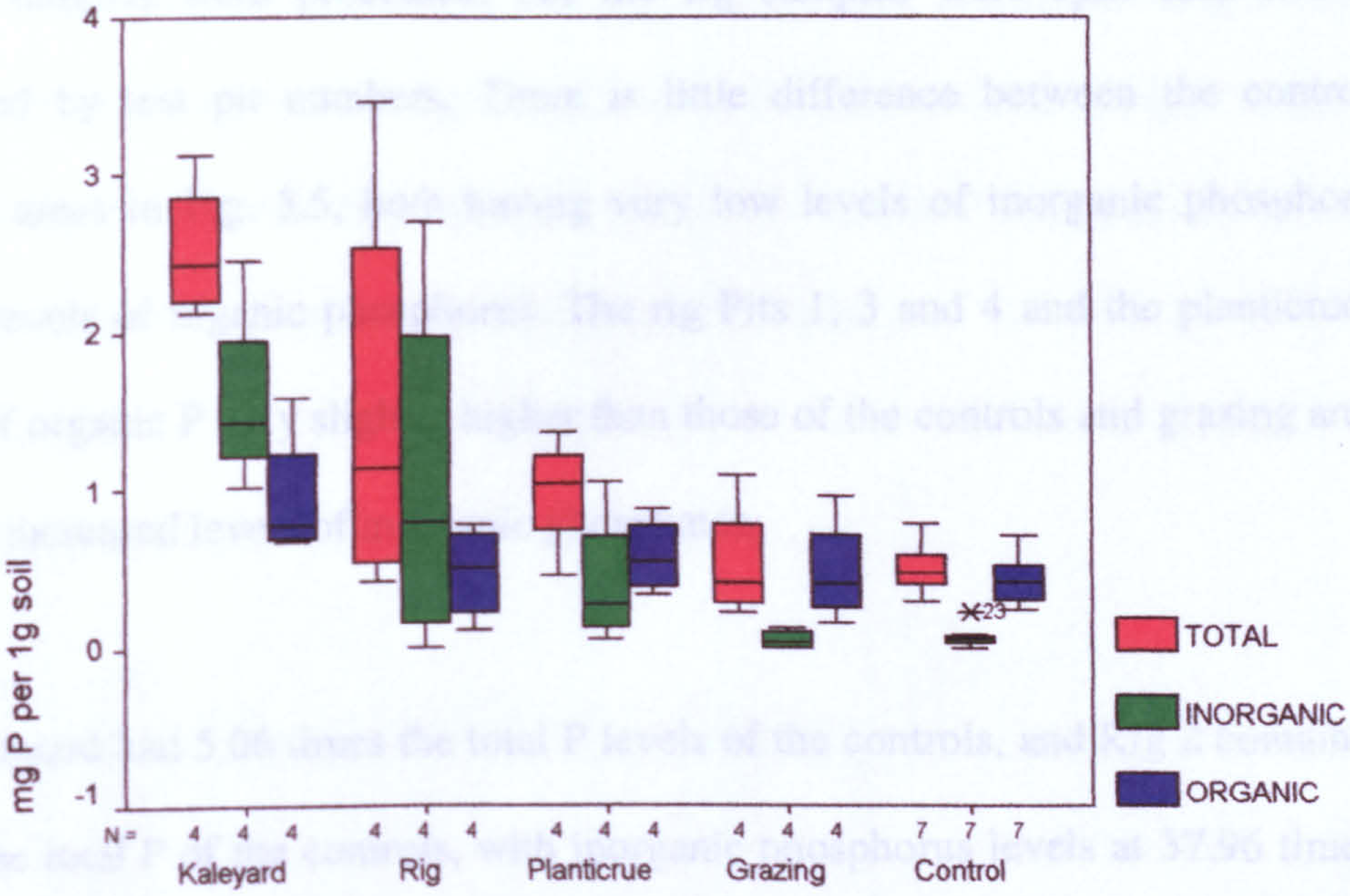



Figure 5.4: Range of phosphorus values at 15 cm

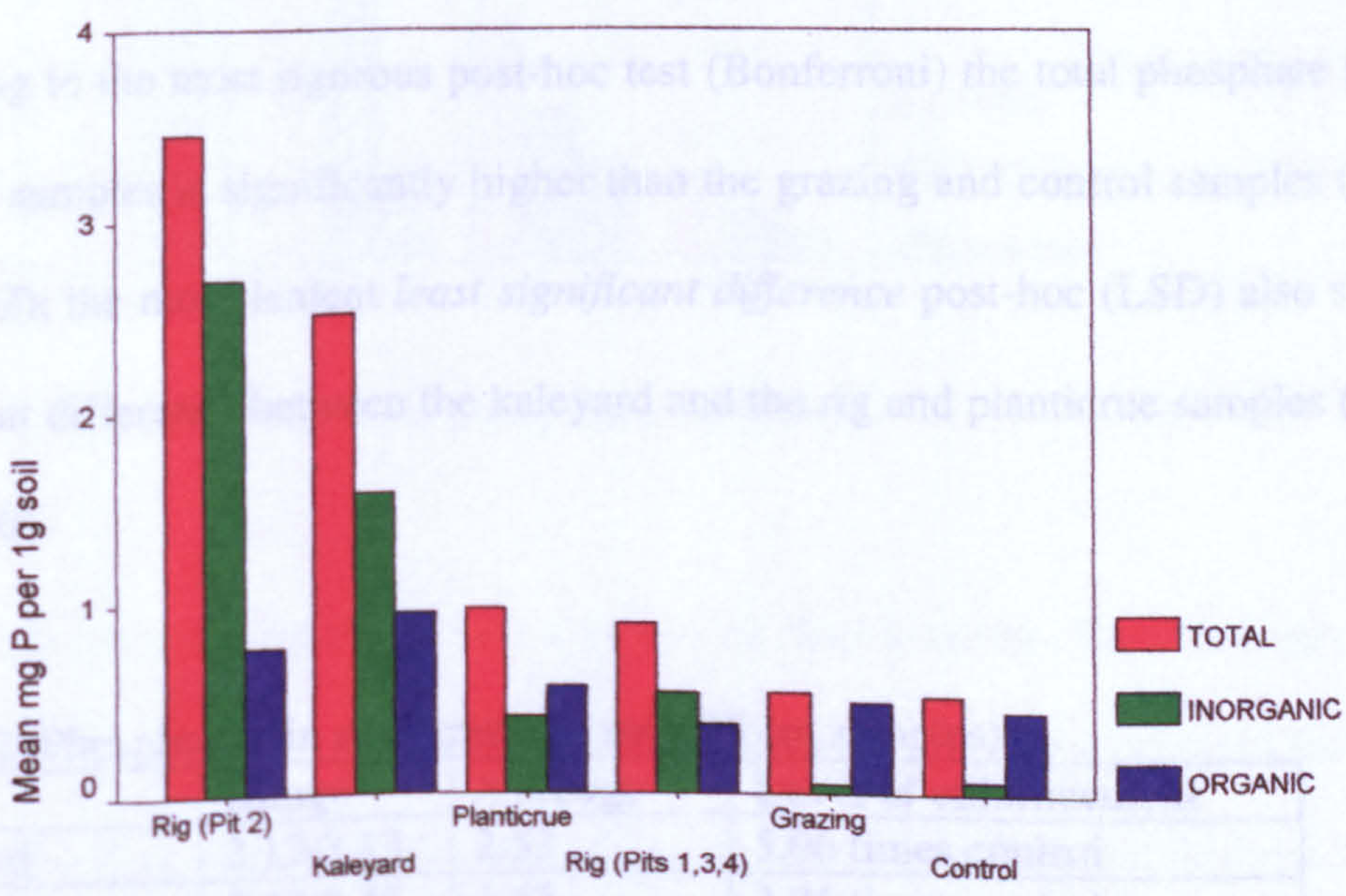



Figure 5.5: Phosphorus at 15 cm

the mean levels of phosphorus in the different functional areas and the controls; no further samples were processed, but the rig samples were split into two groups identified by test pit numbers. There is little difference between the controls and grazing areas in Fig. 5.5, both having very low levels of inorganic phosphorus and higher levels of organic phosphorus. The rig Pits 1, 3 and 4 and the planticrues have levels of organic P only slightly higher than those of the controls and grazing areas, but contain increased levels of inorganic phosphates.

The kaleyard had 5.06 times the total P levels of the controls, and Rig 2 contained 3.06 times the total P of the controls, with inorganic phosphorus levels at 37.96 times those of the controls (Table 5.2). The inorganic fractions in the rig and kaleyard samples are greater than the organic fraction, with the highest organic values in the kaleyard. According to the most rigorous post-hoc test (Bonferroni) the total phosphate from the kaleyard samples is significantly higher than the grazing and control samples (p=0.003 and 0.002); the more lenient *least significant difference* post-hoc (LSD) also showed a significant difference between the kaleyard and the rig and planticrue samples (p=0.004 and 0.000).

Table 5.2: Phosphorus, in mg P per g of soil (15 cm samples)

| Area | Range | Average | Level of enhancement |
|---|---|---|---|
| Kaleyard | 2.12-3.13 | 2.53 | 5.06 times control |
| Rig | 0.42-3.46 | 1.53 | 3.06 times control |
| Grazing | 0.22-1.08 | 0.52 | 1.04 times control |
| Planticrue | 0.45-1.36 | 0.97 | 1.94 times control |
| Control | 0.28-0.78 | 0.5 | --- |

The phosphates in the kaleyard show a decline with depth (Fig. 5.6), with the inorganic P fraction consistently higher than the organic fraction. The single sample recovered from 60cm shows a lower total phosphate level than the controls in Fig. 5.5, but all the kaleyard signatures differ from the controls in that organic P dominates in the controls, whereas inorganic P dominates in the kaleyard samples.

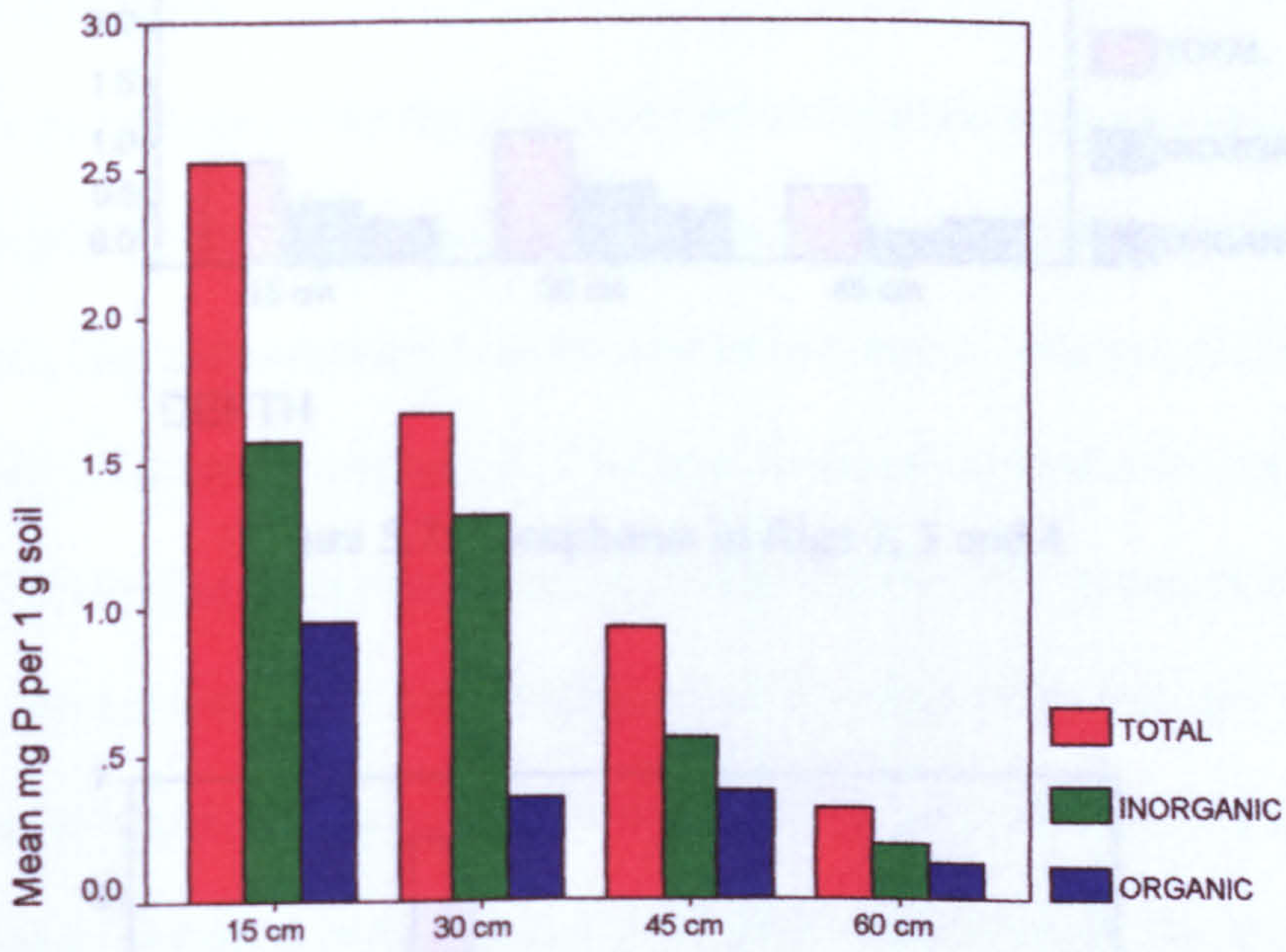



Figure 5.6: Kaleyard phosphates by depth

The phosphates in the rig test pits do not show as clear a pattern. Test Pit 2 was the only pit in which the soil reached a depth of 60 cm; given that this area received the greatest amount of added material, it is not surprising that it also had the highest levels of phosphate. Figs 5.7 and 5.8 show an inconsistent variation with depth and inconsistent organic/inorganic ratios in the rig test pits.

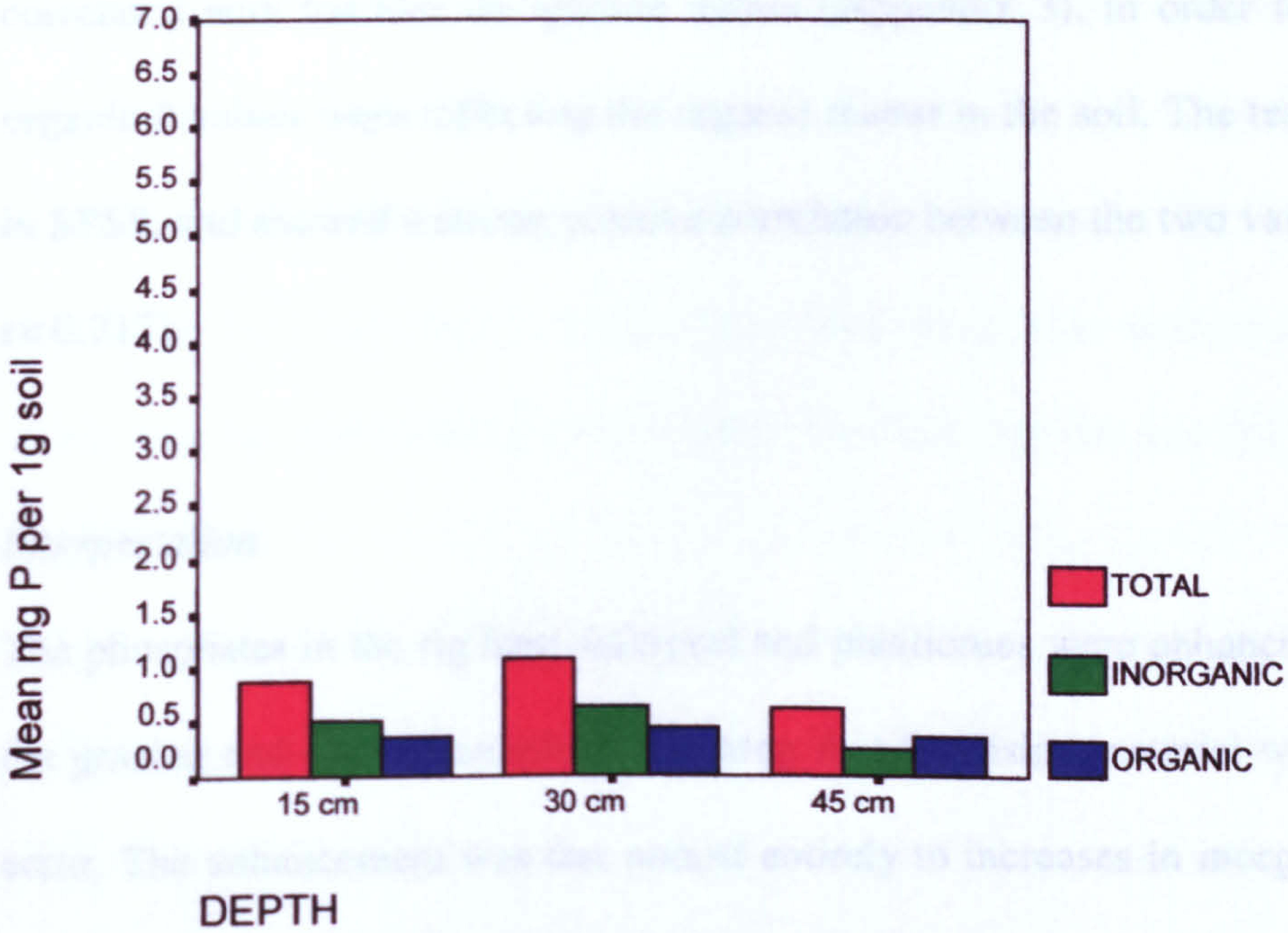



Figure 5.7: Phosphorus in Rigs 1, 3 and 4

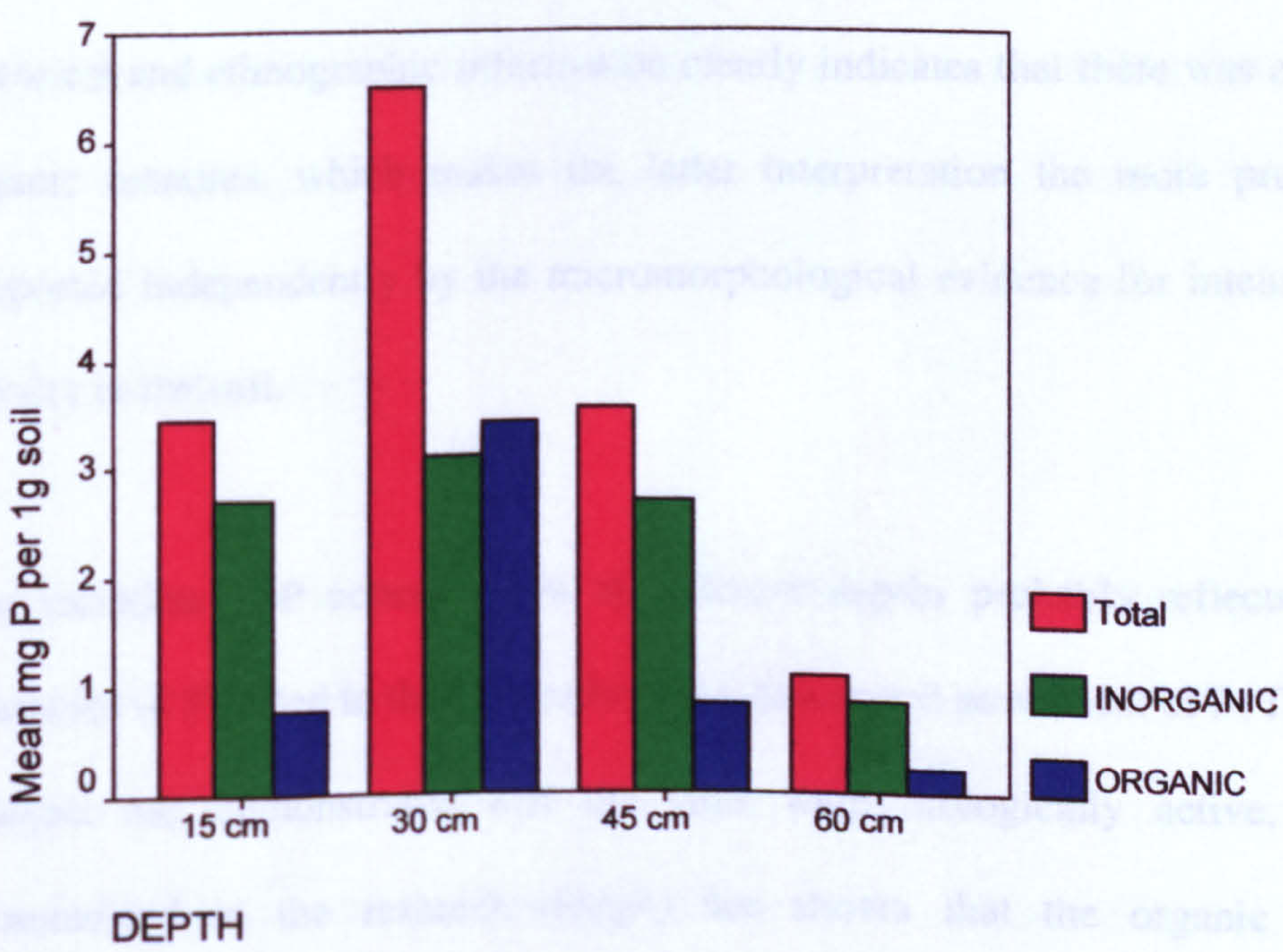



Figure 5.8: Phosphorus in Rig 2

The organic P in the samples from the cultural soils (kaleyard, rig and planticrues) was correlated with the loss on ignition values (Appendix 3), in order to ensure that the organic P values were reflecting the organic matter in the soil. The test was carried out in SPSS, and showed a strong positive correlation between the two variables ($p= 0.000$; $r= 0.717$).

*Interpretation*

The phosphates in the rig land, kaleyard and planticrues were enhanced compared with the grazing and control samples, indicating that fertilising material was added to these areas. The enhancement was due almost entirely to increases in inorganic P, with only slight increases in organic P. The high levels of inorganic P could indicate either that large amounts of ash and bone were added to the soil, or that the bacteria which thrive in organic-rich soils have transformed the organic P into the inorganic form. The historical and ethnographic information clearly indicates that there was a large input of organic manures, which makes the latter interpretation the more probable; this is supported independently by the micromorphological evidence for intensive biological activity in the soil.

The variation in P concentration at different depths probably reflects the differing quantities of P added to the soil, rather than downward movement of P. The thin section analysis has demonstrated that the soils were biologically active, and research (summarised in the research design) has shown that the organic P fraction is transformed into the inorganic form very rapidly in biologically active arable soils

(Sharpley and Smith 1983). Once the phosphates have taken the inorganic form (i.e. once they have bonded to Al, Fe or Ca) they are fairly immobile and are translocated only when a change in pH breaks this bond. The micromorphology showed low levels of iron translocation but accumulations were very rare, apart from K4 at a depth of 60 cm, which had very low P levels. There may have been some movement of the P which was bonded with the translocated iron but this did not build up into major concentrations.

The controls contained a high proportion of organic P due to the high organic content of the peaty soils on the western part of the island. The organic P in the controls was not transformed into inorganic P due to the acidity of the soil, which inhibits biological activity (see section 5.2.7, below). The link between organic P and animal manure content in the soil has been only tentatively established, as the high organic P values could represent added peat as well as added animal manure. The link will be tested further when the lipid analysis is complete and can be correlated with the organic P.

### 5.2.5 Soil Magnetism

*Results*

Magnetic materials in the soil can be characterised by composition, concentration and grain size. The tests which have been applied (mass susceptibility, saturation anhysteretic remanent magnetisation [SARM], saturation isothermal remanent magnetisation [SIRM] and frequency dependent susceptibility [*xfd*]) show the concentration and (debatably) the grain size of the magnetic materials. The raw data are in Appendix 4.

The soil magnetism analyses aimed to test the different magnetic methods in order to see which were able to distinguish between the different areas of the farm. It was noted in the research design that the different methods are sensitive to different grain sizes, which are indicators for different types of material. Mass susceptibility measures all grain sizes but is best at picking up the larger grains, and SARM measures the smaller, single domain and pseudo-single domain grains (Dalan and Banerjee 1998). The smallest grains are identified by *xfd* (Peters, pers. comm.).

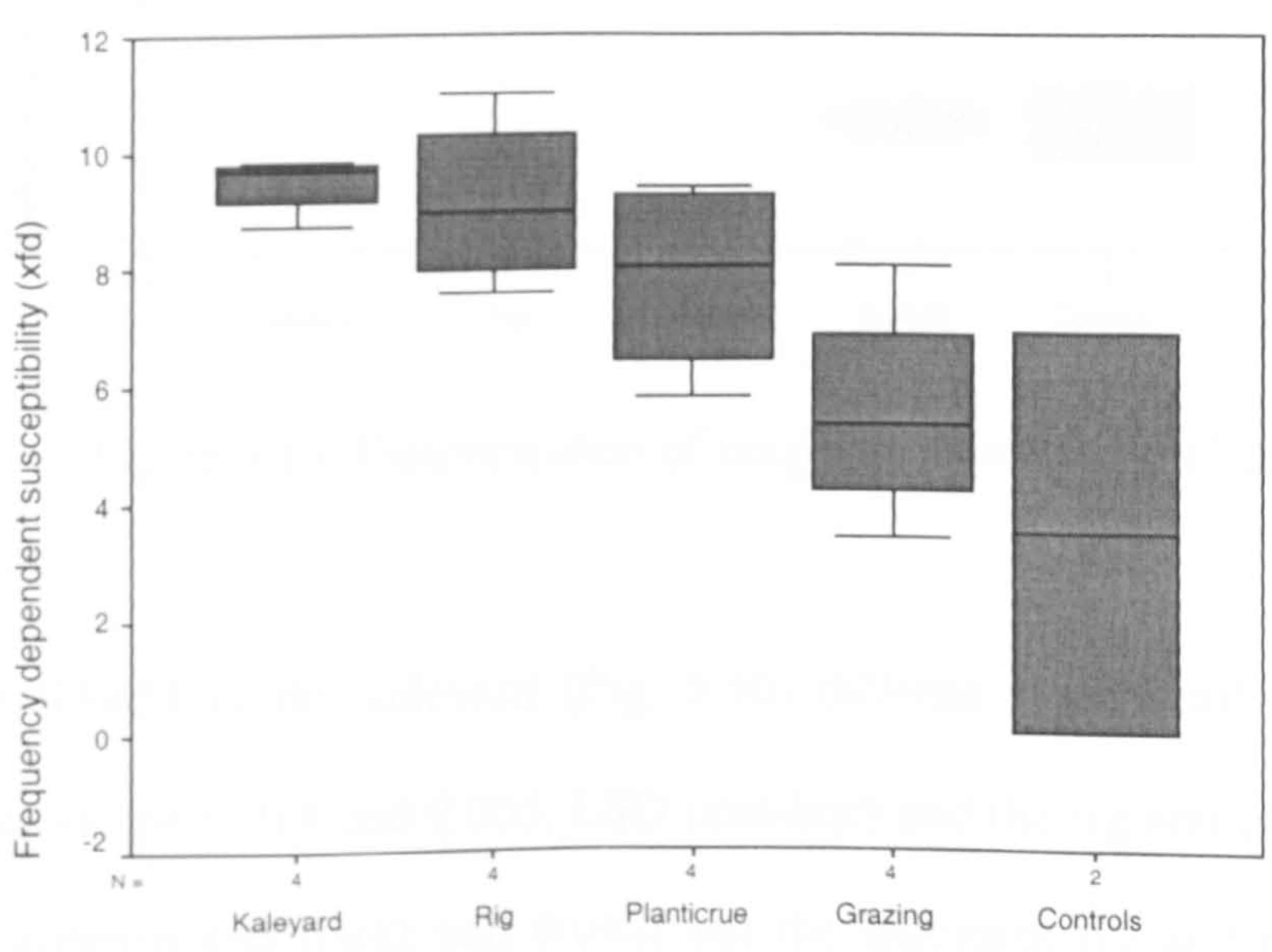



Figure 5.9: Frequency dependent susceptibility at 15 cm

The data produced by each method were entered into SPSS as variables which were then subject to a discriminant analysis in order to show which were most successful in differentiating the areas of the farm. Analyses were done on the 15 cm samples in order to ensure that all were of roughly the same (i.e. the most recent) period. The test showed that the greatest variation between the different areas was due to *xfd* (p=0.016) (Fig. 5.9). An ANOVA on this variable showed that the kaleyard and rig land were significantly different from the grazing and control areas (p= 0.016).

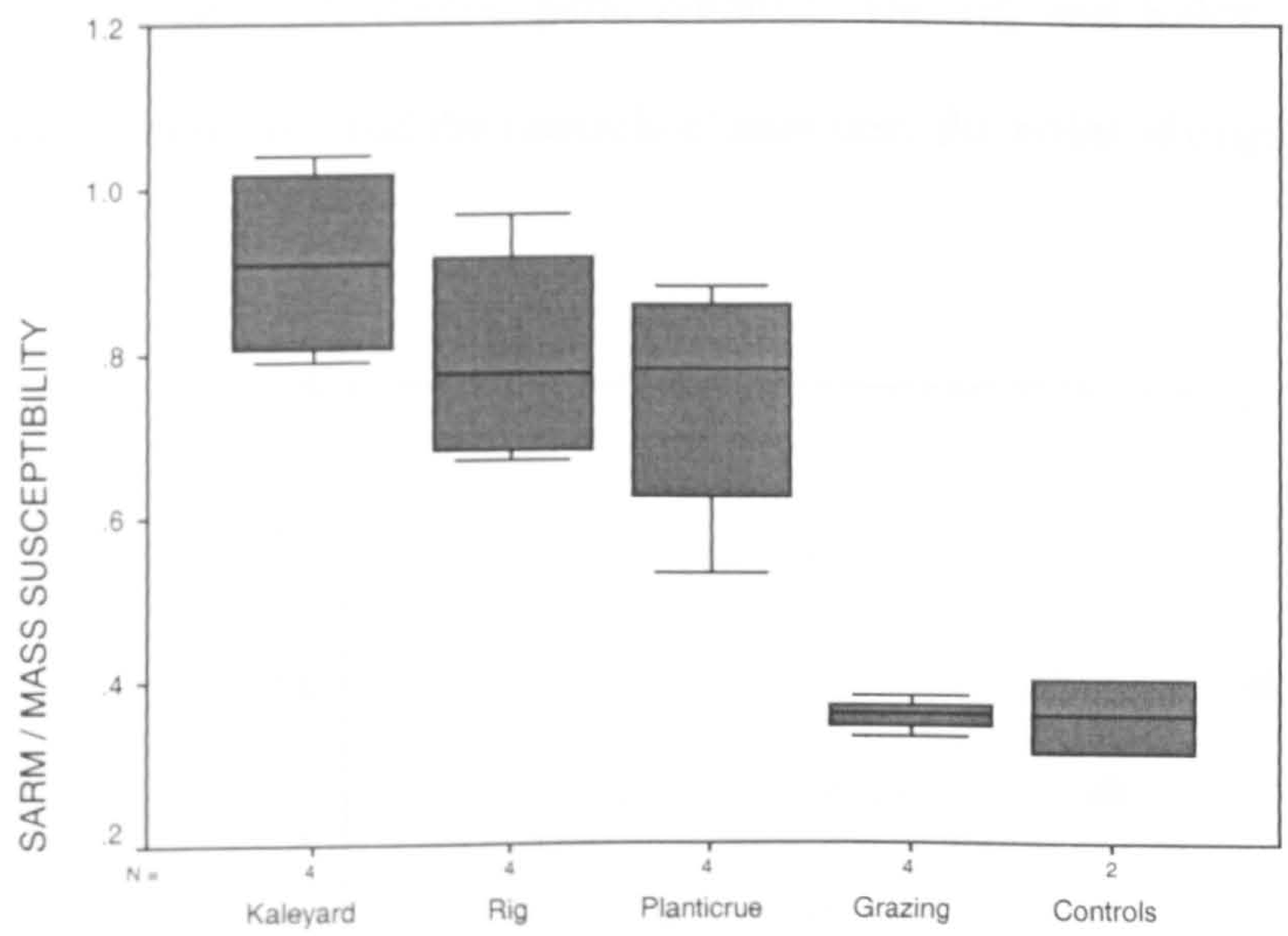



Figure 5.10: Concentration of magnetic materials at 15 cm

The SARM in the kaleyard (Fig. 5.10) differed significantly from the grazing and controls (p= 0.014 and 0.005, LSD post-hoc) and the rig and planticrues differed from the controls (p= 0.041 and 0.042) but the kaleyard, rig and planticrue could not be distinguished from one another, even when the controls and grazing were excluded from the ANOVA (p=0.242). An analysis of variance between the SARM/mass susceptibility in the different areas established that the concentration of magnetic material in the rig, kaleyard and planticrue soils was significantly greater than that of the grazing and control areas (p=0.00). There was no significant variation in the SIRM (p=0.460).

Figure 5.11 shows the concentration of all magnetic materials in the soil as a scatterplot. The lower slope of the grazing and control samples may be an indication of the larger size of magnetic grains in the samples (Dalan and Banerjee 1998), although this is debated (C. Peters, pers. comm.). The rig and kaleyard areas are the most strongly enhanced, and the controls cluster near the point of origin.

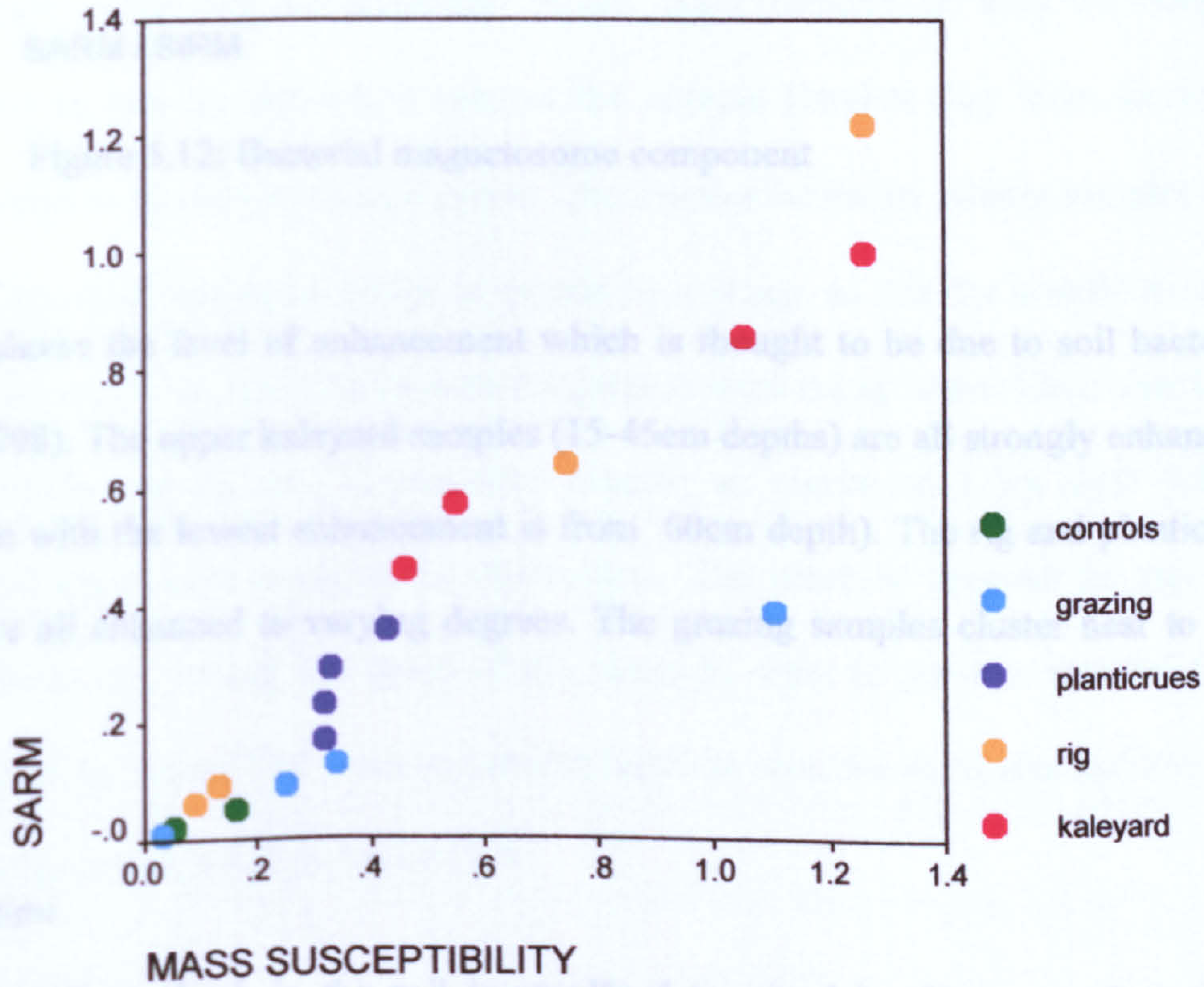



Figure 5.11: Concentration of magnetic materials

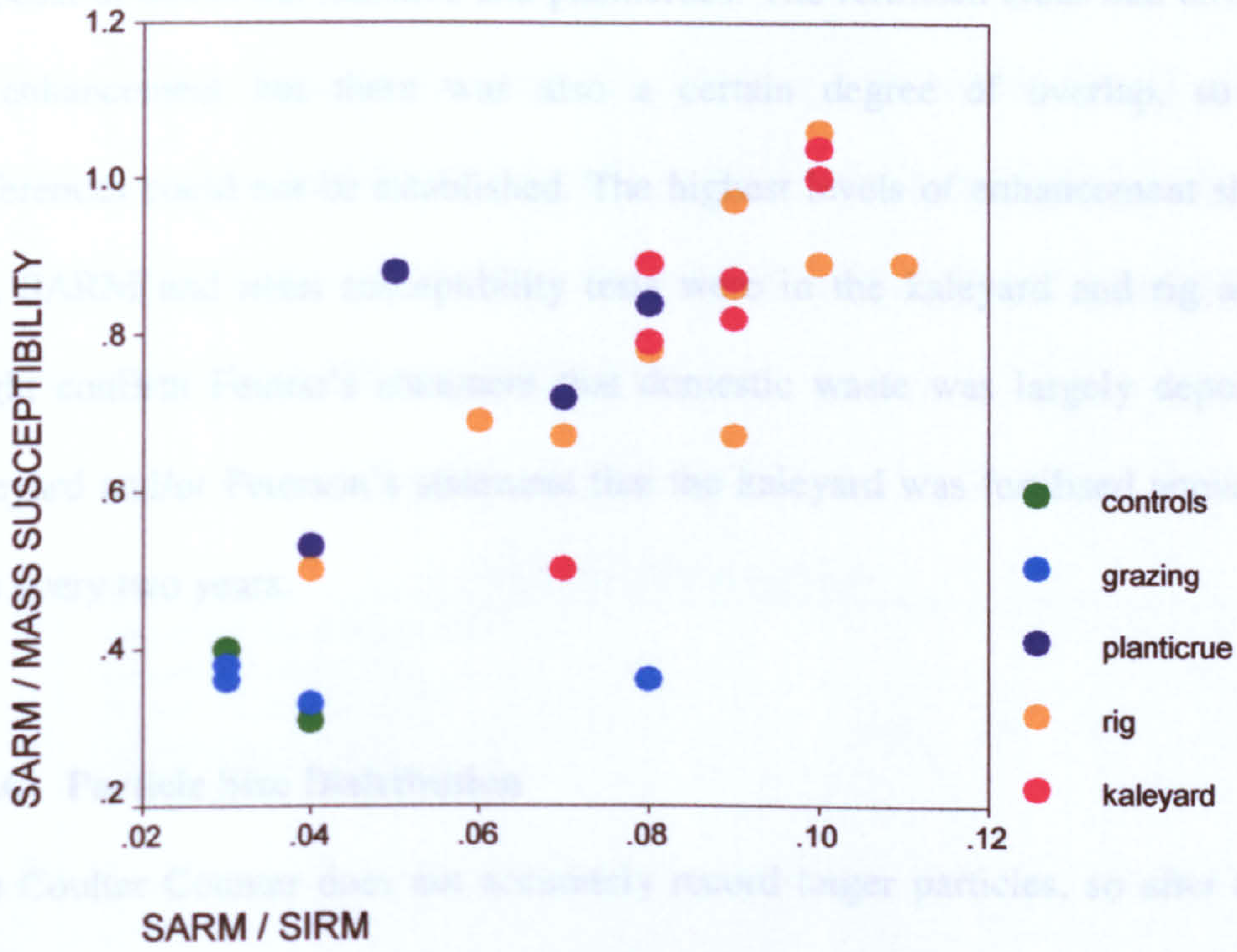



Figure 5.12: Bacterial magnetosome component

Fig. 5.12 shows the level of enhancement which is thought to be due to soil bacteria (Barlow 1998). The upper kaleyard samples (15-45cm depths) are all strongly enhanced (the sample with the lowest enhancement is from 60cm depth). The rig and planticrue samples are all enhanced to varying degrees. The grazing samples cluster near to the controls.

*Interpretation*

The concentration of ash in the soil is usually determined by frequency dependent susceptibility (*xfd*), which quantifies the smallest, superparamagnetic (SP) grains produced by burning. Most of the variation in the samples was due to the *xfd*, i.e. the ash content. This confirms the historical and ethnographic information regarding the disposal of ash in the middens and planticrues. The fertilised areas had differing levels of enhancement but there was also a certain degree of overlap, so significant differences could not be established. The highest levels of enhancement shown in the *xfd*, SARM and mass susceptibility tests were in the kaleyard and rig areas, which might confirm Fenton's statement that domestic waste was largely deposited in the kaleyard and/or Peterson's statement that the kaleyard was fertilised annually and the rigs every two years.

### 5.2.6 Particle Size Distribution

The Coulter Counter does not accurately record larger particles, so after the samples were subject to loss on ignition to remove the organic fraction they were sieved at 500μm to remove the larger mineral grains. The counter works by adding samples to a water tank in which the water is kept in motion by a pump, so that the sample remains in suspension while the machine records the particle sizes using lasers. Each sample is run three times, and the data is presented visually as graphs on a log scale with a standard deviation curve based on the replications. The variation between the samples can be reduced by altering the speed of the pump in order to prevent material from settling out of the water. The mean and median particle size, the skewness and kurtosis of the samples are recorded in Appendix 5.

The particle sizes were fairly homogenous in the cultural soils and were heterogeneous in the control and grazing samples. The kaleyard samples were similar to those of the other areas at 15 and 30 cm, but showed changes in particle size at 45 and 60 cm (Fig.

5.13). At 45 cm the curve was more irregular and more broadly spread, and at 60 cm the curve was more broadly spread and contained finer (coarse silt/fine sand) particles. The remainder of the samples from the cultural soils (kaleyard, planticrues and rig) showed no significant difference (Fig. 5.14).

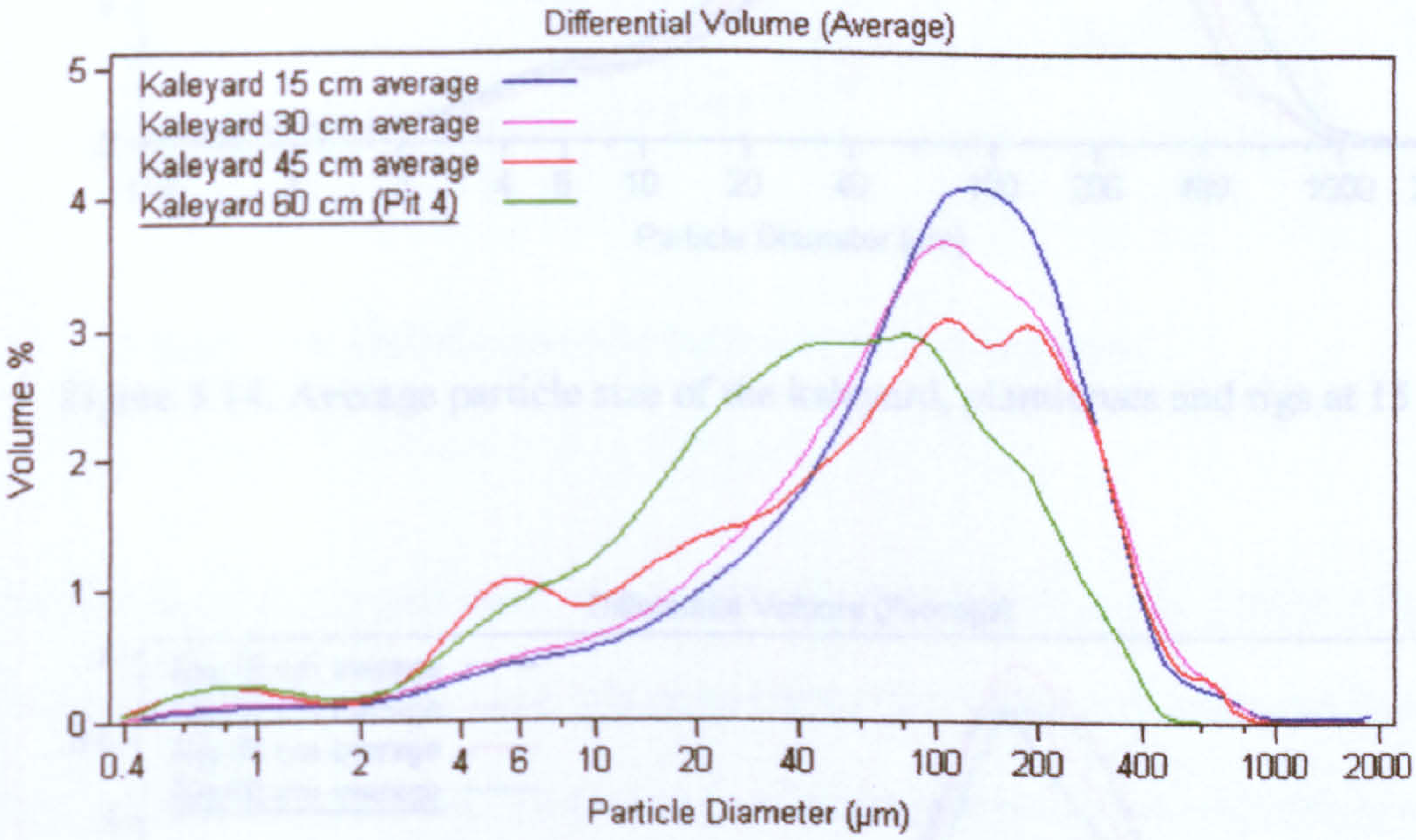



Figure 5.13: Particle size distribution in the kaleyard

The rig samples showed no significant spatial variation or variation with depth (Fig. 5.15), and were also almost identical to the planticrue samples and the upper two kaleyard samples.

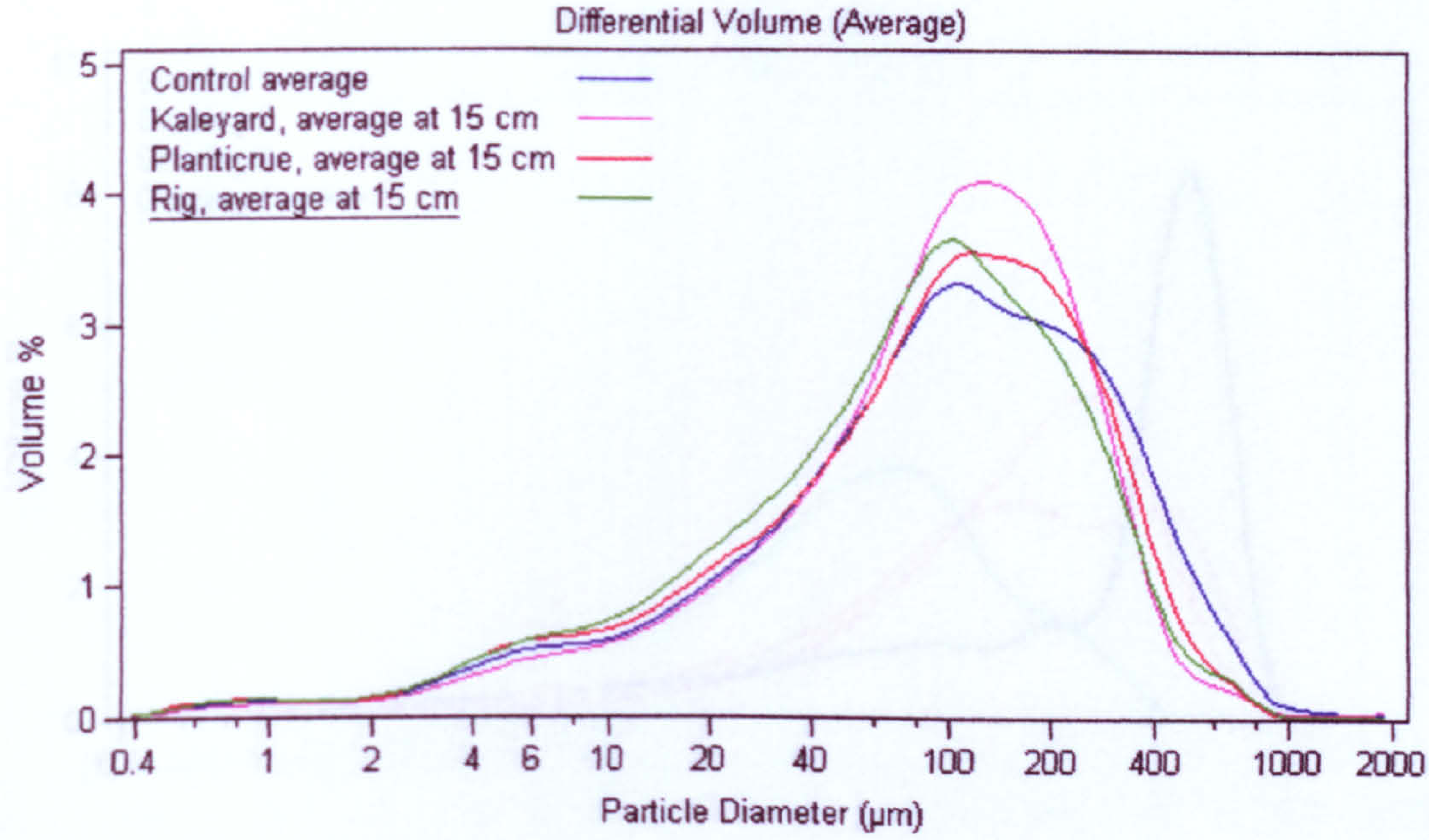



Figure 5.14: Average particle size of the kaleyard, planticrues and rigs at 15 cm

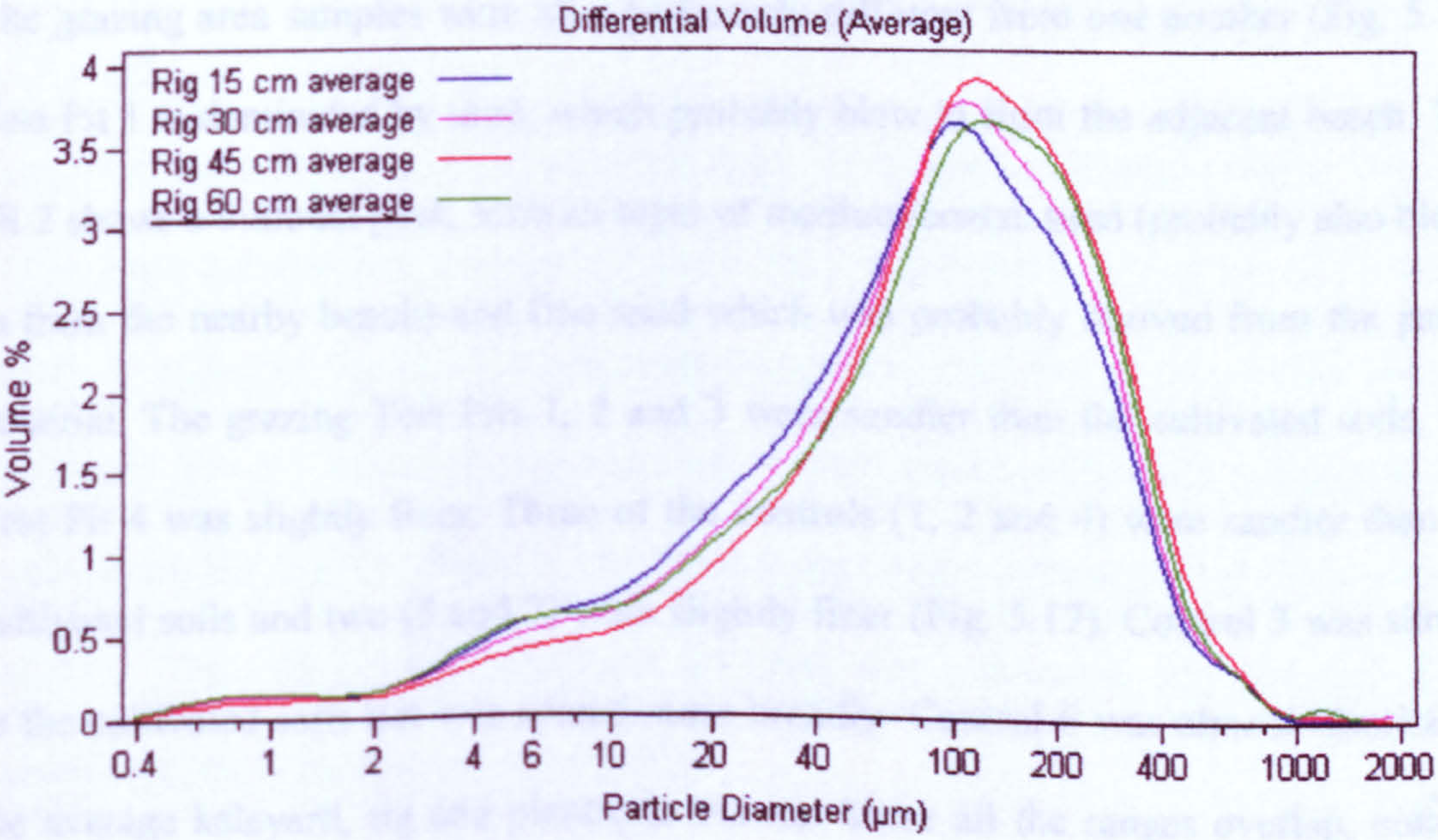



Figure 5.15: Particle size distribution in the Rig land

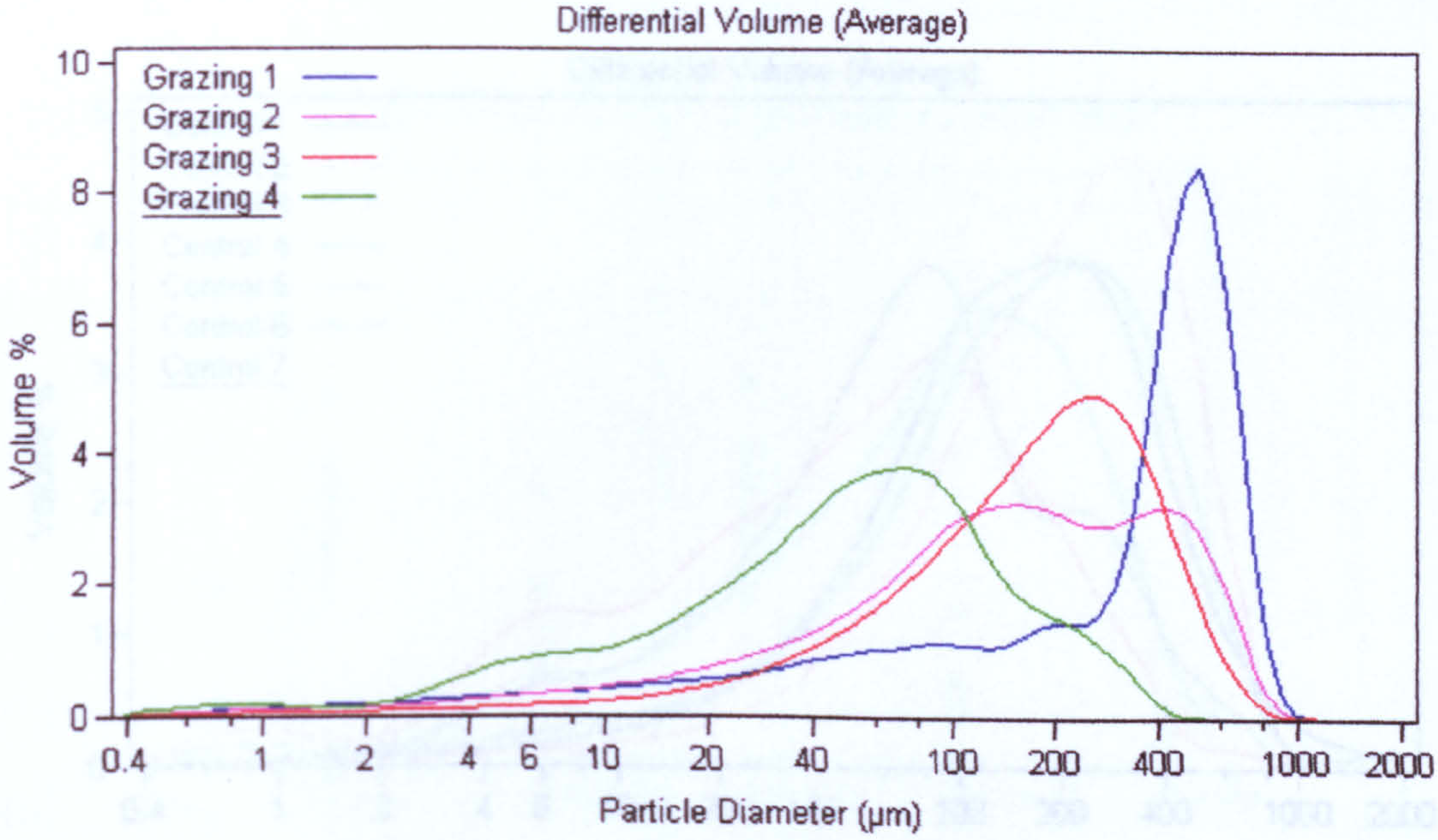



Figure 5.16: Particle size distribution in the grazing areas

The grazing area samples were all significantly different from one another (Fig. 5.16).

Test Pit 1 is dominated by sand, which probably blew in from the adjacent beach. Test Pit 2 shows a bimodal peak, with an input of medium/coarse sand (probably also blown in from the nearby beach) and fine sand which was probably derived from the parent material. The grazing Test Pits 1, 2 and 3 were sandier than the cultivated soils, and Test Pit 4 was slightly finer. Three of the controls (1, 2 and 4) were sandier than the cultivated soils and two (5 and 7) were slightly finer (Fig. 5.17). Control 3 was similar to the cultivated soils but was spread more broadly. Control 6 was almost identical to the average kaleyard, rig and planticrue curves. Since all the ranges overlap, none of the control curves can be ruled out as a possible source.

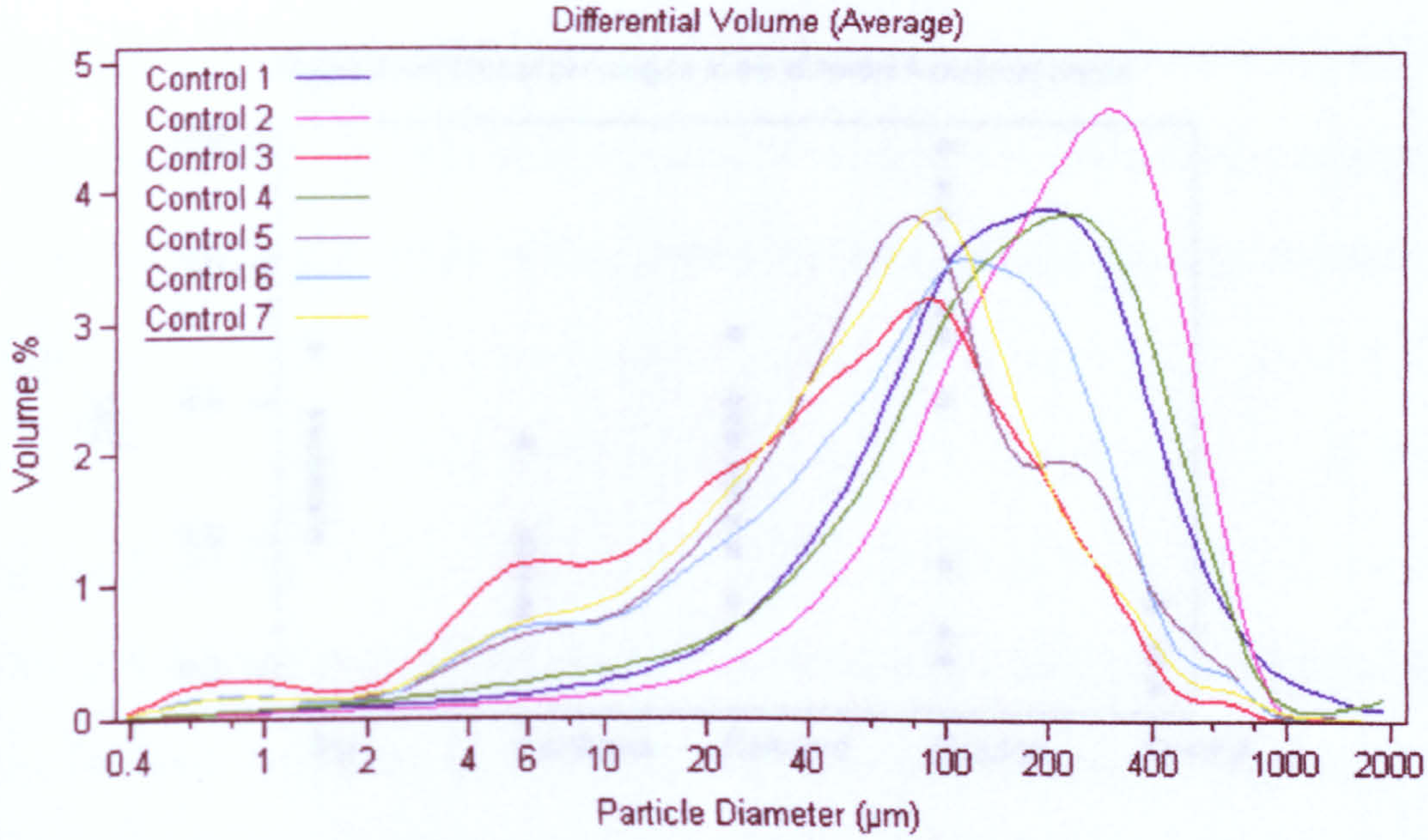
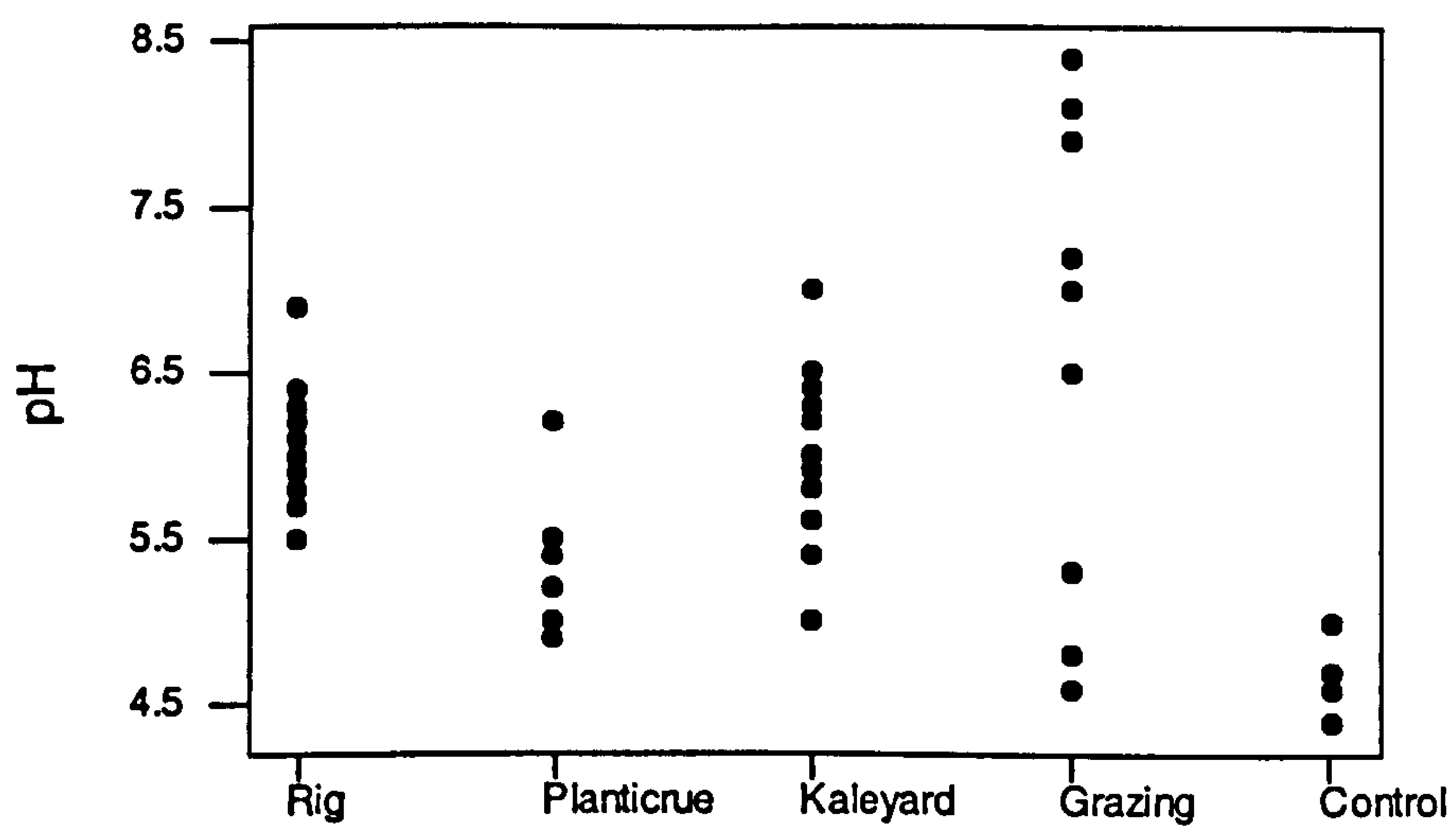



Figure 5.17: Particle size in the control samples

### 5.2.7 pH

The pH of the kaleyard and the rig areas (Fig. 5.18) was significantly higher than that of the controls (pH 4.4-5, average 4.7) ($p=0.002$ and $p=0.001$). At a depth of 15 cm the pH of the kaleyard, rig and grazing areas was higher than that of the control samples ($p=0.010$). The pH of the grazing areas was widely varied, with some samples as acid as the controls (Test Pits 3 and 4, pH 4.6-4.8) and others alkaline (Test Pit 1, average pH 7.5). The pH of the planticrue samples was enhanced, but did not differ significantly from the controls ($p=0.097$).

Figure 5.18: Plot of pH ranges in the different functional areas




The proximity of Test Pit 1 to the sea initially suggested that the difference was caused by calcareous shell sand blowing inland from the beach, and this has been confirmed by thin section analysis (Appendix 2).

### 5.2.8 Taphonomy

The agricultural soils have clearly been affected by biological reworking, in the upper samples in particular. The lower samples are reworked but some have retained their heterogeneity, so that the different materials which have been added to the soil are still identifiable. Coarse textural pedofeatures in these lower samples, which probably relate to the later agricultural phases of the stratigraphy above, have survived the biological mixing. The very rare, very thin clay coatings on the mineral grains could have formed *in situ*, or could be relict features of processes which took place in the peat which was added to the soil. The identification of thin clay coatings which were later than the silt pedofeatures suggests that they formed in situ. There has been some precipitation of iron in the soil, most notably at depth but also in the 15 cm samples in Kaleyard 4 and Planticrue 2. There has been some compaction of the soil in the kaleyard, indicated by the decrease in porosity, but in the rig Test Pit 2 the porosity actually increases with depth.

## 5.3 Discussion

The agricultural soils at Bragasetter were characterised by deepened A horizons, raised pH, enhanced magnetic susceptibility and enhanced phosphates. The soils were biologically active, which was demonstrated by the thin section analysis and by the enhanced bacterial magnetosome component in the cultivated areas. The intensified biological activity and the enhanced levels of phosphate are both indicative of a soil which is high in organic material.

### 5.3.1 Stratification

The field observations and laboratory evidence demonstrated that a buried soil survived the mixing effects of cultivation and biological activity in Rig test pit 2. This indicates that material was added at a rate sufficiently rapid to bury the early A horizon before it could be incorporated into the new layer. The buried topsoil horizon (the 45 cm sample) was distinctly more heterogeneous in thin section than the two samples above, due to the presence of several distinct soil microfabrics which were probably derived from different sources. The sample heterogeneity was also due in part to soil forming features (secondary iron minerals and transported silt) which probably accumulated after the initial anthropogenic soil formation. There is no date for the earlier A horizon.

Another distinction between the samples was the differing particle size distribution of the two deepest (45 and 60 cm) kaleyard samples. In Kaleyard Test Pit 4, 45 cm depth (K4.45) the increase in finer particles did not appear to be the result of translocated material (i.e. fine particles washed down through the soil profile), although this could have been the case for the 60cm sample, which had a greater quantity of clay coatings and a higher birefringence. The differences appear to be more a matter of pedological horizonation rather than archaeological stratification.

### 5.3.2 The functional areas

*Grazing*

According to the historical and ethnographic accounts, no fertilisers were added to the infield grazing areas, apart from the manure of the grazing animals. This is confirmed by the phosphate analysis (Fig. 4), which shows little difference between the infield grazing and outfield control signatures, both of which have very low levels of inorganic phosphorus and higher levels of organic P. The phosphate proportions suggest very low levels of microbial activity, which is also suggested by the bacterial magnetosome component. The thin section analysis showed an absence of added peat and peat ash in the grazing area. The grazing area slide (G1) was also the only one in which there were no clay coatings on the mineral grains, which suggests that either 1) the coated mineral grains derive from the peaty turf taken from the hill land, in which the leaching of clays would have occurred naturally, or 2) the clay coatings are the result of disturbance *in situ.* In either case the clay coatings can be interpreted as indicators for cultivation. The micromorphological evidence for clay coatings which formed *after* the silt coatings suggests that they formed *in situ.*

*Planticrues*

According to both Fenton (1978) and the long-term resident of Bragasetter (George Peterson, pers. comm.), planticrues were not intensively fertilised because this would make the soil 'too strong' for the young seedlings. This is borne out by the phosphate tests, which show that the planticrues received less fertiliser than the other cultivated areas. The bacterial magnetosome component in the planticrue was enhanced compared to the controls, but was not as strongly enhanced as Rig 2 and the kaleyard. The SARM, mass susceptibility and *xfd* all showed slightly lower levels of magnetic enhancement in the planticrue in comparison with the rig and kaleyard, which confirms the resident's statements.

*Rig land and kaleyard*

The historical and ethnographic information indicates that barley was grown in the fields nearest to the farmstead, and that this area was fertilised more intensively than the outer fields. Rig test pit 2, the test pit nearest the farm, had by far the highest phosphate values on the site, with nearly four times the total P as in test pits 1, 3 and 4 and a higher value than the intensively cultivated kaleyard. Rig 2 was also in the cluster with the highest bacterial magnetosome component. These characteristics suggest that Rig Test Pit 2 may have been located in one of the former barley fields.

The buried A horizon in the rig land was similar to the upper A horizon, all of the samples containing similar quantities of peat ash (2-5%). There was slightly less unburned peat in the buried soil, but bone occurred throughout the profile. Coal first appeared in the uppermost sample.

According to the ethnographic evidence supplied by the resident of Bragasetter, the rig and kaleyard were treated with largely the same materials. Byre manure was composted with seaweed, which was spread on both areas. This information differs from that supplied by Fenton (pers. comm.), who stated that most of the manure and composting middens went onto the cultivated fields, and that the kaleyards were fertilised with domestic waste. The thin section analysis demonstrated that the unburned peat fragments, probably derived from the byre bedding, were most common in the kaleyard. The uppermost kaleyard samples contained a higher level of organic phosphates than any other area, which might confirm George Peterson's comment that within his lifetime byre manure was added to the kaleyard as well as the rig land; the kaleyard also had the highest total phosphate levels and the highest levels of magnetic enhancement. The evidence supports the resident's description of the manuring system, and suggests that the difference between the rig and kaleyard may have been quantitative rather than qualitative.

According to Fenton (1978), kaleyards were first built in the 18$^{th}$ century. There were no major differences in the Bragasetter kaleyard profile to show changes over time, apart from the appearance of coal in the uppermost sample in test pit 4. There were large quantities of burnt and unburned peat throughout the profile, and very rare bone fragments only in the upper two samples.

### 5.3.3 Conclusions

The historical and ethnographic sources describe a 19th-20th century manuring regime which employed animal dung, peat/turf (used as bedding and then as fertiliser), peat ash and seaweed to fertilise the soil. The addition of animal dung has been identified and to some degree quantified through phosphate analysis. Unburned peat fragments occurred in all of the cultivated areas and probably derived from cattle bedding which was mucked out onto the fields and kaleyard; the peat in the planticrue was probably taken straight off the hill land without passing through the byre first (Fenton 1978). Peat ash has been identified through thin section analysis and quantified by analysis of soil magnetism. The seaweed component is expected to be identified through isotope and lipid analysis which is currently underway at Bristol University.

Thin section analysis can be used to identify arable activity where biological activity has not eradicated the indicators and where indicators occur in suites (Macphail 1998). At Bragasetter the silt pedofeatures indicated disturbance to the soil and the great depth of homogenised soil was indicative of soil mixing; both are suggestive of cultivation. The key micromorphological indicators at Bragasetter, as Davidson and Carter stated (1998 and 2000), were the added manuring materials. The organic/inorganic phosphate method, also successful in buried soils (e.g. Ottaway 1984), was less so on this biologically active site, although the total phosphates identified in the analysis were distinctly different in the different functional areas. The soil magnetism tests showed significant differences between the enhanced and unenhanced areas, and with a larger number of samples might also show significant differences between the functional areas. The methods were informative, but would be more so on soils which were not biologically active, i.e. on soils which were either acidic, waterlogged, or rapidly and deeply buried. Lipid analysis would be a particularly appropriate method, as it is not dependent on these factors (Evershed et al 1997; Simpson et al 1998a).

# CHAPTER 6: TOFTS NESS

## 6.1 Introduction

The multi-period prehistoric site of Mound 11, Tofts Ness was selected as a study area because of the longevity of the settlement, the range and preservation of the deposits and because preliminary excavation had already established the chronology of the structures and deposits (Dockrill 1993; Dockrill et al 1994). The preliminary thin section analysis, carried out by Simpson et al (1998a), focused on the Bronze Age soil and did not investigate the underlying Neolithic soil or the archaeological deposits in the settlement. The current study aims to analyse these deposits and to carry out further analysis on the Bronze Age soil. The work was funded by Historic Scotland and the excavation was designed and carried out with the aid of AOC Archaeology.

Tofts Ness (NGR HY 757 464) is the northernmost peninsula on Sanday, Orkney (Fig. 6.1). The solid geology of the island (and of most of Orkney) is comprised of Upper and Middle Devonian Old Red Sandstone. The drift deposits include boulder clay, but about one third of the island (including the Tofts Ness Peninsula) is covered by calcareous windblown sand. The peninsula is mostly under 5m OD, and is liable to flooding in the winter due to the high water table. The soils of the Tofts Ness peninsula are calcareous gleys, brown calcareous soils and regosols of the Fraserburgh Association, formed on shelly windblown sand (Dry and Robertson 1982). Fraserburgh soils are coarse textured, with a weak structure and low levels of organic matter. The presence of shell fragments causes their high pH, which contributes to deficiencies in cobalt, copper and manganese (*ibid.*) The soils today are used predominantly for grazing, and because of their sandiness they are highly susceptible to erosion (*ibid.*).

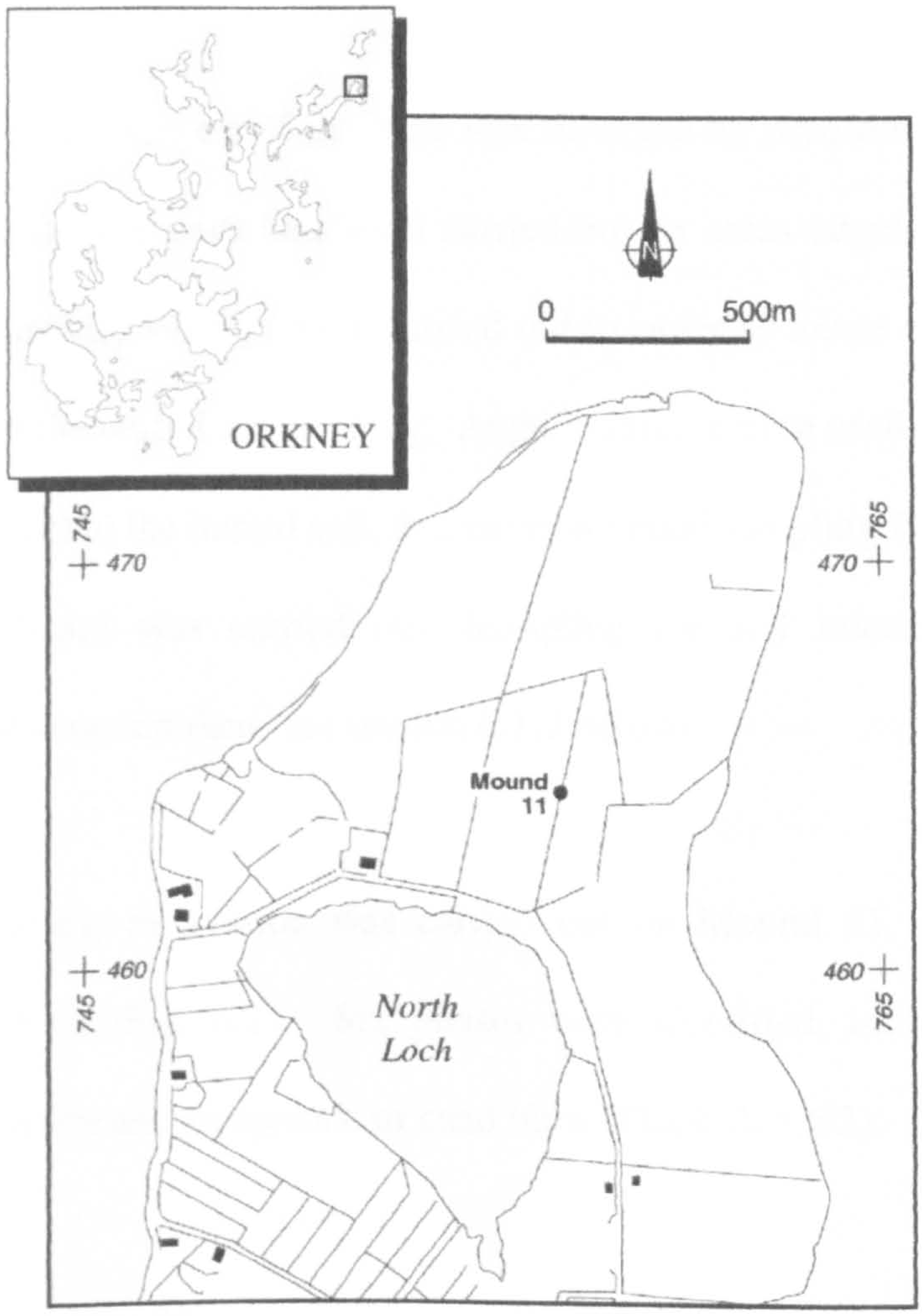



Figure 6.1: The Tofts Ness peninsula

### 6.1.1 Archaeological Background

The archaeological features of the Tofts Ness landscape include banks, enclosures, seven large mounds and more than 300 small mounds and cairns (Dockrill 1993). The settlement site which is now known as Mound 11 was exposed by deflation in 1818, when it was first recorded by an anonymous source (cited in Dockrill 1993). A more thorough description was compiled in the New Statistical Account in 1845 (NSA 1845).

The archaeological landscape at Tofts Ness was surveyed by Bradford University in the 1980s, and exploratory excavations were carried out on areas targeted by the survey. Magnetic and resistivity surveys were carried out in order to locate sites and to try to identify aspects of the buried archaeology. Auger transects were used to trace the depth and any changes within the buried soil, and environmental sampling for macrobotanical remains and molluscs was carried out. Sampling for soil micromorphology and phosphates was also undertaken (see section 6.1.3 below).

Following the survey, excavation was carried out on Mound 11, a settlement site covering 70 x 35 m (Fig. 6.2). Six phases were identified, including periods of archaeological activity and an episode of sand blow (Dockrill 1993):

*Phase 1: Neolithic (Area A)*

The principal feature was a robbed-out Neolithic structure (Structure 1) with a central hearth (replaced by a later hearth) and an ash floor. There was evidence for robbed-out stone furniture, and contemporary tip and midden deposits were found to the north and south of the structure. The structure and the middens overlie a buried soil showing magnetic and phosphate enhancement. The structure was radiocarbon dated to 3360-

2920 cal BC (GU-2209 & GU-2210) and a cattle bone from the middens overlying the buried soil provided a date of 2200-2180 cal BC or 2150-1880 cal BC (GU-2105).

Table 6.1: Tofts Ness phasing

| Phase | Period | Structures | Middens | Soils |
|---|---|---|---|---|
| 1 | Neolithic | 1 (Area A) | Area A | Ard marks in Area A. Elsewhere the basal soil is sealed by a thin layer of blown sand. Soil contexts 200, 217, 237, 243, 248, 249 |
| 2 | Neolithic--Early Bronze | -- | Areas A & B | |
| 3 | Early Bronze | 2 (Area B) | -- | Deepened arable soil up to *c.* 30 cm, containing large amounts of nightsoil. Soil contexts 201, 202, 204, 229, 230, 233, 238, 239, 242, 244, 245, 246, 250, 251 |
| 4 | Late Bronze | 3 & 4 (Area C) | -- | |
| 5 | Blown sand in all areas. No structures. | | | |
| 6 | Late Bronze-Early Iron | 5 (Area C) | Area J | Ard marks cut into the Phase 5 sand in all of the excavated areas |

*Phase 2 : Neolithic to Early Bronze Age (EBA) (Areas A and B)*

The Neolithic Structure 1 was sealed by reddish-brown midden deposits of the 3rd-early 2nd millennium BC. Frequent animal bone was recovered from the middens, including an articulated bull.

*Phase 3 : Early Bronze Age (Area B)*

A second structure (Structure 2) was cut into the Phase 2 middens. The walls were extensively robbed, but the flagged stone floor was largely intact. The structure was probably part of a larger complex of buildings which extended under the western baulk. A radiocarbon date from the infill of the structure indicates that it was abandoned by 1690-1430 cal BC (GU-2104).

*Phase 4 : Late Bronze Age (LBA) (Area C)*

Two structures were built in the Late Bronze Age. The oval-shaped Structure 3 was heavily robbed-out, but a stone tank and a flagged floor survived. Structure 4 was a large circular building with a double wall and radial divisions; this was the first Atlantic Roundhouse to have been built on the site. Within the structure were a hearth and two stone drains.

*Phase 5 : Late Bronze Age / Early Iron Age (LBA-EIA) (All areas)*

Up to 0.20 m of windblown sand was deposited over the site. The identification of ard marks in this deposit in all of the trenches indicate that cultivation continued to be carried out (Plate 14).

*Phase 6 : Late Bronze Age - Early Iron Age (Area C)*

A later Atlantic Roundhouse, Structure 5, had several floor surfaces and structural alterations indicating several phases of building and rebuilding. During one of these renovations an annexe was added. The structure and its stone furniture were well preserved, probably because of the rapid burial of the structure by over a metre of windblown sand. Midden deposits believed to be contemporary with Structure 5 were excavated in the adjacent Area J.

Plate 15 shows the stratigraphy of the site; the yellowish till at the base of the section is overlain by the Neolithic soil. Above this is a pale band which derives its colour from blown shell sand; above this is the darker coloured Bronze Age soil. The LBA-EIA sand-based soil is indistinguishable in this photograph from the wind-blown sand layer

Plate 14: LBA-EIA ard marks cutting into the Bronze Age soil. Photo by Alan Duffy.

Plate 15: Section face, Test Pit 3. Photo by Mary Harris.

that accumulated above. The large turves in the uppermost horizon were turned over as a result of ploughing of the pasture 4 or 5 years before the excavation took place.

### 6.1.2 The Bronze Age soils

A buried soil around Mound 11 was investigated in two trenches (D and J) and a test pit (Simpson et al 1998a). Radiocarbon dates from the top and bottom of the horizon produced dates of 899-795 cal BC (SRR 5256) from the top (i.e. Late Bronze Age) and 1360-1346 cal BC (SRR 5247) from the base (i.e. Early Bronze Age) (*ibid.*). Analysis of the associated molluscs suggests an initial clearance by burning, followed by a period of windblown sand deposition (Milles 1994). Both shade-loving species and those of shorter, damper grassland were present, and the assemblage was thought to be associated with cereal agriculture (*ibid.*). The soil also contained fuel ash slag and burnt root and stem fragments including alder, willow, heather and crowberry leaves (Bond 1994b). Burnt seaweed (*Fucus/Ascophyllum*) was also identified, and the marine component in the soil was confirmed by stable carbon isotope analysis (Simpson et al 1998a).

Thin section analysis of the Bronze Age soil at Mound 11 indicated that the principal added material was a grassy turf with incipient podzolisation; the iron depletion which characterised the coarse components would have to have taken place in an acidic environment, rather than the calcareous conditions in which the soils were buried (Simpson et al 1998a). The soil contained phytoliths (indicating the presence of grass) and occasional diatoms (indicating wet surface conditions) (*ibid.*), although these materials could also indicate the addition of animal dung (Courty et al 1989). The turf may have been recovered from the north and east sides of North Loch, where sand deposition had not buried the land surface. Indications of light burning (oxidised stones and charcoal) were evident in all of the samples, and small amounts of ash from turf or manure burning were also present. Small bone fragments, some of which were burnt, were present in all of the samples. Although the soil phosphate levels were enhanced, the soil organics were mostly decomposed. Frequent excremental pedofeatures were indicative of the enhanced biological activity which is associated with large amounts of organic material in the soil. Textural pedofeatures, including the translocation of silt, indicate a moderate degree of disturbance, which is usually linked with agriculture (Macphail et al 1987).

Stable isotope ratios indicate that the organics within the soil were predominantly from terrestrial sources, with a slight input of marine sources (Simpson et al 1998a). This was confirmed by analysis of the soil lipids (GC and GC-MS analysis and GC-C-IRMS). The large input of grasses which was indicated by the phytoliths was confirmed by the $C_{31}$ component (an n-alkane common in temperate grasses). The analysis of the 5β-stanol ratio and the associated bile acids indicates that human faecal matter was added to the soil.

Mound 11 was one of four mounds investigated in Dockrill's preliminary survey. The survey took a broad based approach which aimed to study the Tofts Ness landscape before focussing in on a particular settlement. In keeping with the survey aims, only one or two test pits were excavated near each of the three mounds. Attention was concentrated on the substantial Bronze Age soil, and the basal, Neolithic soils and the settlement deposits were not investigated.

## 6.2 Results

### 6.2.1 Fieldwork

The aim of the fieldwork was to re-expose and sample the soils and midden deposits that were recorded during Bradford University's excavations on Mound 11 in the 1980s (Dockrill 1993; Dockrill et al 1994). Test pits were excavated within two of Dockrill's former trenches (A and J, Fig. 6.2) in order to sample the stratigraphy from the section faces where the chronology had already been established, but which had not been sampled for thin section analysis. The Neolithic soil and the midden deposits were of particular interest, as they were not investigated in the initial phase of work. In the first test pit (Area J; Fig. 6.3) the Bronze Age soil was sealed by a very sandy LBA-EIA soil, which was sealed below Early Iron Age middens which were believed to be associated with Structure 5. There were two horizons in the Bronze Age soil, which sealed a basal horizon interpreted, tentatively, as a Neolithic soil. In the second test pit (Area A; Fig. 6.4) an agricultural soil (identified by the ard marks which cut into the till below) was sealed by Neolithic middens. The middens were sealed by the Bronze Age soil, which was sealed by the sandy LBA-EIA soil. Above this was a layer of shell sand, which was overlain by the modern ploughsoil. Samples were taken from all phases of the buried soils and middens.

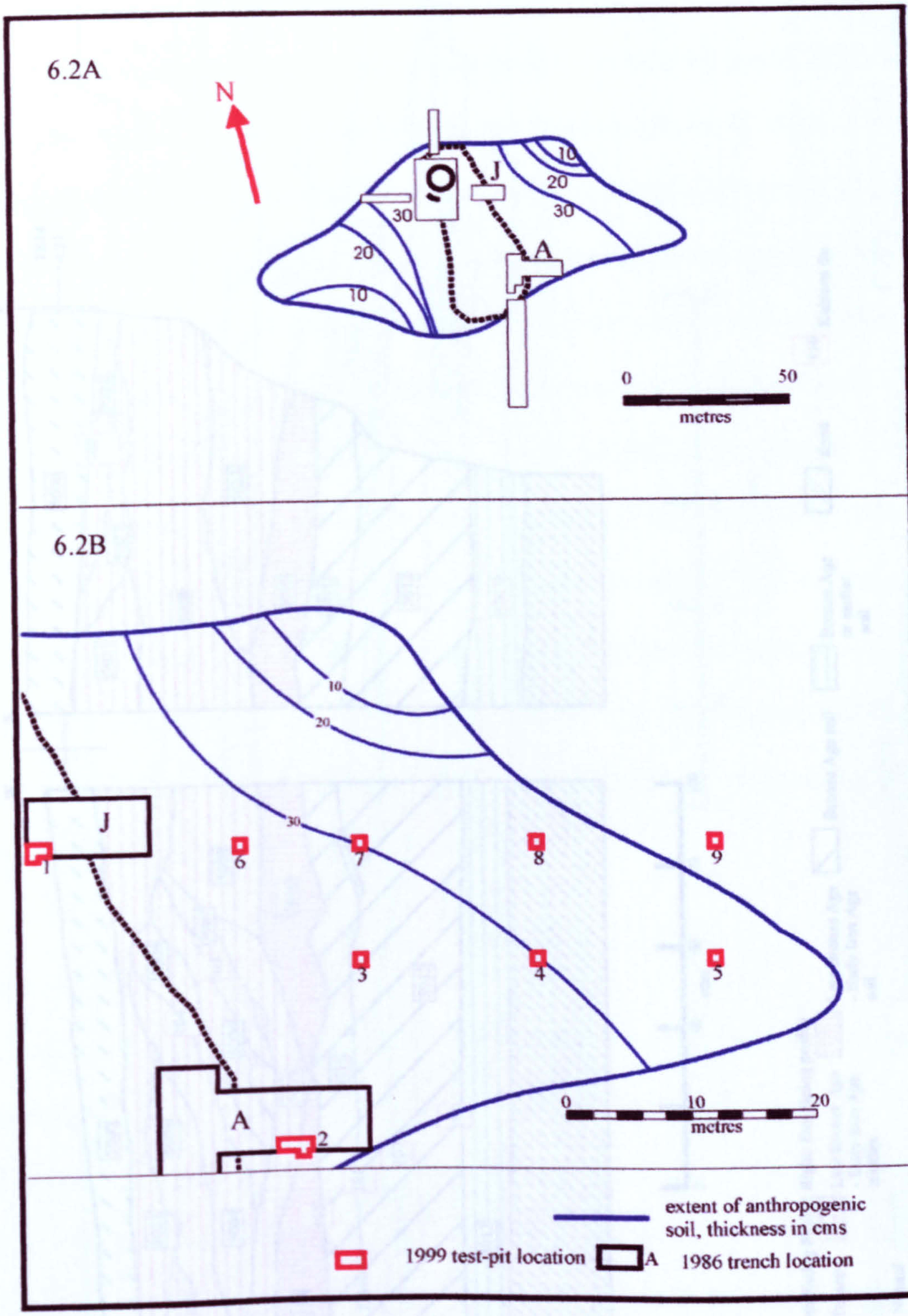



Figure 6.2A: Extent of soil around Mound 11 and location of 1986 trenches.
Figure 6.2B: Location of Test Pits.
Drawing courtesy of AOC Archaeology

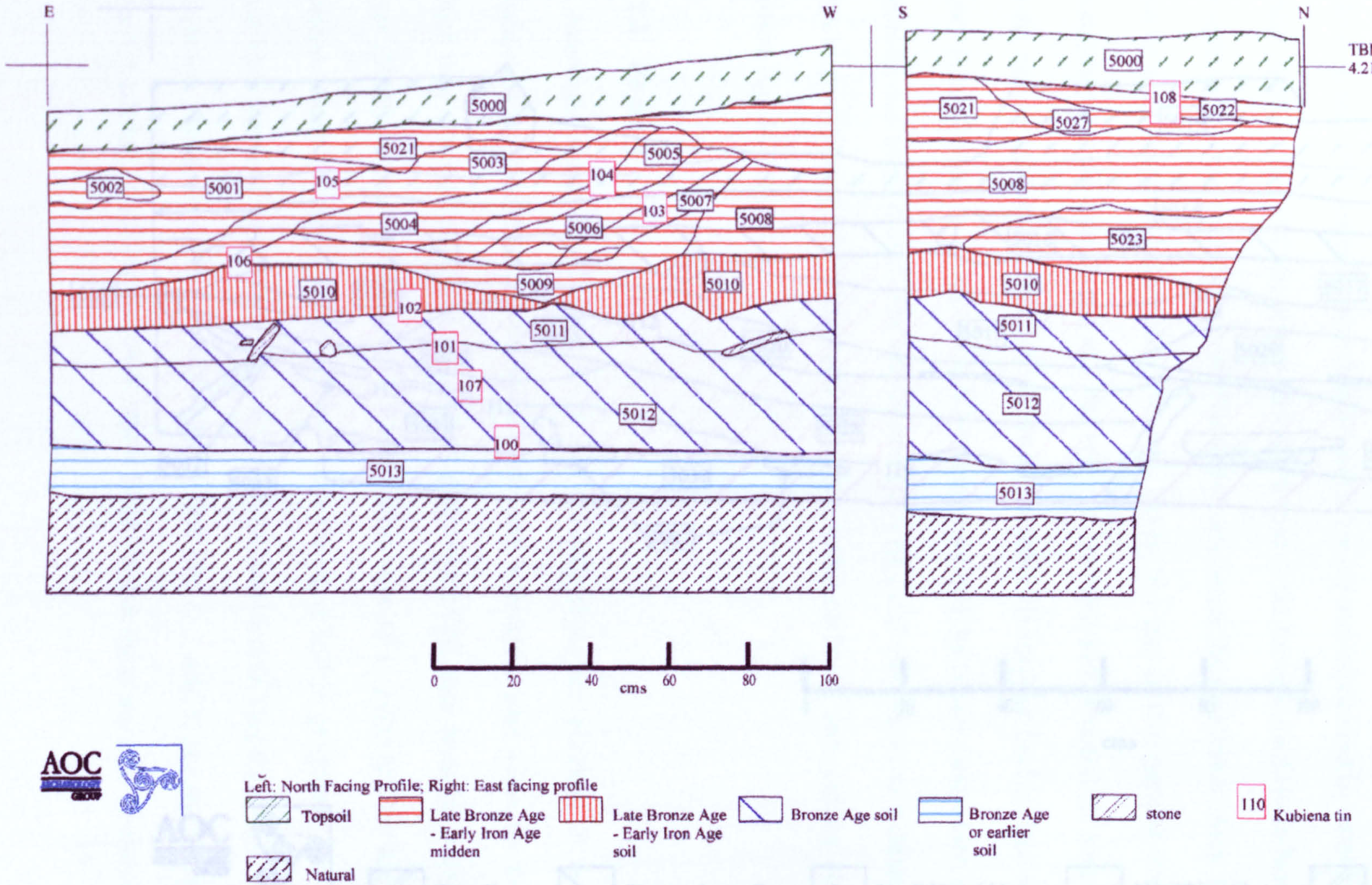



Figure 6.3: Section , Area J. Drawing courtesy of AOC Archaeology

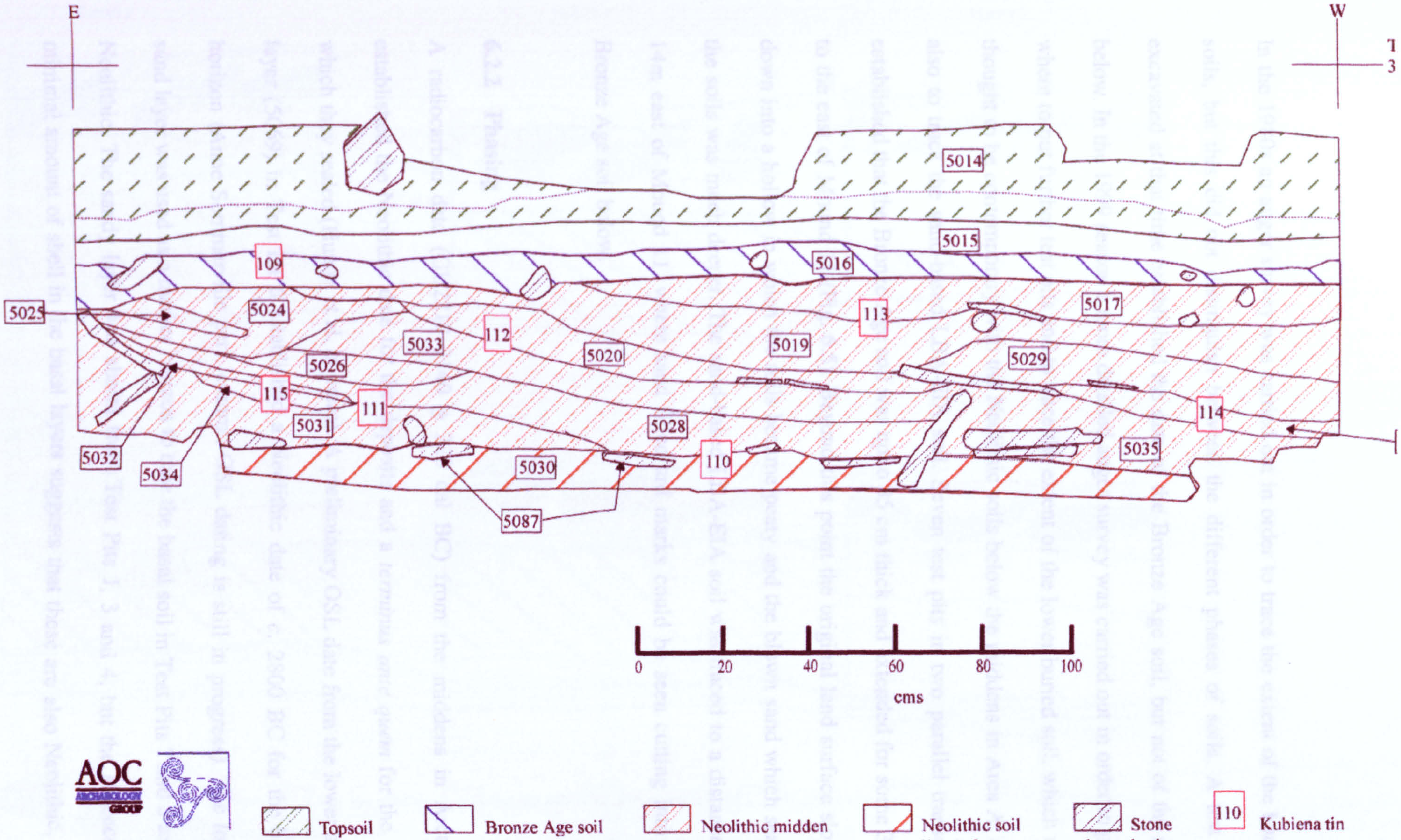


Figure 6.4: Section, Area A. Drawing courtesy of AOC Archaeology. See Appendix 1 for context descriptions

In the 1980s an auger survey was carried out in order to trace the extent of the buried soils, but this did not distinguish between the different phases of soils. A test pit excavated at that time established the date of the Bronze Age soil, but not of the soil below. In the 1999 season a more detailed auger survey was carried out in order to plan where to put further test pits and to trace the extent of the lower buried soil, which was thought to be contemporary with the Neolithic soils below the middens in Area A, and also to trace the sand-based LBA-EIA soil. Seven test pits in two parallel transects established that the Bronze Age soil was up to 35 cm thick and extended for some 36m to the east of Mound 11 (Fig. 6.5). Beyond this point the original land surface sloped down into a hollow in which the soils became peaty and the blown sand which sealed the soils was much deeper. The sand-based LBA-EIA soil was traced to a distance of 14m east of Mound 11, where sand filled ard marks could be seen cutting into the Bronze Age soil below.

### 6.2.2 Phasing

A radiocarbon date (GU2210 3140 ± 220 cal BC) from the middens in Area A established the Neolithic date for the deposits and a *terminus ante quem* for the soil which they sealed (Hunter et al, in press). A preliminary OSL date from the lower sand layer (5069) in Test Pit 6 established a Neolithic date of *c.* 2800 BC for the basal horizon (Anne Sommerville pers. comm.; OSL dating is still in progress). The lower sand layer was used as a marker horizon to date the basal soil in Test Pits 7 and 8 to the Neolithic. The sandy layer was absent from Test Pits J, 3 and 4, but the absence or minimal amount of shell in the basal layers suggests that these are also Neolithic, and

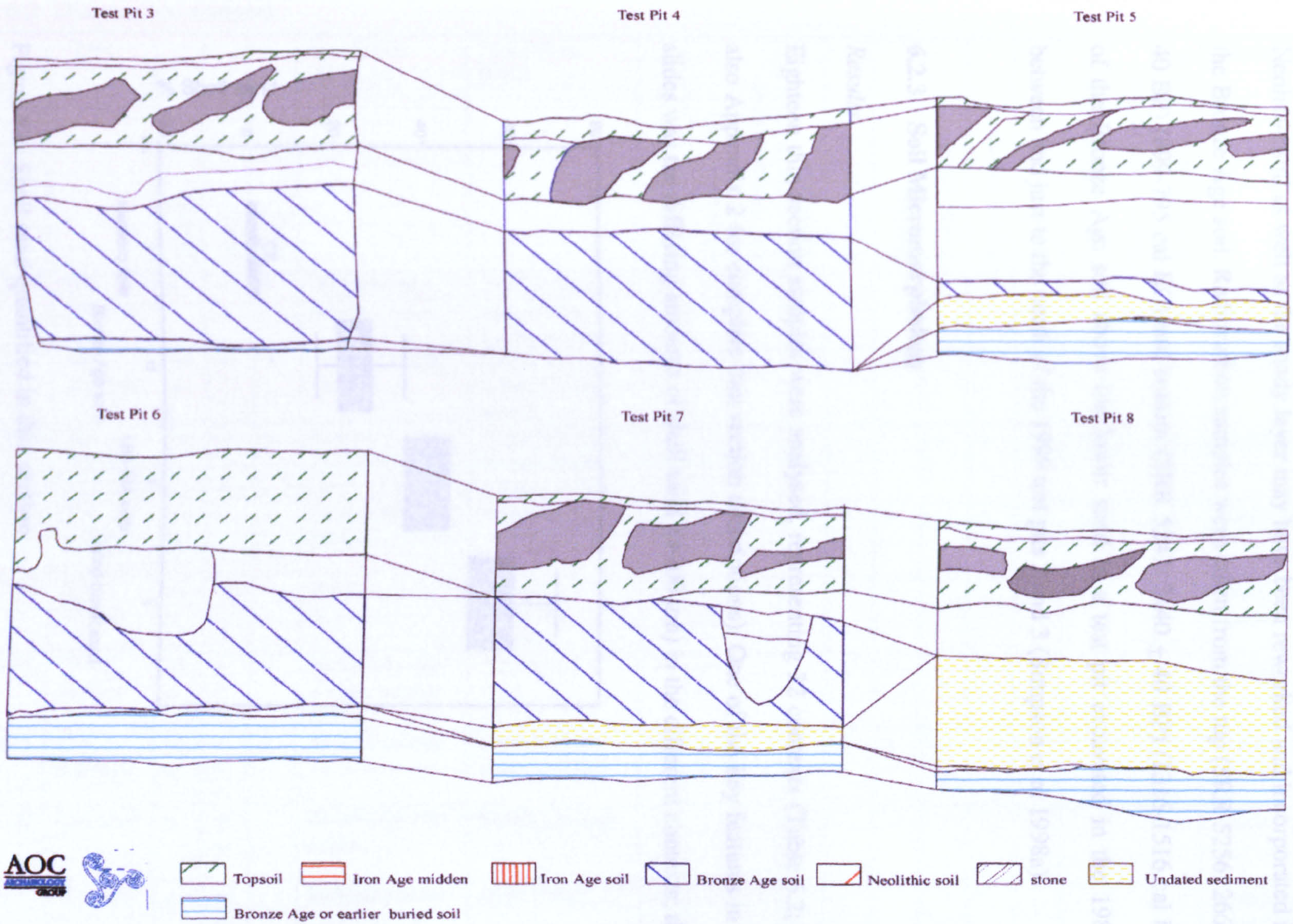



Figure 6.5: Section through soils and sediments in the Test Pits. Drawing courtesy of AOC Archaeology

that the sand layer which sealed them was incorporated into the Bronze Age soils above. In Test Pit 4 the basal horizon contained 20-30% shell, which suggests that the Neolithic soil as well as the sandy layer may have been reworked and incorporated into the Bronze Age soil. Radiocarbon samples were taken from the top (SRR 5256: 2665 ± 40 BP) (899-795 cal BC) and bottom (SRR 5247: 3140 ± 40 BP) (1316-1516 cal BC) of the Bronze Age soil above the lower sand in a test pit excavated in the 1980s, between and just to the north of the 1999 test pits 2 and 3 (Simpson et al 1998a).

### 6.2.3 Soil Micromorphology

*Results*

Eighteen thin section samples were analysed, representing 32 contexts (Table 6.2; see also Appendix 2 for complete thin section descriptions). One of the key features in the slides was the differing amounts of shell sand (>200 μm) in the different contexts; the

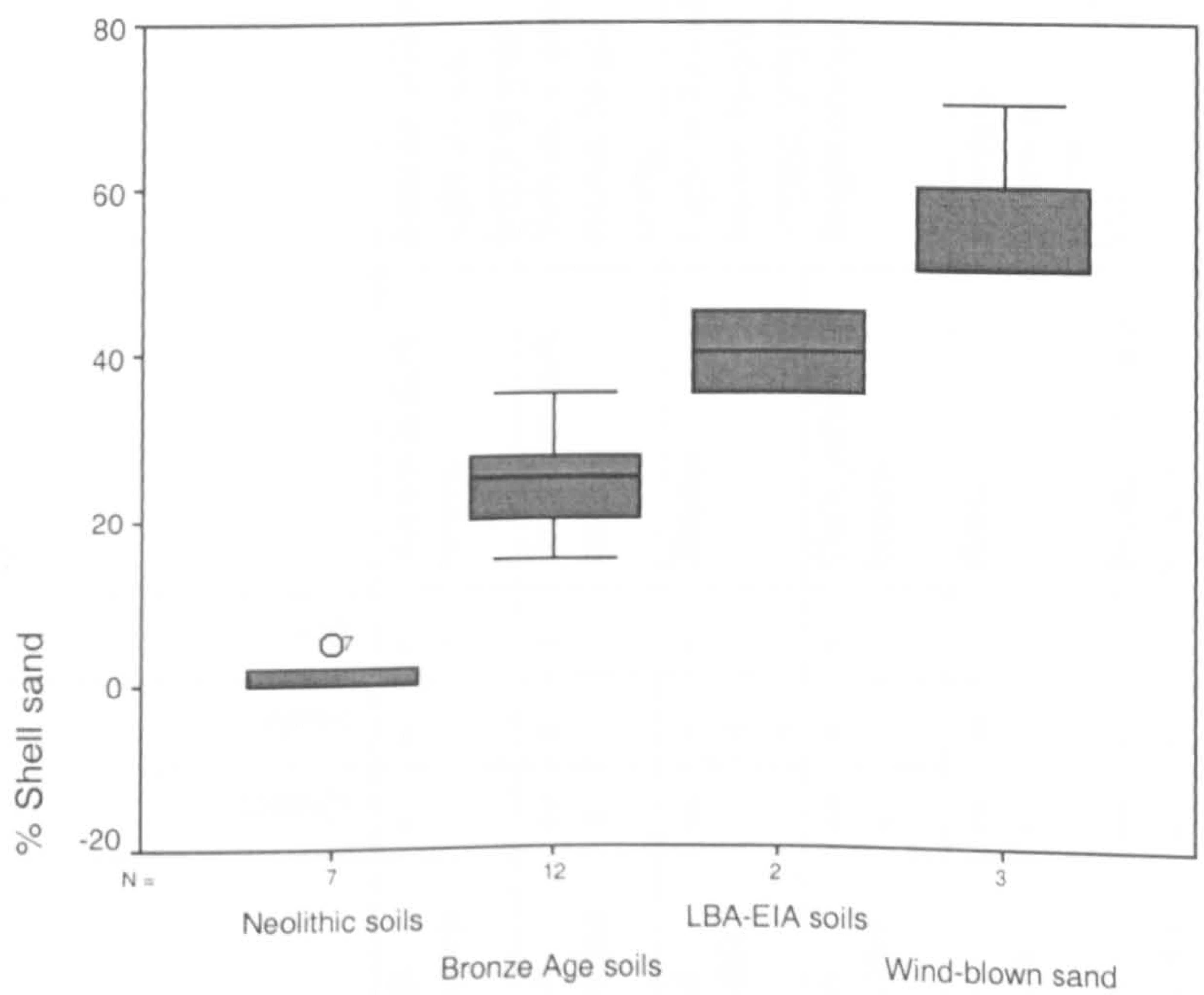



Figure 6.6: Shell sand quantified in thin section

Table 6.2: Thin section analysis

| (Context) and Sample | Level (metres O.D.) | Date | Quartz | Shell | Bone | Fine Fabric (PPL) | Fine Fabric (OIL) | Charcoal (peat/turf) | Charcoal (wood) | Red fibrous material | Spherulites | Phytoliths | Diatoms | Fungal spores | Porous excrement | Dense excrement | Fe hypocoatings & segs | Bright orange nodules | Amorphous organo-min | Microstructure | Related Distribution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (5001) 105 Area J | 3.91 | EIA midden | • | • | ++ | Brown to dark brown | Reddish yellow, light brown, bright orange | • | ++ | | + | | + | ? | + | | | | ++ | Vughy | Close porphyric |
| (5003) 105 Area J | 3.89 | EIA midden | ••• | • | + | Brown to dark brown | Yellow, v. pale brown, bright orange | • | ++ | + | + | ? | + | | + | | | | • | Channel | Close porphyric |
| (5004) 104 Area J | 3.94 | EIA midden | •• | +++ | + | Brown | Light yellowish brown, bright orange, yellow | •• | ++ | | + | + | | + | + | | | | + | Vughy | Close porphyric |
| (5005) 104 Area J | 3.90 | EIA midden | ••• | • | + | Dark yellowish brown | Bright orange | •• | ++ | + | + | + | + | | + | | | | ++ | Vughy, with channels | Close porphyric |
| (5006) 103 Area J | 3.86 | EIA midden | ••• | •• | | Brown | Brownish yellow to yellow | •• | ++ | | + | + | + | | | + | | | +++ | Spongy, with channels | Close porphyric |
| (5007) 103 Area J | 3.83 | EIA midden | ••• | +++ | + | Reddish brown to dark reddish brown | Yellow | • | ++ | | + | + | + | | + | | | | +++ | Channel | Close porphyric |
| (5003/ 5009) 106 ( J) | 3.71 | EIA middens | ••• | +++ | • | Reddish brown | Light brown, reddish yellow | •• | ++ | | + | + | + | | | | | | ++ | Spongy, with cracks and channels | Porphyric |
| (5055) 123 TP 3 | 3.20 | EIA sand | • | •••• | | Reddish brown to red | Reddish brown | + | | | | | | | | | | | + | Single grain | Dominant. Monic; gefuric |
| (5015) 109 Area A | 3.31 | EIA sand | • | •••• | | Reddish yellow | Light brown | + | | | | | | | + | | | | | Single grain. Small areas of bridged. | Monic. (gefuric) |

KEY: + Very Rare (<0.5%), ++ Rare (0.5-2%), +++Very Few (2-5%), • Few (5-15%), •• Frequent (15-30%), ••• Common (30-50%), •••• Dominant/Very Dominant

Table 6.2: Thin section analysis

| (Context) and Sample | Level (metres O.D.) | Date | Quartz | Shell | Bone | Fine Fabric (PPL) | Fine Fabric (OIL) | Charcoal (peat/turf) | Charcoal (wood) | Red fibrous material | Spherulites | Phytoliths | Diatoms | Fungal spores | Porous excrement | Dense excrement | Fe hypocoatings & segs | Bright orange nodules | Amorphous organo-min | Microstructure | Related Distribution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (5010) 106 Area J | 3.67 | LBA-EIA soil (top) | •• | ••• | ? | Yellowish red | Reddish yellow | +++ | + | | + | | + | | | ? | | + | + | Bridged/ spongy | Dominant gefuric; (porphyric) |
| (5010) 102 Area J | 3.60 | LBA-EIA soil (base) | • | ••• | | Red to reddish brown | Brown | ++ | + | | | + | | + | | | | ++ | ++ | Bridged | Gefuric |
| (5016) 109 Area A | 3.27 | Bronze Age soil | •• | •• | + | Dark reddish brown/ red | Red | + | + | | | | | | + | ?? ?? | ++ | + | ++ | Slightly spongy—few voids | Close porphyric |
| (5011) 102 Area J | 3.55 | Bronze Age soil (upper) | • | •• | + | Reddish brown to yellowish red | Reddish brown | ++ | + | | | + | | + | | ?? ?? | ++ | ++ | ++ | Spongy, with channels | Close porphyric |
| (5011) 101 Area J | 3.50 | Bronze Age soil (lower) | •• | ••• | + | Brown and dark brown | Reddish brown | +++ | + | | | | | + | | | | +++ | ++ | Spongy, with channels and chambers | Close porphyric |
| (5012) 101 Area J | 3.46 | Bronze Age soil | ••• | • | + | Strong brown | Light reddish brown to reddish brown | +++ | ++ | | | | | | | | | ++ | +++ | Spongy, with channels and chambers | Porphyric |
| (5012) 100 Area J | 3.24 | Bronze Age soil | •• | •• | + | Reddish brown & strong brown | Reddish yellow | • | ++ | | | + | + | + | | | ++ | | +++ | Spongy, with channels | Close porphyric |
| (5068) 129 TP 6 | 3.02 | Bronze Age soil (base) | • | ••• | + | Brown to strong brown | Reddish yellow | ++ | | | | + | | | • | ++ | | | + | Intergrain microaggregate | Enaulic |
| (5083) 126 TP 8 | 2.76 | Bronze Age soil (base) | •• | •• | + | Dark brown to strong brown | Brown | +++ | + | | | + | | | | •• | | | | Spongy crumb structure | Close porphyric |

KEY: + Very Rare (<0.5%), ++ Rare (0.5-2%), +++Very Few (2-5%), • Few (5-15%), •• Frequent (15-30%), ••• Common (30-50%), •••• Dominant/Very Dominant

Table 6.2: Thin section analysis

| (Context) and Sample | Level (metres O.D.) | Date | Quartz | Shell | Bone | Fine Fabric (PPL) | Fine Fabric (OIL) | Charcoal (peat/turf) | Charcoal (wood) | Red fibrous material | Spherulites | Phytoliths | Diatoms | Fungal spores | Porous excrement | Dense excrement | Fe hypocoatings & segs | Bright orange nodules | Amorphous organo-min | Microstructure | Related Distribution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (5056) 123 TP 3 | 3.19 | Bronze Age soil | • | •• | + | Yellowish red & dark reddish brown | Reddish brown | +++ | + | | | | | | +++ | | +++ | | • | Spongy, with channels | Close porphyric |
| (5057) 122 TP 3 | 2.96 | Bronze Age soil | •• | •• | + | Dark reddish brown | Reddish yellow | +++ | + | | | | | | +++ | •• | | + | +++ | Spongy, with channels | Close porphyric |
| (5042) 117 TP 4 | 2.80 | Bronze Age | • | •• | + | Strong brown to v. dark brown | Brown | ++ | + | | | | | | ++ | • | | | + | Slightly spongy, with small vughs and channels | Close porphyric |
| (5043) 117 TP 4 | 2.76 | Bronze Age? | •• | •• | + | Strong brown to v. dark brown | Brown | +++ | + | | + | + | | | +++ | • | • | + | • | Slightly spongy, with small vughs and rare channels | Close porphyric |
| (5043) 116 TP 4 | 2.66 | Bronze Age? | •• | •• | + | Yellowish red and dark reddish brown | Reddish brown | +++ | + | | | ? | + | | •• | •• | | | | Channel structure; fabric is slightly spongy | Close porphyric |
| (5017& 5019) 113 (A) | 3.19 | Neolithic middens | •• • | ++ | ++ | Yellowish red | Reddish yellow. Rare bright orange. | +++ | + | + | | | + | | •• | •• | ++ | ++ | +++ | Channel structure with few vughs | Porphyric |
| (5020) 112 Area A | 3.13 | Neolithic midden | •• •• | + | + | Brown to light brown | Bright orange-yellow | +++ | | ++ | | + | + | + | | ?? ?? | + | | +++ | Intergrain channel | Open porphyric |
| (5033) 112 Area A | 3.09 | Neolithic midden | •• | | ++ | Dark brown | Reddish yellow. V. rare bright orange | +++ | + | | | ? | + | | ++ | ?? ? | + | + | ++ | Channel, with few vughs | Close porphyric |
| (5028) 110 Area A | 2.85 | Neolithic midden | •• •• | | • | Brown to dark brown | Reddish yellow, yellow and bright orange | +++ | | ++ | | ++ | + | | | | + | | +++ | Crack, with channels and vughs | Open porphyric |

KEY: + Very Rare (<0.5%), ++ Rare (0.5-2%), +++Very Few (2-5%), • Few (5-15%), •• Frequent (15-30%), ••• Common (30-50%), •••• Dominant/Very Dominant

Table 6.2: Thin section analysis

| (Context) and Sample | Level (metres O.D.) | Date | Quartz | Shell | Bone | Fine Fabric (PPL) | Fine Fabric (OIL) | Charcoal (peat/turf) | Charcoal (wood) | Red fibrous material | Spherulites | Phytoliths | Diatoms | Fungal spores | Porous excrement | Dense excrement | Fe hypocoatings & segs | Bright orange nodules | Amorphous organo-min | Microstructure | Related Distribution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (5069) 129 TP 6 | 2.94 | Post-Neo sand | • | •• • | | Brown to strong brown | Reddish yellow | + | | | | ? | | + | + + + | | | | | Intergrain microag., w/ areas single grain & areas of porphyric | Dominant monic |
| (5070) 129 TP 6 | 2.97 | Neolithic soil | •• | + | + | Brown to strong brown | Reddish brown, reddish yellow | + + | + | | | ? | + | ? | + + + | •• • | | | + + | Spongy | Porpyric |
| (5030) 110 Area A | 2.81 | Neolithic soil | •• •• | | + + + | Brown to strong brown | V. pale brown to yellow | + + + | | | | + + + | | | | | + | | + + + | Very dense spongy | Porphyric |
| (5013) 100 Area J | 3.19 | Neolithic soil | •• • | + + + | + | Strong brown | Reddish yellow | + + | | | | + | + | + | | •• | + + | | + + + | Spongy | Porphyric |
| (5086) 126 TP 8 | 2.76 | Neolithic soil | •• • | | | Strong brown | Reddish yellow | + + | + | | | ? | | | + + | | | | + + | Slightly spongy | Porphyric |
| (5058) 122 TP 3 | 2.92 | Neolithic soil | •• | + + + | + | Brown to strong brown | Reddish yellow | + + + | + | | | + | + | | | ?? ?? | + + | + | + + + | Spongy | Close porphyric |
| (5058) 121 TP 3 | 2.83 | Neolithic soil | •• | | + | Strong brown | Reddish yellow | + + | + + | | | + | | + | + + + | •• •• | | + | + + | Channel and chamber | porphyric |
| Till, 116 TP 4 | 2.62 | Glacial till | •• | + + + | ? | Yellow, yellowish red, strong brown | Yellow and brownish yellow | + + | | | | | | | + + + | •• | | + | | Spongy, with small vughs and channels | Porphyric |
| (5059) 121 TP 3 | 2.78 | Glacial till | •• | | ?? ? | Strong brown | Yellow | + | | | | ? | | | + + + | •• • | | + | + + | Spongy, with channels | Porphyric |

KEY: + Very Rare (<0.5%), ++ Rare (0.5-2%), +++Very Few (2-5%), • Few (5-15%), •• Frequent (15-30%), ••• Common (30-50%), •••• Dominant/Very Dominant

Bronze Age soils contained between 10-40% shell sand (average 25%), whereas the Neolithic soils contained between 0-5% (average 1.4%) (Fig. 6.6; see Table 6.2 for sample, context and phase cross referencing).

Charred peat fragments made up 2-5% of the Neolithic middens, 5-30% of the EIA middens, 0.5-5% of the Neolithic soils and <0.5-10% of the Bronze Age soils. The amount of charred material in the soils did not diminish with distance from the mound. Woody charcoal fragments were rare (0.5-2%) in the EIA middens, very rare (<0.5%) or absent in the Neolithic middens and rare or very rare in the other soils. The EIA middens were distinct from the other deposits in that all but 5001 contained wood ash, identified by the birefringent calcitic calcium oxylates (Courty et al 1989; Canti 1997). Contexts 5004 and 5005 were separated by a band of wood ash. The EIA middens also contained calcitic spherulites (Canti 1997), which only appeared in two other deposits (the LBA-EIA soil in Area J and 5043, a Bronze Age horizon in Test Pit 4). Phytoliths were found in very small quantities throughout the areas and phases, but were found in higher levels in the Neolithic soil in Area A and in the midden deposit above this soil. Diatoms were found in some of the Neolithic, LBA-EIA and Bronze Age soils but were more consistently found in the EIA and Neolithic midden deposits. The birefringence of the fine fabric was generally low, apart from the EIA middens, one of the Neolithic midden deposits, two of the Bronze Age samples, one of the till samples and some of the sandier deposits.

The Munsell colour of the fine fabric of the midden deposits in reflected light was 6/8 or higher (Plate 16), showing a similar range of colours to the reference slides of peat ash.

Table 6.3: Munsell colours in OIL

| Area | Sample | Context | Description | Munsell colours in Oblique Incident Light (OIL) | | |
|---|---|---|---|---|---|---|
| 3 | 123 | 5056 | BA soil | 5YR | 4/4 | |
| J | 102 | 5010 | LBA-EIA soil | 7.5YR | 4/4 | |
| 4 | 117 | 5042 | BA soil | 7.5YR | 4/4 | |
| 4 | 117 | 5043 | BA soil | 7.5YR | 4/4 | |
| J | 102 | 5011 | BA soil | 5YR | 5/4 | to 4/4 |
| J | 101 | 5011 | BA soil | 2.5YR | 5/4 | |
| 3 | 123 | 5055 | Sand (LBA-EIA?) | 2.5YR | 5/4 | |
| 4 | 116 | 5043 | BA soil? | 5YR | 5/4 | |
| 8 | 126 | 5083 | BA soil (base) | 7.5 YR | 5/4 | |
| A | 109 | 5016 | BA soil | 2.5YR | 5/6 | |
| J | 101 | 5012 | BA soil | 5YR | 6/4 | to 5/4 |
| 3 | 121 | 5058 | Neo soil | 5YR | 6/6 | |
| 3 | 122 | 5057 | BA soil | 5YR | 6/6 | |
| 3 | 122 | 5058 | Neo soil? | 5YR | 6/6 | |
| J | 106 | 5010 | LBA-EIA soil | 7.5YR | 6/6 | |
| 6 | 129 | 5068 | BA soil (base) | 7.5YR | 6/6 | |
| A | 109 | 5015 | Sand over LBA | 5YR | 6/8 | 7.5YR 6/4 |
| A | 113 | 5017/19 | Neo middens | 5YR | 6/8 | Bright yellow. |
| 3 | 121 | 5059 | Till | 10YR | 7/6 | |
| J | 100 | 5013 | Neo soil? | 7.5YR | 7/6 | and 6/6 |
| J | 100 | 5012 | BA soil | 7.5YR | 7/6 | and 6/6 |
| A | 110 | 5030 | Neo soil | 10YR | 7/6 | to 7/4 |
| J | 106 | 5003/9 | EIA middens | 7.5YR | 7/6 | to 7.5YR 6/4 |
| J | 105 | 5001 | EIA midden | 7.5YR | 7/6 | 7.5YR 6/4, bright orange |
| J | 104 | 5004 | EIA midden | 10YR | 7/6 | 10YR 6/4; bright orange |
| 8 | 126 | 5086 | Neo soil? | 7.5YR | 7/6 | |
| 6 | 129 | 5069 | Sand over Neo | 7.5YR | 7/6 | |
| 6 | 129 | 5070 | Neo soil | 7.5YR | 7/6 | |
| J | 104 | 5005 | EIA midden | 10YR | 7/6 | Bright orange. |
| A | 111 | 5028 | Neo midden | 5YR | 7/8 | |
| A | 111 | 5031 | Neo midden | 5YR | 7/8 | |
| A | 112 | 5033 | Neo midden | 5YR | 7/8 | |
| 4 | 116 | Till | Till | 10YR | 8/8 | 10YR 6/6 & 7/6 |
| A | 112 | 5020 | Neo midden | 10R | 8/8 | Bright orange |
| J | 105 | 5003 | EIA midden | 10YR | 8/8 | 10YR 7/4; 7/6; bright orange |
| J | 103 | 5006 | EIA midden | 10YR | 8/8 | 10YR 6/6-8/6; bright orange |
| J | 103 | 5007 | EIA midden | 10YR | 8/8 | 10YR 7/6 |
| A | 110 | 5028 | Neo midden | 10YR | 8/8 | 7.5 + 5YR 7/6, bright orange |

The Bronze Age and LBA-EIA soils were all 6/6 or lower. The Neolithic soils were overlapping with both ranges, with OIL colours between 6/6 and 7/6 (Plate 17). The till

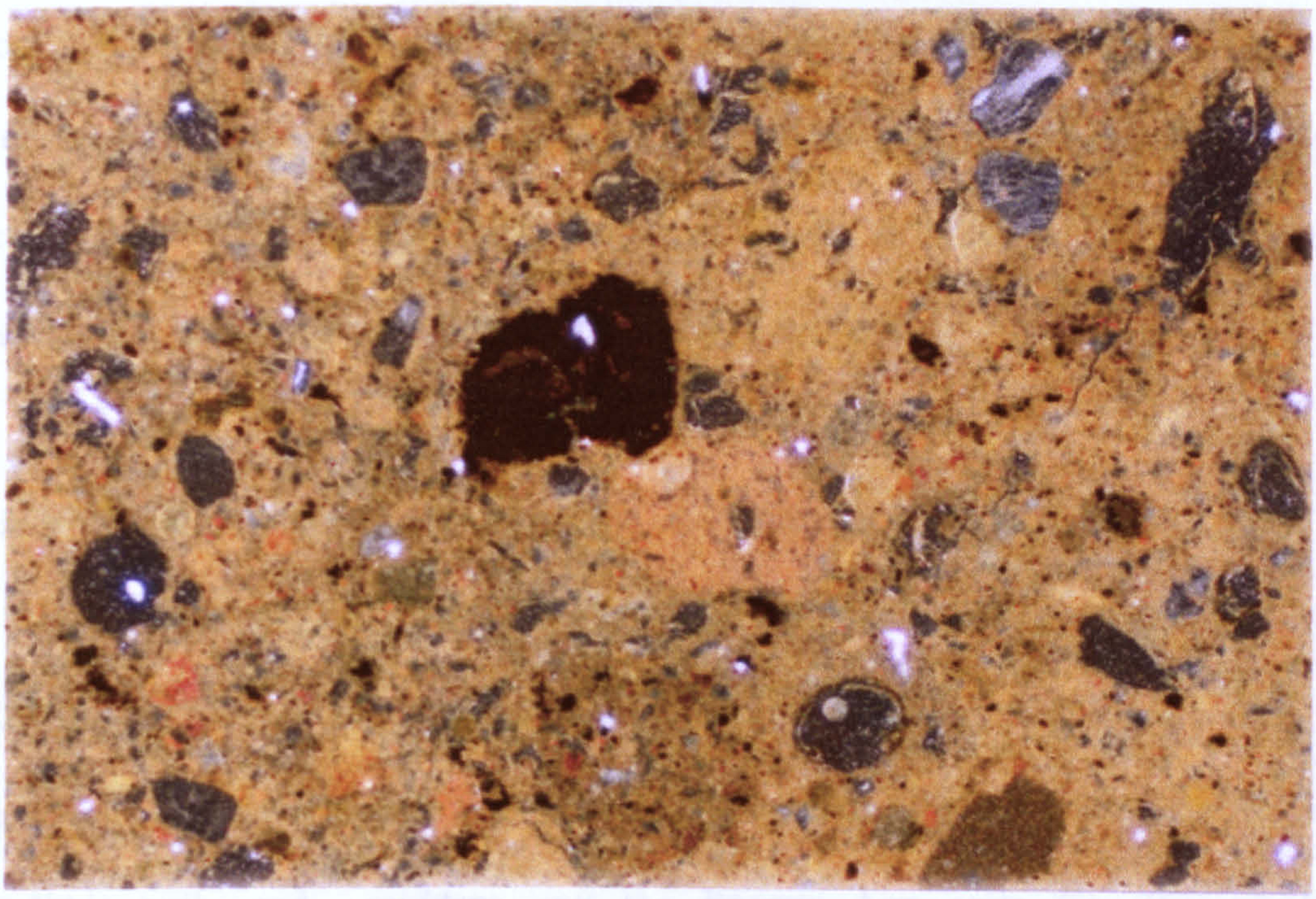


Plate 16: Neolithic midden, Tofts Ness (Magnification x 25, OIL)

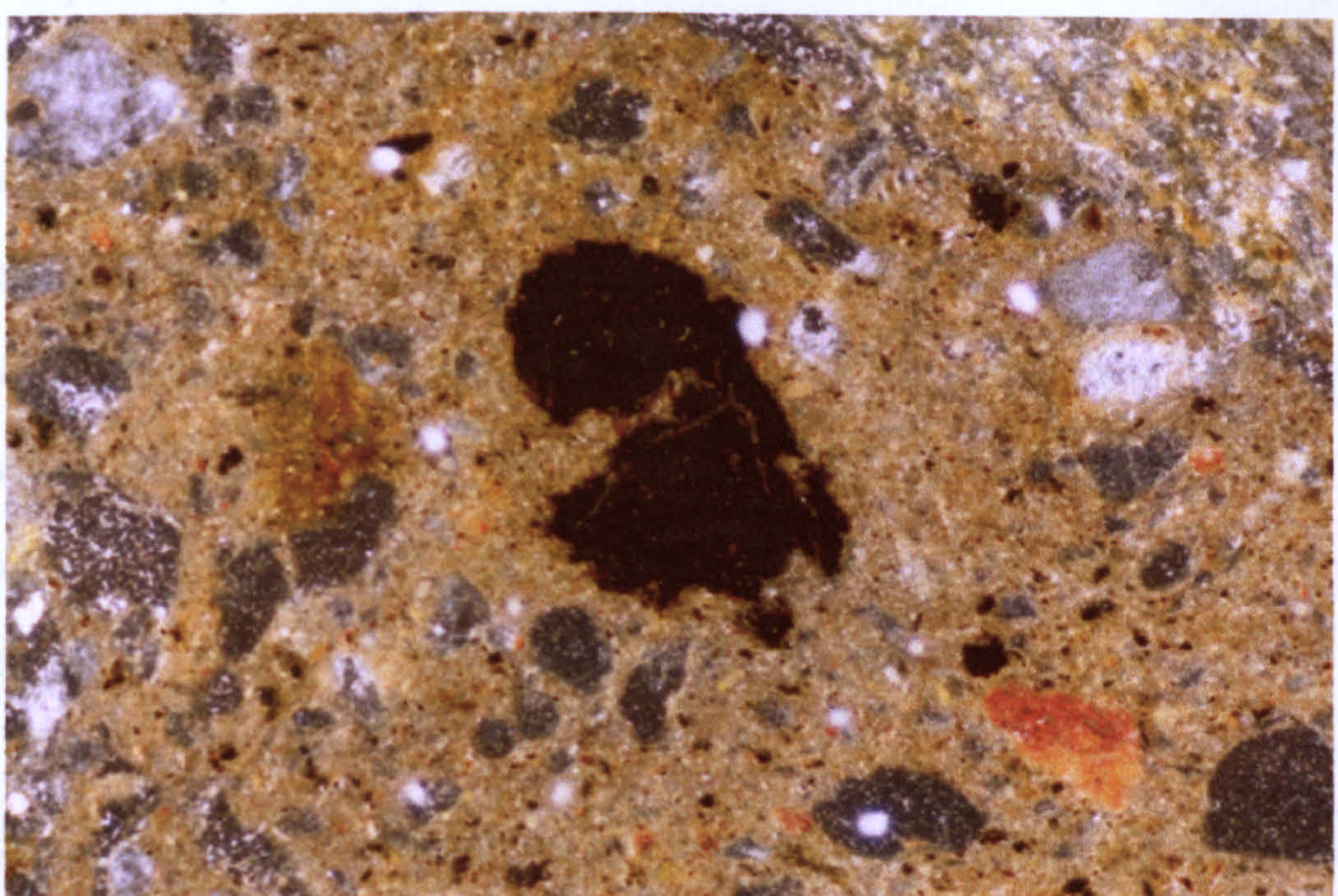


Plate 17: Neolithic soil, Tofts Ness (Magnification x 50, OIL)

from which the Neolithic soils was derived was from 7/6 to 8/8. Table 6.3 shows the Munsell colours of the deposits in OIL, with increasing brightness as the Munsell numbers increase. The midden deposits are shown in bold, which emphasises the clustering of these deposits at the brighter end of the scale.

The Neolithic middens and the Neolithic and Bronze Age soils had excremental fabric in varying densities, and some of the deposits also had channels and chambers. In the EIA midden deposits biological activity was limited to small areas of porous excrement. Iron movement was evident as hypocoatings and segregations in the Neolithic soils and middens and the Bronze Age soils (i.e. deposits below 3.55m.O.D.). Bright orange nodules measuring *c.* 20-50 µm (OIL) occurred in deposits of all periods apart from the EIA middens (i.e. between 2.62-3.67 m. O.D.) (Plate 18).

*Soil micromorphology: Interpretation*

Shell sand began blowing inland late in the Neolithic period. From the late Neolithic and throughout the Bronze Age there may have been low levels of sand blowing inland continuously, or there may have been occasional storms which resulted in the accumulation of large sand deposits which were subsequently ploughed into the soil. The sandy LBA-EIA soil might represent such a catastrophic sand blow.

The charred peat in the soils and middens is probably derived from fuel residue, and the wood charcoal may be from woody fragments within the peat as well as fragments from driftwood used as fuel; this suggestion is supported by the recovery of charred root and

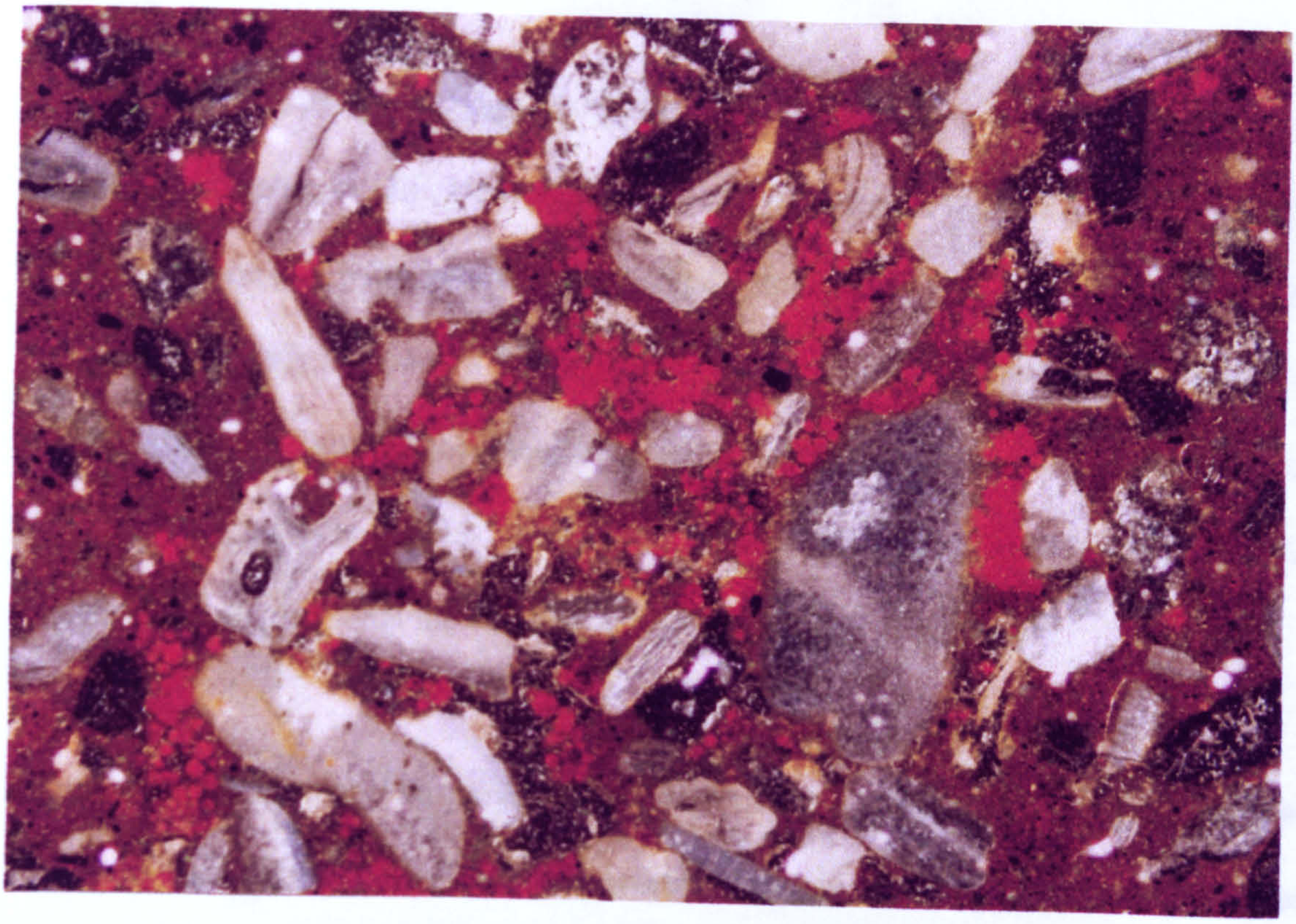


Plate 18: Nodules in the Bronze Age soil (Magnification x 20, OIL)

stem fragments from the soil (Bond 1994b). The bright yellow and orange colours of the midden material in OIL are indicative of a high peat ash content, an interpretation which is supported by the presence of charred peat fragments in the midden deposits. The parent material (till) was a bright yellow in OIL, which probably accounts for the brighter yellow colour of the Neolithic soil as compared with the later soils. The Neolithic soil in Area A was particularly bright and was a similar colour to the middens; this suggests that the soil had a particularly high ash content.

Excremental fabric and the presence of channels and chambers indicate biological activity in most of the soils. The compaction of the excremental aggregates indicates ageing of the material (Bullock et al 1985). The iron hypocoatings and segregations are the result of natural soil processes which are accelerated by wet conditions. The radial structure of the bright orange nodules suggests that they are biological in origin, i.e. they result from biomineralisation (Becze-Deák, pers. comm.).

### 6.2.4 Phosphates

*Results*

The deepest profiles and the most securely dated horizons were in Areas A (Fig. 6.7) and J (Fig. 6.8), which were cut into the edge of the settlement mound. The till in both of these areas contained organic phosphates which may derive from rootlets, earthworm contamination or leaching. The dated Neolithic soil in Area A was strongly enhanced in phosphates (5.5 times the level of the modern pasture topsoil), with a signature almost identical to that of the midden deposits above (90.32% organic P in the soil and 94.10%

in the middens). The Bronze Age phosphate levels were much lower than the levels in the Neolithic middens, but had a slightly higher proportion of inorganic P. The Bronze

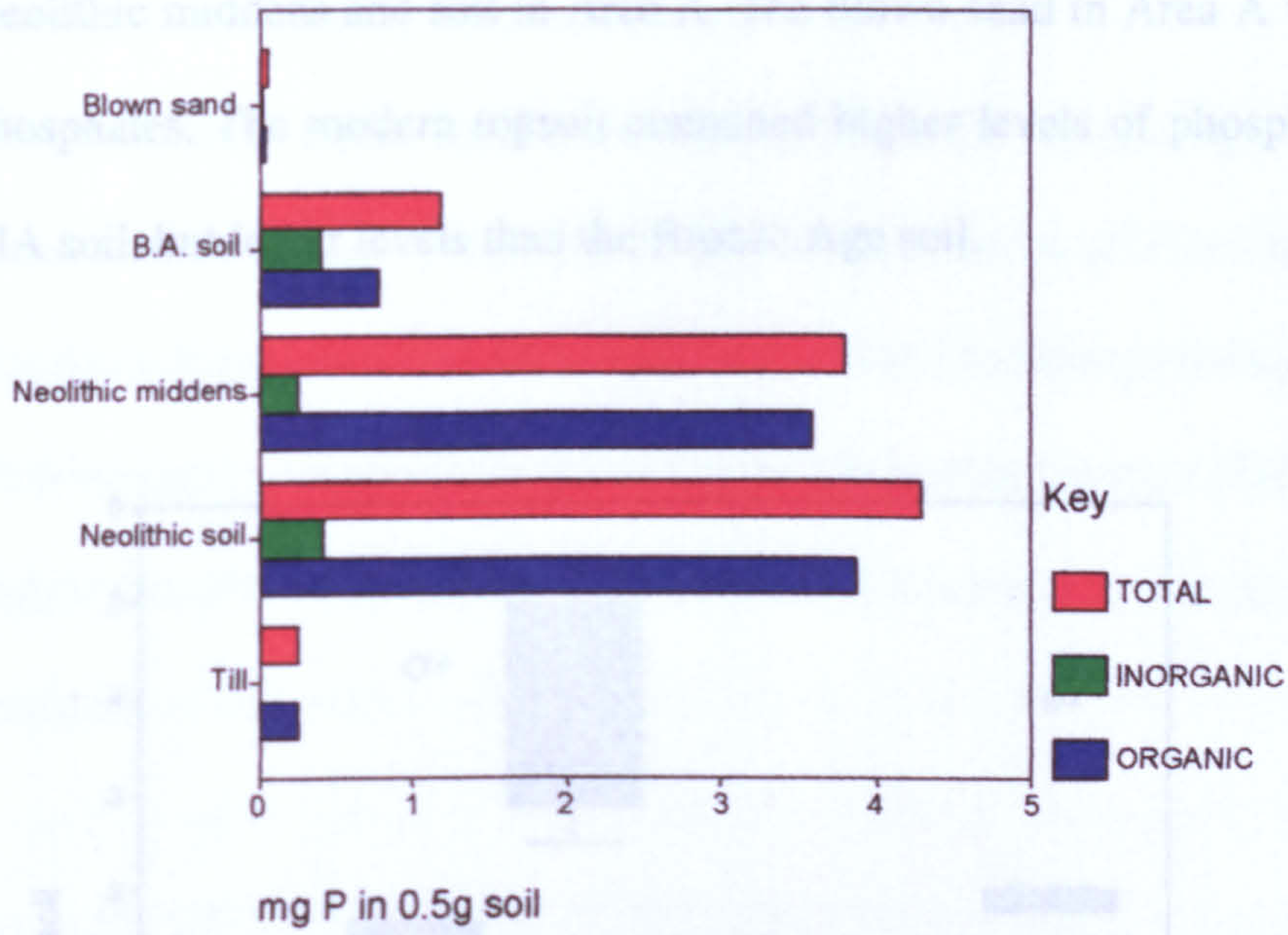



Figure 6.7: Phosphates, Area A

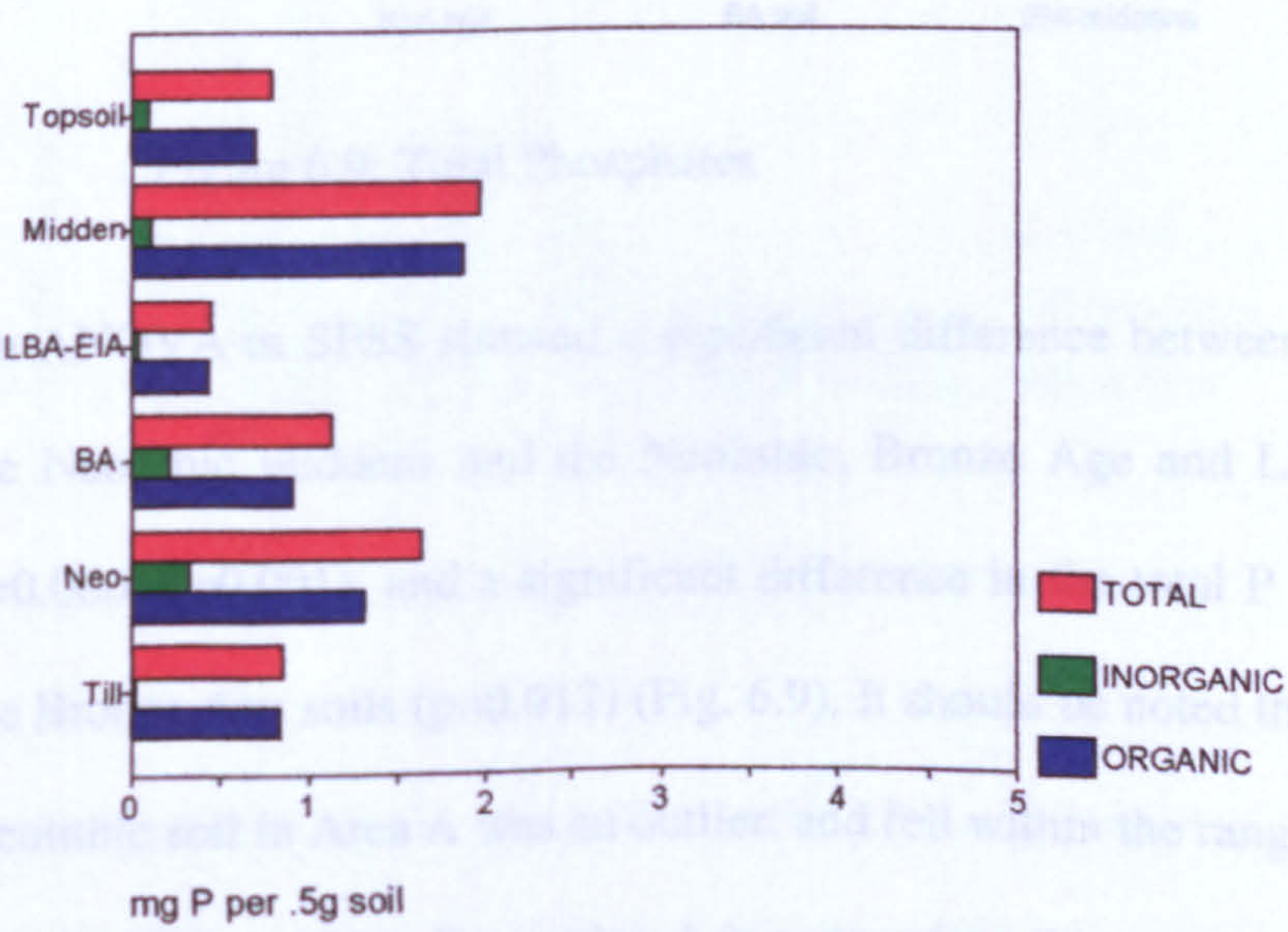



Figure 6.8: Phosphates, Area J

Age soil signature in Area J was very similar (Fig. 6.8). The LBA-EIA soil had very low levels of predominantly organic phosphates. The EIA middens had higher concentrations of phosphates than any other deposits on the site apart from the Neolithic middens and soil in Area A. The blown sand in Area A was nearly devoid of phosphates. The modern topsoil contained higher levels of phosphates than the LBA-EIA soil, but lower levels than the Bronze Age soil.

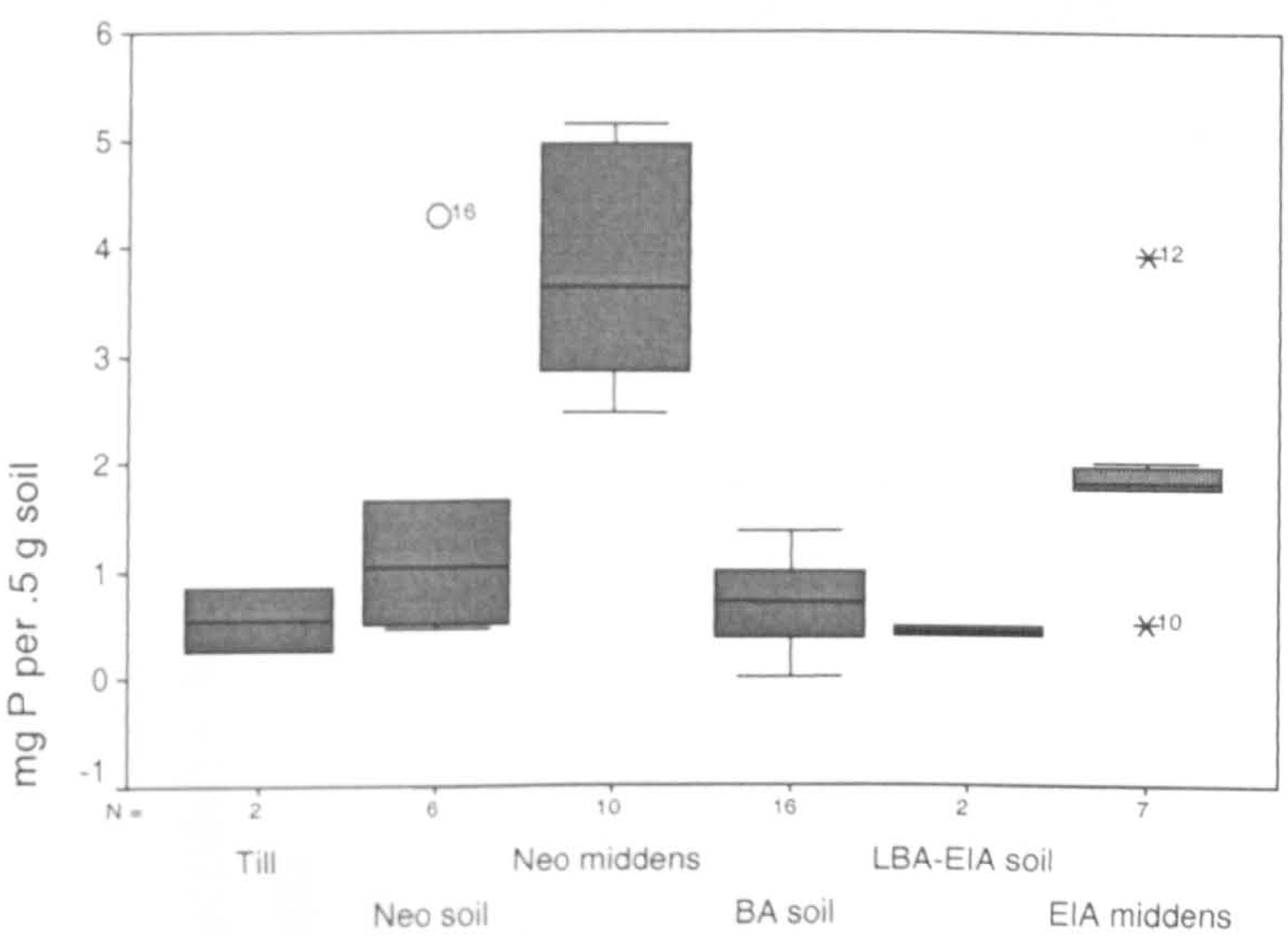



Figure 6.9: Total Phosphates

An ANOVA in SPSS showed a significant difference between the total phosphates in the Neolithic middens and the Neolithic, Bronze Age and LBA-EIA soils (p=0.006, p=0.000, p=0.001), and a significant difference in the total P in the EIA middens and the Bronze Age soils (p=0.012) (Fig. 6.9). It should be noted that the P sample from the Neolithic soil in Area A was an outlier, and fell within the range of the upper quartile of the Neolithic midden P samples, however, when this was removed from the data the results of the ANOVA were still the same. There was no significant difference between the Neolithic and Bronze Age soils, although the total P in Test Pits J, A and 3 was higher in the Neolithic than in the Bronze Age samples. In Test Pit 6 the Neolithic P was higher than the basal Bronze Age sample but lower than the middle Bronze Age horizon (context 5067, sample 251).

The phosphates in the uppermost samples from the Bronze Age soil diminished with distance from the settlement mound (Fig. 6.10; location of Test Pits shown in Fig. 6.2). The phosphates increased with depth in the Test Pits through the soil, apart from in Test Pit 6 where the sample from the middle of the profile (context 5067, sample 251) had a higher phosphate concentration than the basal Bronze Age sample (Fig. 6.5 for Test Pit sections).

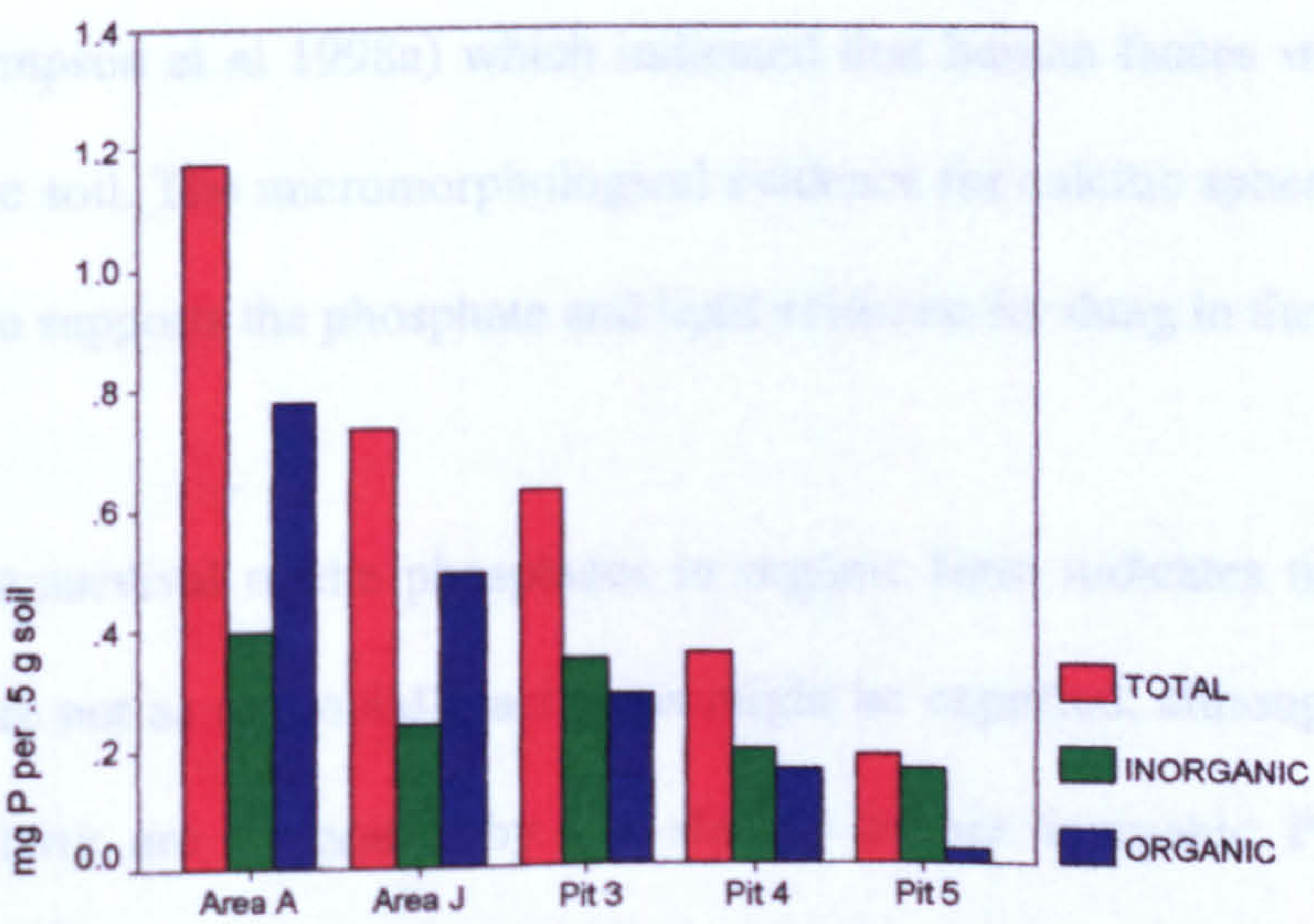



Figure 6.10: Phosphates, BA soil surface

The organic/inorganic phosphate ratio (i.e. the amount of organic P) varied considerably between the samples, but generally increased with depth, apart from in

Test Pit 6, where it decreased. There was no significant difference in the proportion of organic P between the different soils and the midden deposits (p=0.085).

*Phosphates: Interpretation*

All of the archaeological deposits and the buried soils were enhanced in phosphates, but two points are of particular interest: 1) The Neolithic soil in Area A has a phosphate signature almost identical to that of the overlying midden, and 2) the phosphates in the middens and many of the soils are predominantly organic. The level of P in the Neolithic soil in Area A suggests that it is a cultivated midden rather than a soil with added midden material, and the survival of organic P in the soil indicates that organic material predominated in most soils and middens. This ties in with the lipid results (Simpson et al 1998a) which indicated that human faeces were present in the Bronze Age soil. The micromorphological evidence for calcitic spherulites in the EIA middens also supports the phosphate and lipid evidence for dung in these deposits.

The survival of the phosphates in organic form indicates that the soils and middens were not as microbially active as might be expected, although low levels of microbial activity are suggested by the slightly higher inorganic P content in the soils as compared to the middens. Arable soils are usually dominated by inorganic P (Sharpley and Smith 1983), even when large amounts of organic manures have been added; this was demonstrated in the work at Bragasetter Farm, Papa Stour. The high proportion of organic P at Tofts Ness may be due to the rapid burial of the soils or to waterlogging, both of which would inhibit the activity of soil microbes.

The high proportion of organic phosphates in the middens is also significant, as it suggests that waste material was not used selectively. The middens in the settlement were not purely derived from fuel residues and kitchen waste, but also contained organic material. The lipid results are therefore of particular interest, as they will provide information on the sources of this organic waste and will determine whether the organic material in the middens is the same as that in the soils.

### 6.2.5 Soil Magnetism

*Results*

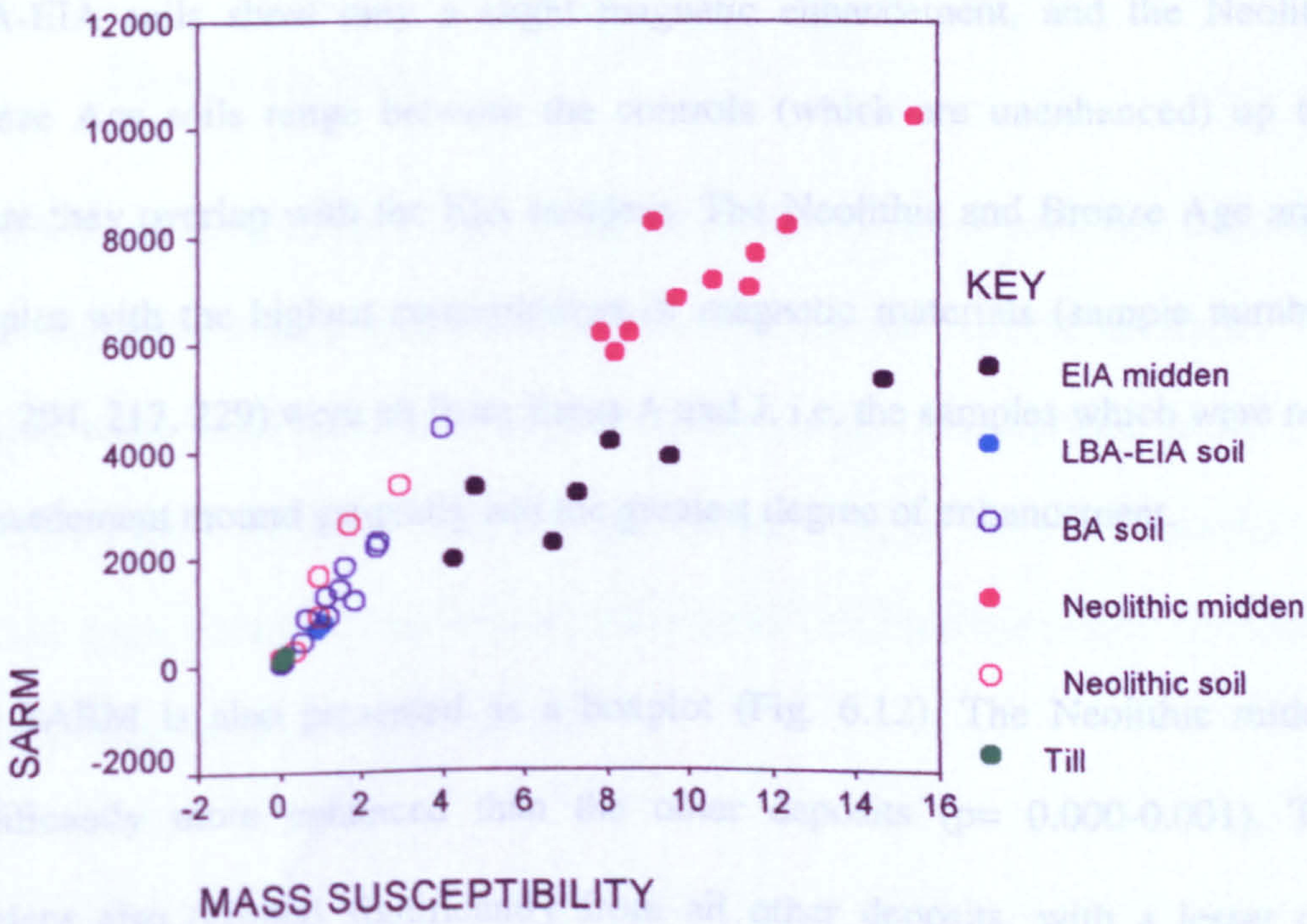



Figure 6.11: Soil magnetism

Figure 6.11 shows the mass susceptibility of the Tofts Ness samples plotted against the saturation anhysteretic remanent magnetisation (SARM). Increases in both axes indicate increased concentration of magnetic grains, so the greater the distance from the point of origin, the higher the concentration of magnetic material in the sample. Samples which have higher SARM measurements have steeper slopes, indicating finer grain sizes, whereas lower slopes indicate larger grain sizes which may represent the magnetite component (Dalan and Banerjee 1998).

The cluster of Neolithic midden samples show the highest magnetisation. The EIA middens have a lower concentration of magnetic material (apart from sample 211) and the material has a significantly larger grain size (ANOVA on ARM99, p=0.009). The LBA-EIA soils show only a slight magnetic enhancement, and the Neolithic and Bronze Age soils range between the controls (which are unenhanced) up to levels where they overlap with the EIA middens. The Neolithic and Bronze Age arable soil samples with the highest concentration of magnetic materials (sample numbers 200, 201, 204, 217, 229) were all from Areas A and J, i.e. the samples which were nearest to the settlement mound generally had the greatest degree of enhancement.

The SARM is also presented as a boxplot (Fig. 6.12). The Neolithic middens are significantly more enhanced than the other deposits (p= 0.000-0.001). The EIA middens also differed significantly from all other deposits, with a lesser magnetic concentration than the Neolithic middens (p=0.000-0.029). The SIRM showed similar results to the SARM but was slightly less effective in distinguishing the different areas.

An ANOVA on the *xfd* successfully distinguished the Bronze Age soils from the Neolithic soils (p=0.033), and also distinguished the Bronze Age soils from both the Neolithic (p=0.019) and the EIA middens (p=0.001).

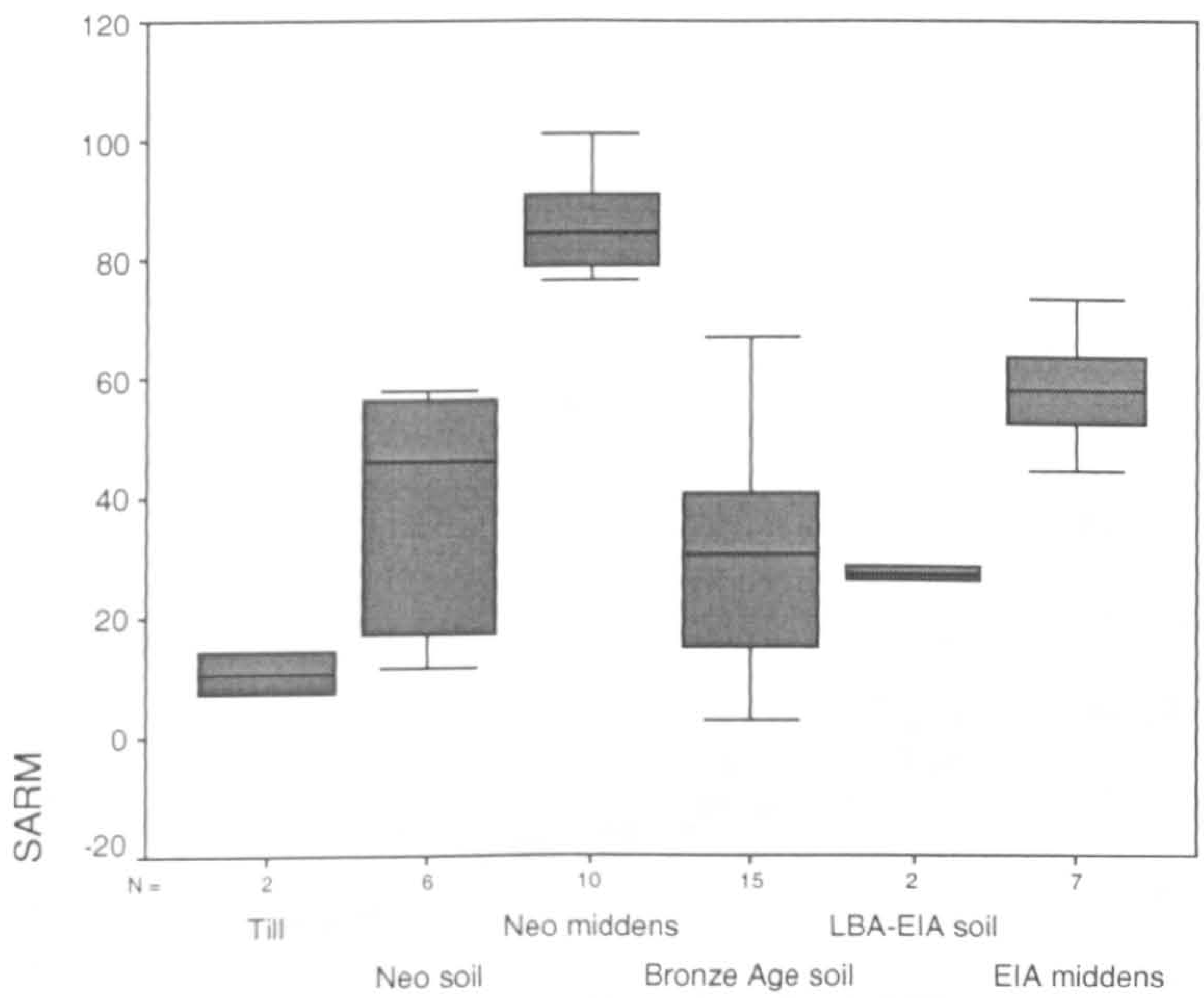



Figure 6.12: SARM

In Area J and in Test Pits 3, 4 and 6 there were distinct horizons within the Bronze Age soil. Micromorphology samples were taken across the horizon interfaces, and bulk samples were taken from each horizon adjacent to the Kubiena tins. In Area J and in Test Pits 3 and 4 the lower of the Bronze Age soil samples was more strongly enhanced than the upper (based on the SARM), whereas in Test Pit 6 the sample from the middle of the profile was higher than the base.

Figure 6.13 shows the amount of magnetic material generated by soil bacteria; this is a way of comparing microbial activity in the different samples (Barlow 1998). The plot shows that the EIA middens have the lowest bacterial magnetosome component, and that the LBA-EIA soils and nine out of the ten Neolithic midden samples also have low levels. The Bronze Age and Neolithic soils have varying quantities and do not fall into clusters.

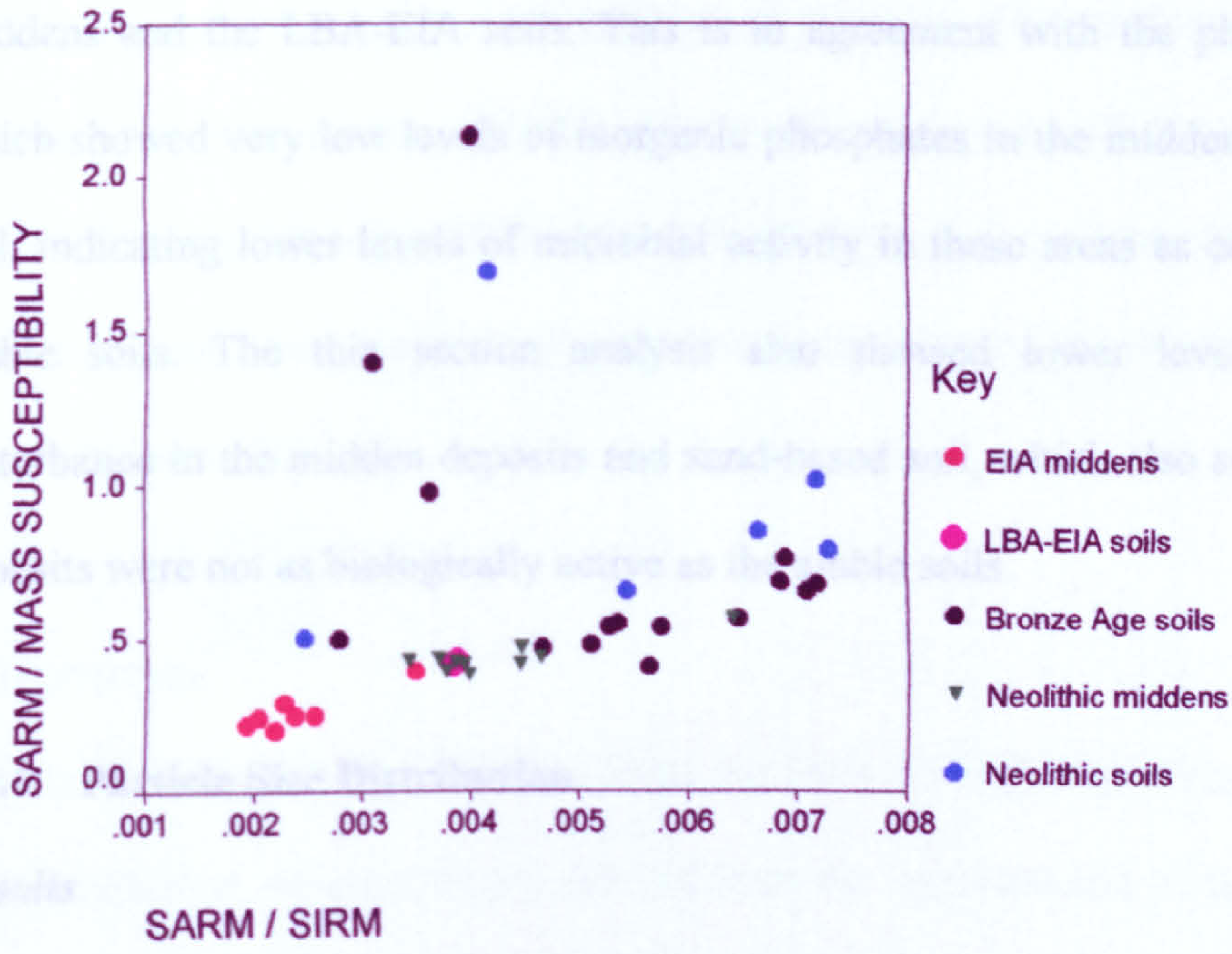



Figure 6.13: Bacterial magnetosome component

*Soil magnetism: interpretation*

The Neolithic middens had a higher concentration of magnetic materials than the other soils and sediments at Tofts Ness, which suggests that these deposits had the highest concentration of ash. The second highest levels of ash were in the EIA middens, which also had larger magnetic grains. The larger magnetic grain size of the EIA middens suggests that the fuel ash in these deposits is from a different source. The grain size may be reflecting greater concentrations of wood ash in the EIA as opposed to peat ash in the Neolithic middens; the thin section analysis showed consistently higher levels of wood charcoal in the EIA deposits and wood ash was also identified in these deposits and was not noted anywhere else.

The EIA middens had the lowest levels of bacterial activity, followed by the Neolithic middens and the LBA-EIA soils. This is in agreement with the phosphate analysis, which showed very low levels of inorganic phosphates in the middens and sand-based soil, indicating lower levels of microbial activity in these areas as compared with the arable soils. The thin section analysis also showed lower levels of earthworm disturbance in the midden deposits and sand-based soil, which also suggests that these deposits were not as biologically active as the arable soils.

### 6.2.6 Particle Size Distribution

*Results*

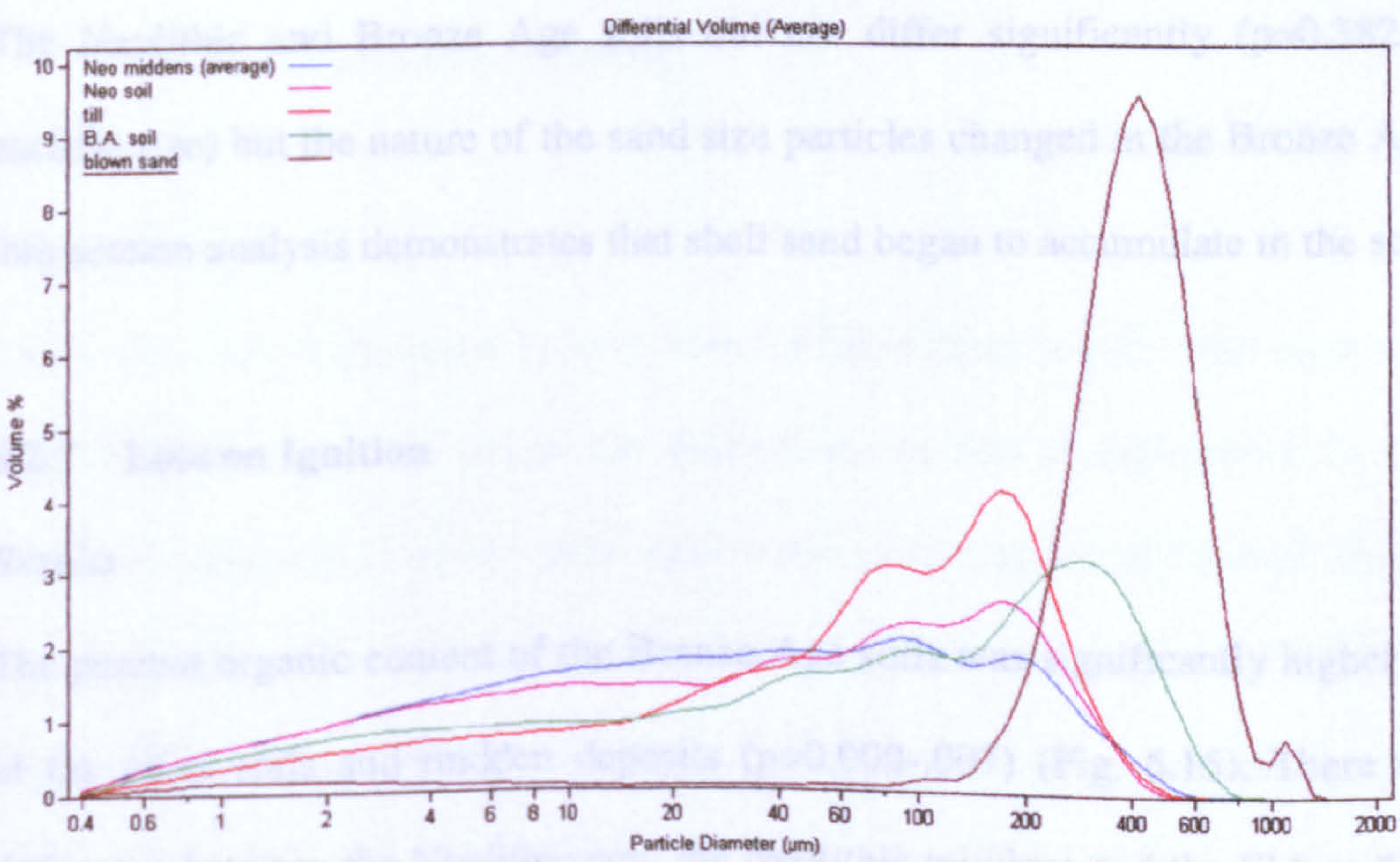



Figure 6.14: Particle size distribution in Area A

Figure 6.14 shows the similarity between the Neolithic soil and middens in Area A, and the increased sandiness of the Bronze Age soil. For further detail see Appendix 5. There was a significant difference (p=0.000) between the finer median particle sizes of the middens and the coarser particle size of the soils. The median psd did not differ between the soils of the different phases. The skewness of the Neolithic midden deposits was significantly different from those of the soils, and the skewness of the EIA midden deposits was significantly different from those of the Bronze Age and LBA-EIA soils (p=0.000).

*Interpretation*

The midden deposits were distinct from the soils, having a significantly finer particle size distribution which probably derives from the large amount of ash in the deposits. The Neolithic and Bronze Age soils did not differ significantly (p=0.382, median particle size) but the nature of the sand size particles changed in the Bronze Age, when thin section analysis demonstrates that shell sand began to accumulate in the soil.

### 6.2.7 Loss on Ignition

*Results*

The percent organic content of the Bronze Age soils was significantly higher than that of the other soils and midden deposits (p=0.000-.007) (Fig. 6.15). There was little difference between the Neolithic soil, the Neolithic middens and the EIA middens. The

LBA-EIA sand-based soil was lower in organic matter than the other soils and middens, but not significantly so (p=1.00).

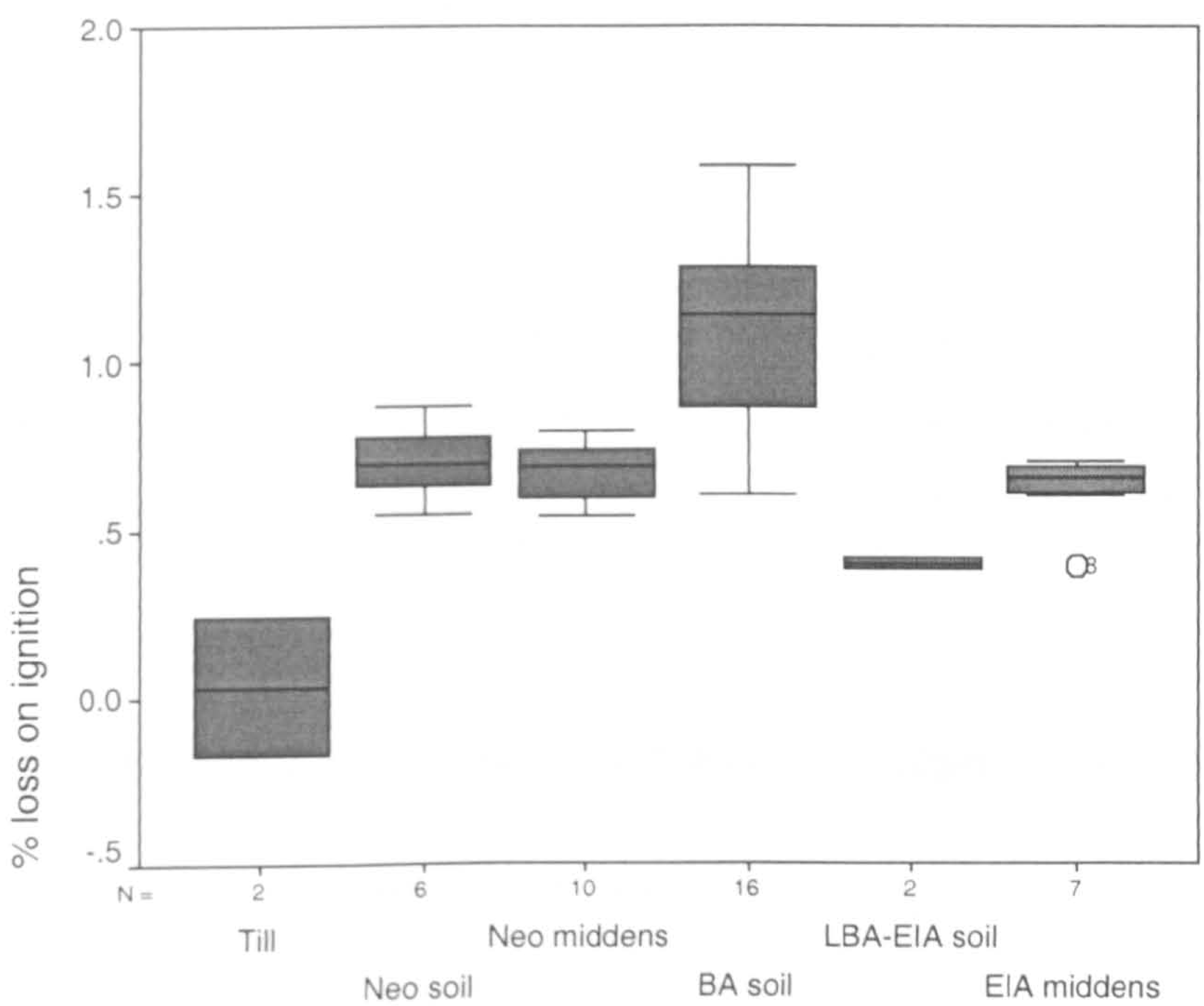



Figure 6.15: Loss on ignition

*Interpretation*

The Bronze Age soils appear to have been fertilised more heavily with organic material than the Neolithic soils, unless the differences are due to differential decay, which seems unlikely; the Neolithic soils were wetter and more deeply buried and therefore may be better preserved. The large amount of organic material in the soils has led to higher microbial and biological activity, which has led to an interesting contrast of correlations. The phosphates in the Neolithic and Bronze Age soils have been transformed into inorganic P to the extent that there is a negative correlation between

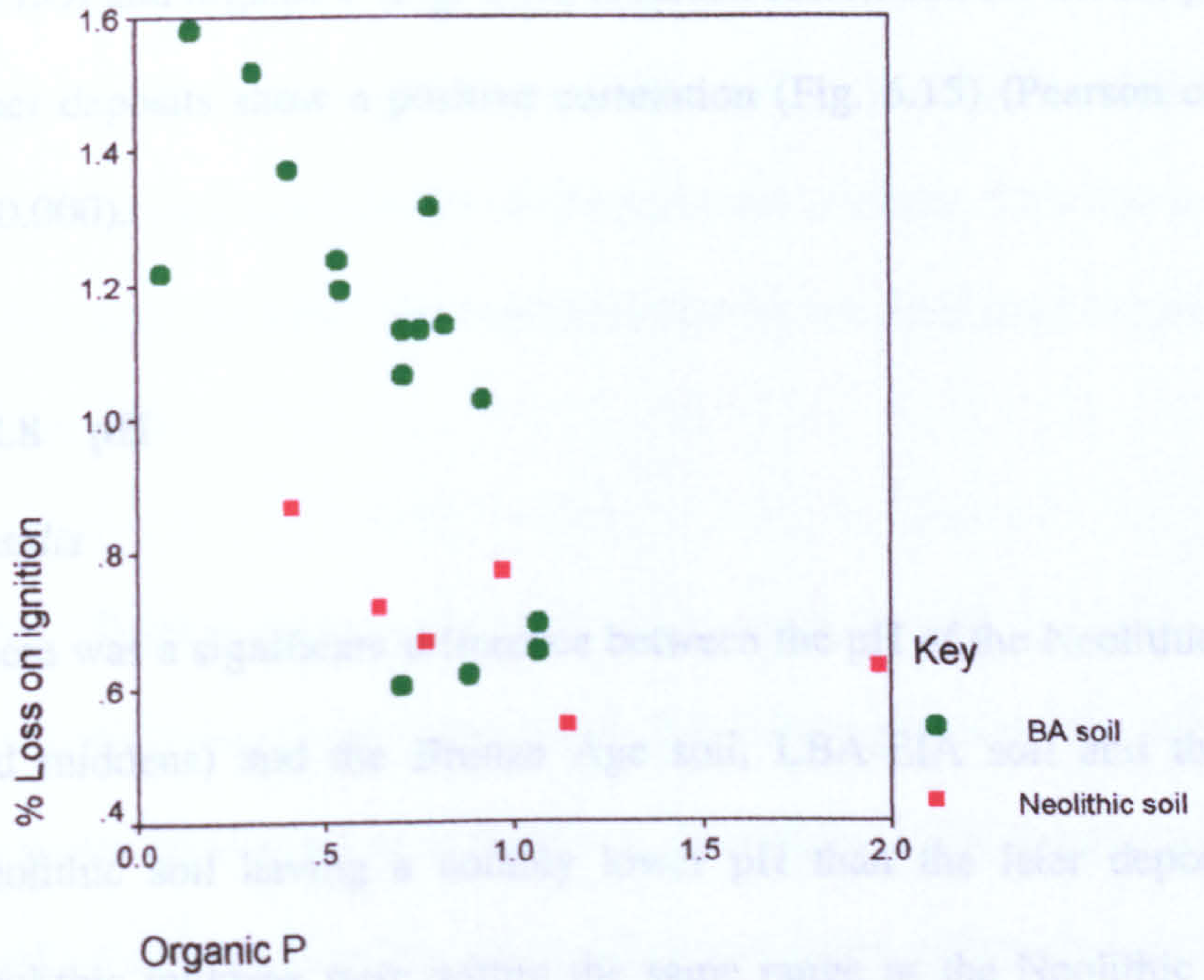



Fig. 6.16: Loss on ignition and organic P (negative correlation)

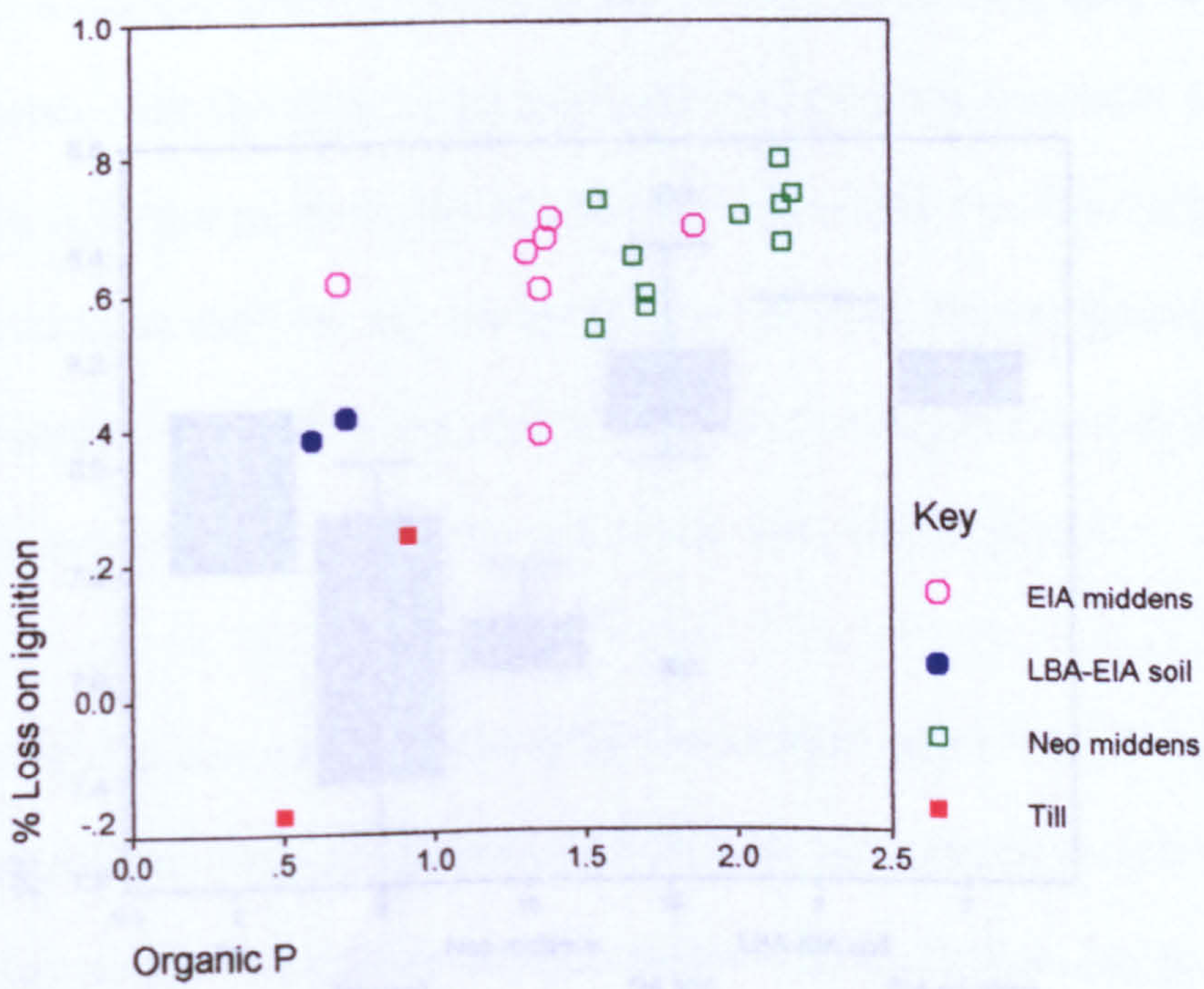



Fig 6.17: Loss on ignition and organic P (positive correlation)

the LOI and organic P (Fig. 6.16) (Pearson correlation r= -0.668, p=0.001), whereas the other deposits show a positive correlation (Fig. 6.15) (Pearson correlation r= 0.732; p=0.000).

### 6.2.8 pH

*Results*

There was a significant difference between the pH of the Neolithic horizons (both soils and middens) and the Bronze Age soil, LBA-EIA soil and the EIA middens, the Neolithic soil having a notably lower pH than the later deposits (Fig. 6.18). The Neolithic middens were within the same range as the Neolithic soil. All of the soils were alkaline.

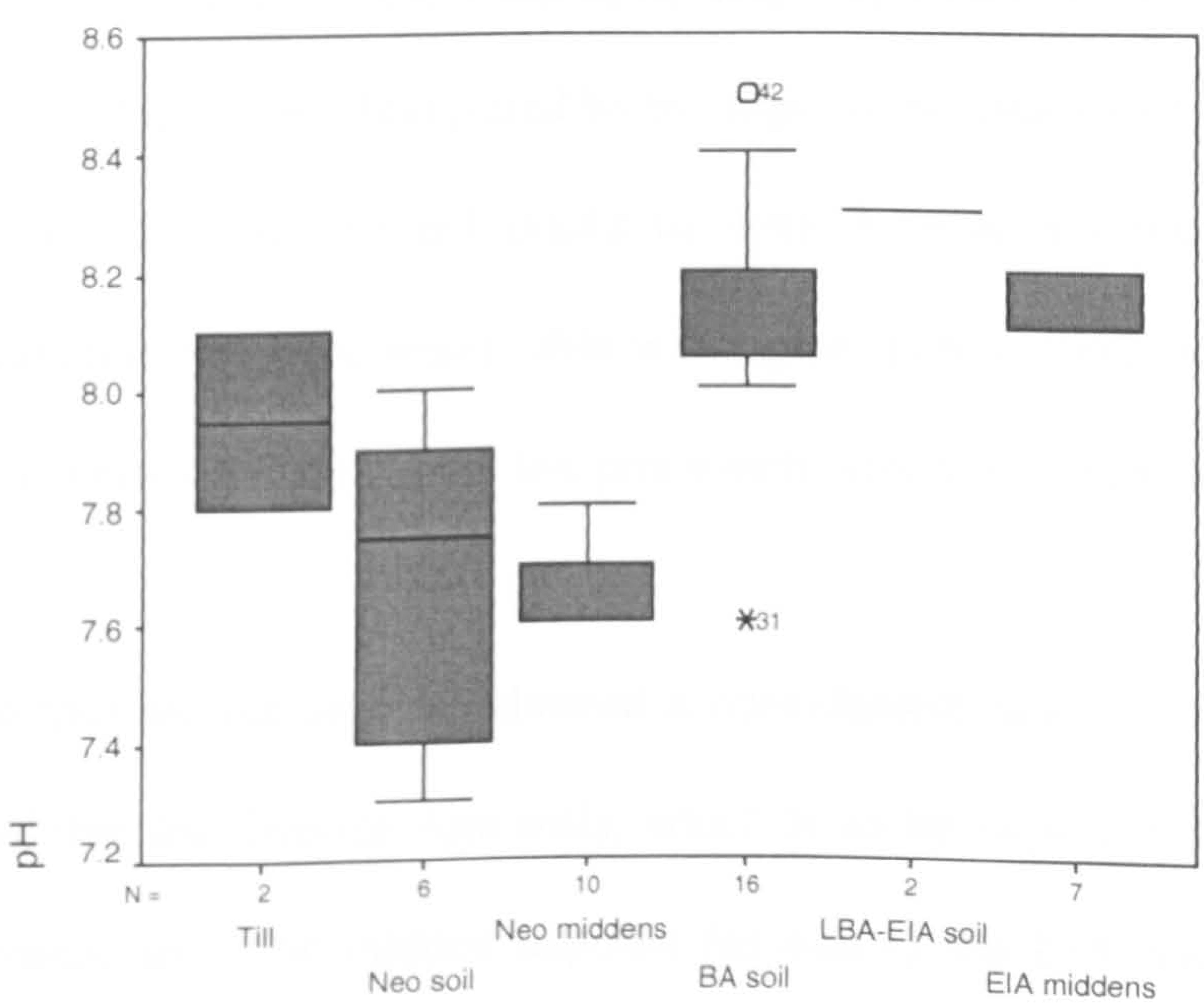



Figure 6.18: Soil and sediment pH

*Interpretation*

The pH reflects the shell content in the calcareous till (Dry and Robertson 1982) and the blown shell sand content in the soils and middens. This ties in clearly with the thin section analysis which demonstrated that blown shell sand began to accumulate in the Bronze Age.

### 6.2.9 Taphonomy

The Tofts Ness site is mostly below 3m O.D., and during the course of the excavation the water table stood at 2.75m O.D. According to the farmer, the land is often under standing water during the winter. This may cause differential preservation between the deposits which make up the settlement mound and the lower lying soils and middens. The wood ash and spherulites in the EIA middens may have survived because the deposits were above the water table, and may formerly have been present in the earlier soils. A further problem posed by the high water table was the recognition of ard marks cut into the till; the ard marks in Area A were not recognised during the 1980s excavation when the water table was higher than in 1999, and similarly it may be that there were ard marks in the test pits which were not recognised.

The thin section analysis showed a considerable amount of biological activity in the Neolithic and Bronze Age soils, which is to be expected in calcareous, organic-rich, manured soil. The midden deposits (especially the EIA middens) and the sand-based LBA-EIA soil showed much more limited signs of disturbance by soil biota. The magnetic enhancement produced by soil bacteria was in agreement with the thin section analysis, also showing more disturbance in the soils than in the midden deposits, the

EIA middens being particularly low. The field was ploughed in 1994 or 1995, although the mound itself was not disturbed. According to the farmer, the pasture is ploughed at intervals in order to keep the grass growing.

## 6.3 Discussion

The evidence from the thin section analysis, the phosphate analysis and the magnetic susceptibility has demonstrated that the Neolithic and EIA midden deposits contained significantly larger quantities of ash, charred material and phosphates than the Neolithic, Bronze Age and LBA-EIA soils. The buried Neolithic horizon in Area A was exceptional, however, in that it contained levels of phosphates and quantities of peat ash (identified in thin section) which were comparable to the overlying middens. This evidence suggests that the layer was a midden deposit, while the ard marks which cut into the till below the deposit are an indication that the layer was cultivated. The creation of intensively cultivated plots on the midden heaps may explain the preponderance of weed seeds associated with garden plots (rather than arable field weeds) which were found in the Neolithic middens (J. Bond, pers. comm.).

Analysis of the Neolithic soils in the surrounding test pits has shown that the horizon in Area A was exceptional. The Neolithic soils in Area J and the test pits were not significantly different from the overlying Bronze Age soils, and the two phases could not be distinguished on the basis of phosphate levels or magnetic susceptibility enhancement, even when the outlier in Area A was removed from the tests. The Neolithic soils on the whole seemed to contain larger amounts of anthropogenic material than the Bronze Age, although it may be that the Bronze Age soils were 'diluted' with windblown sand; on average the Bronze Age soils were 44% mineral and shell whereas the Neolithic soils were only 26% mineral.

There were very rare phytoliths in all phases of soil and midden deposits, but there were larger amounts in the Neolithic soil in Area A and in the midden deposit directly above. This could be an indication either of added turf or peat ash (both deposits contain 2-5% charred peat) or of added animal manure (both deposits have enhanced phosphate levels). The diatoms which were found in most of the midden samples and many of the soils could also have been introduced either in peat/turf, peat/turf ash or animal dung. The palaeobotanical analysis established that charred remains of aquatic and damp-loving species were found throughout the Neolithic deposits, but these too could have been introduced either in peaty turf (Bond 1994b) or in cow dung. These species are much less frequent in later deposits, perhaps indicating the exhaustion of the peat source.

The EIA midden deposits were distinct from the Neolithic middens in that they contained larger amounts of charred peat and woody charcoal; they were also the only deposits to contain wood ash, although the survival of ash crystals may be a taphonomic factor due to the level of the middens above the water table (ash crystals are water soluble). The SARM showed a larger grain size in the EIA middens than in the Neolithic, possibly indicating a different fuel source.

Animal dung may have been burned for fuel in the Neolithic (Bond 1994b), which would explain the absence of stigmastanols in the arable soil (Simpson et al 1998a), but where was the fuel ash actually going if this were the case? Burning would transform the organic P into inorganic P, and all deposits on site are clearly dominated by the organic form. The high levels of organic P in the middens suggests that animal dung was deposited there instead of being spread onto the fields. Since the middens, at least in the earliest phase, were being cultivated, the nutrients from the dung were not lost. In the EIA, however, spherulites are found in the uncultivated midden dumps, indicating the presence of dung which could have been used to enhance the fertility of the arable soils. It may be that this midden material was never used because the site was abandoned.

The finer particle size of the midden deposits probably reflects the higher ash content. What the particle size plots did not show was the very notable differences in the blown shell sand in the soils, which was identified in the thin sections (and also reflected in the pH). There was little or no shell sand in the Neolithic soils, and the shell-filled earthworm burrows identified in thin section suggest that the little shell that occurred was probably worked down into the soil from the layers above. During the Neolithic the blown shell sand began to accumulate on the land surface; in places this survives as a thin layer, while in others it is incorporated into the Bronze Age ploughsoil. The shell sand makes up on average 25% of the Bronze Age soil, which suggests that it continued to blow inland throughout the Bronze Age. The sand-based LBA-EIA soil (phase 5) which developed at the end of the Bronze Age indicates that either the sand blow increased or manuring decreased. Dockrill (1993) suggested that the sand blow of Phase 5 could have accumulated in a single gale. Such catastrophic sand blows are recorded in 18th and 19th century accounts from the coastal regions of Scotland:

> The road beyond Aberdeen grew more stony, and continued equally naked of all vegetable decoration. We travelled over a tract of ground near the sea, which not long ago, suffered a very uncommon and unexpected calamity. The sand of the shore was raised by a tempest in such quantities, and carried to such a distance, that an estate was overwhelmed and lost. Such and so hopeless was the barrenness superinduced, that the owner, when he was required to pay the usual tax, desired rather to resign the ground (Johnson, 1775).

The middens of the roundhouse (Phase 6) overlay the sandy LBA-EIA soil, so we know that settlement continued despite the sand deposition, but the soil would have been very unproductive and may have gone out of use altogether while the site was still inhabited; the EIA middens contained spherulites indicating the presence of organic manures, which could have been spread out onto the fields to increase cohesion and fertility, if the fields had still been maintained. It may be that by this stage the site was obtaining grain through trade with other settlements on more productive soils. The final sand blow which sealed the LBA-EIA ploughsoil also sealed the EIA middens. This could have occurred after the site was abandoned, or, as Dockrill suggests, could have caused the abandonment of the site. The evidence from the Bronze Age and later soils indicates that the inhabitants of Mound 11 had been coping with blown sand accumulation for some time, however, and the site may have been abandoned for social rather than environmental reasons.

# CHAPTER 7: OLD SCATNESS

## 7.1 Introduction

Old Scatness is a multi-period settlement mound located at the southern tip of Mainland Shetland (NGR HU 3895 1070), to the west of Sumburgh airport (Fig. 7.1). The mound is located in the abandoned village of Old Scatness, which is shown on the 1st edition O.S. map of 1878 to the north of the present day village of Scatness. The 5m high mound was formed by the accumulation of rubbish and structural debris which built up as a result of building and rebuilding on the same plot of land over the course of millennia. The land surrounding the settlement mound was also aggraded, partly through the addition of fertilising materials to the fields around the settlement and partly through the deposition of wind-blown sand (Simpson et al 1998b). The site was excavated from 1995-2000 by the University of Bradford under the direction S. Dockrill and was selected as a study site for the same reasons as Tofts Ness, i.e. because of the excellent preservation, the multiple phases of activity and because the chronology of the site has been established (based on stratigraphic analysis, radiocarbon dating and OSL dating) (Nicholson and Dockrill 1998). The settlement at Old Scatness was even more long-lived than Tofts Ness, having been occupied for *c.* 5000 years (although not necessarily continuously).

Preliminary work on the soils surrounding the settlement mound established that the Neolithic/Bronze Age soil was fertilised primarily with domestic waste, i.e. with

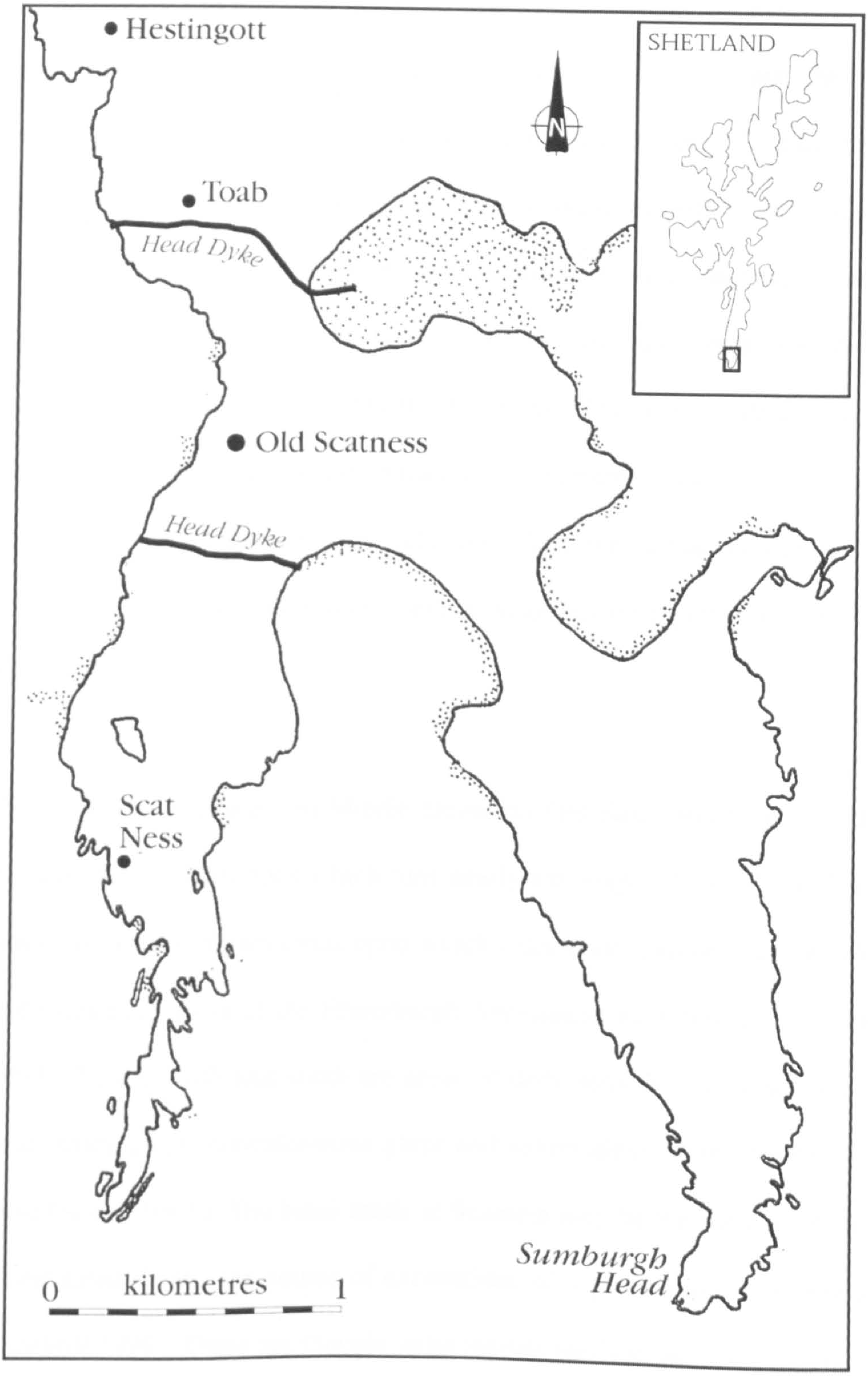



Figure 7.1: Location of Old Scatness, showing head dykes and control sample locations

kitchen refuse and ash from domestic hearths (Simpson et al 1998b). In the Middle or Late Iron Age there was a change in the type of fertilising materials and the soils became more rich in phosphates and in organic matter (*ibid.*). The current project was undertaken in order to analyse the midden deposits within the settlement and to compare these with the soils. If certain types of waste material were deliberately selected for use as fertiliser on the arable fields, then other types of waste material may have accumulated unused within the settlement. The work at Bragasetter (Chapter 5) demonstrated that it is possible to trace the movement of materials from moorland onto the settlement and then onto the fields on a farm which has been recently abandoned; this work aims to trace the movement of materials on a prehistoric settlement and its hinterland.

Old Scatness is situated on Middle Devonian Old Red Sandstone. To the north is a band of metamorphic rock which runs nearly the length of the island. The site is on a low-lying area of blown sands upon which calcareous regosols, brown calcareous soils and calcareous gleys of the Fraserburgh Association have formed (Dry and Robertson 1982). To the north and south are areas of drift derived from sandstone, upon which peat, peaty gleys, noncalcareous gleys and saline gleys of the Skelberry Association have formed (*ibid.*). The basal sands at Scatness may be the same as those which were investigated during the course of excavations of a prehistoric house site at Sumburgh (Dockrill 1998). These are thought to be marine sands from a post-glacial raised beach 2 m above the current sea level.

The southern tip of Mainland Shetland has been inhabited since the Neolithic and was very fertile before the sand blows of the 17$^{th}$ and 18$^{th}$ centuries. An observer in 1774 described the scene as

> ...an Arabian desert in miniature, here the clouds of sand flying as far as the eye can reach, there the crowds of travellers, scarce to be seen for the drifting sand, riding to church; near the sea, the church, with foundations almost blown away, the corpses entirely bare, in many instances the bones bleached white; farther inland the ruins of scattered buildings, both ancient and modern, all contribute to render the scene more distressing, and add to the depression of spirits occasioned by this dreary view. The sand penetrates everywhere; when I stept into the kirk, observed it found its way thro' the minutest crannies, covering the whole pews, and thus becomes very troublesome in time of divine service, especially if the wind blows from the sea, whence the sand shower seems to proceed. (Low 1779)

There were several crofts at Quendale, to the north of Scatness, which were abandoned after they were buried in sand in the 19$^{th}$ century. Around the turn of the century Marram grass (*Psamma arenaria*) was introduced by the local landlord to stabilise the coastal dunes (Jim Irvine, Sumburgh Farm, pers. comm.); this method has been recognised at least since the reign of Elizabeth (1558-1603), who forbade the destruction of the grass because of this beneficial effect (Borlase 1932). The measure seems to have been reasonably successful, and the sand blows no longer bury the local fields (Irvine pers comm).

### 7.1.1 Archaeological Background

The southern tip of Mainland Shetland is currently being surveyed as part of the Jarlshof Environs Survey, which is recording all of the archaeological features in the region and trial trenching sites of particular interest (Turner 1998). Sumburgh Head, Compass Head, the Scat Ness peninsula and an area around Eastshore have been surveyed to date. The earliest structure in the Sumburgh area is a chambered cairn, and the remains of a house and field system with small fields and clearance cairns have also been recorded. These fields are characteristic of the Neolithic and Bronze Age and are at the same height above sea level as more securely dated sites of these periods (Turner 1998). There is an Iron Age blockhouse fort (a structure type which pre-dates the brochs) at Sumburgh Head, and another two on the Scat Ness peninsula (Carter et al 1995). In addition to the broch at Scatness there is one at Eastshore and another at Toab. There is also a possible Pictish building (figure of eight style) on the Scat Ness peninsula. The Orkneyinga Saga describes 'a good many people' meeting the Earl Rognvald at Sumburgh Head (Palsson and Edwards 1981), but the only known Viking structures in the area are the longhouses at Jarlshof, less than 2 km to the south of the Old Scatness site (Hamilton 1956).

Jarlshof is a multi-period settlement similar to Old Scatness in that it spans the Neolithic to the medieval periods, and it is therefore an important parallel. The earliest structures at Jarlshof were four oval houses dating to the Neolithic and Bronze Age (*ibid.*). Towards the end of the Bronze Age these were replaced by circular structures. Later in the Iron Age a broch was built, and subsequently a roundhouse was built in the broch courtyard. Still later in the Iron Age three wheelhouses were built, one of them sited within the broch. The Iron Age structures were sealed in up to 2 m of sand before Pictish structures were built, later to be sealed beneath a cluster of Norse longhouses. The Norse settlement was occupied and rebuilt over a long period of time, and settlement continued into the medieval period with the construction of a substantial 16$^{th}$ century house (*ibid.*).

Jarlshof was initially excavated by the owner of the site between 1897 and 1905, and was later excavated by A. Curle and G. Childe. The work was completed by J.R.C. Hamilton and published in 1956. Very limited environmental archaeology was carried out in excavations of this time, which tended to focus on establishing the plans and sequence of buildings. The current excavation at the similar site at Scatness is aimed at redressing this shortcoming by carrying out extensive palaeoenvironmental and palaeoeconomic sampling and analysis on all of the deposits.

### 7.1.2 The Old Scatness excavation

The Scatness settlement mound is about 5m high and is made up of a series of structures and midden deposits (Fig. 7.2). The surrounding land surface has also been built up, partly through the addition of fertilising materials to the soil and partly through the deposition of blown sand, which has sealed and preserved the soils. Five phases of activity have been identified in the course of the excavations, but the work is ongoing (Nicholson and Dockrill 1998):

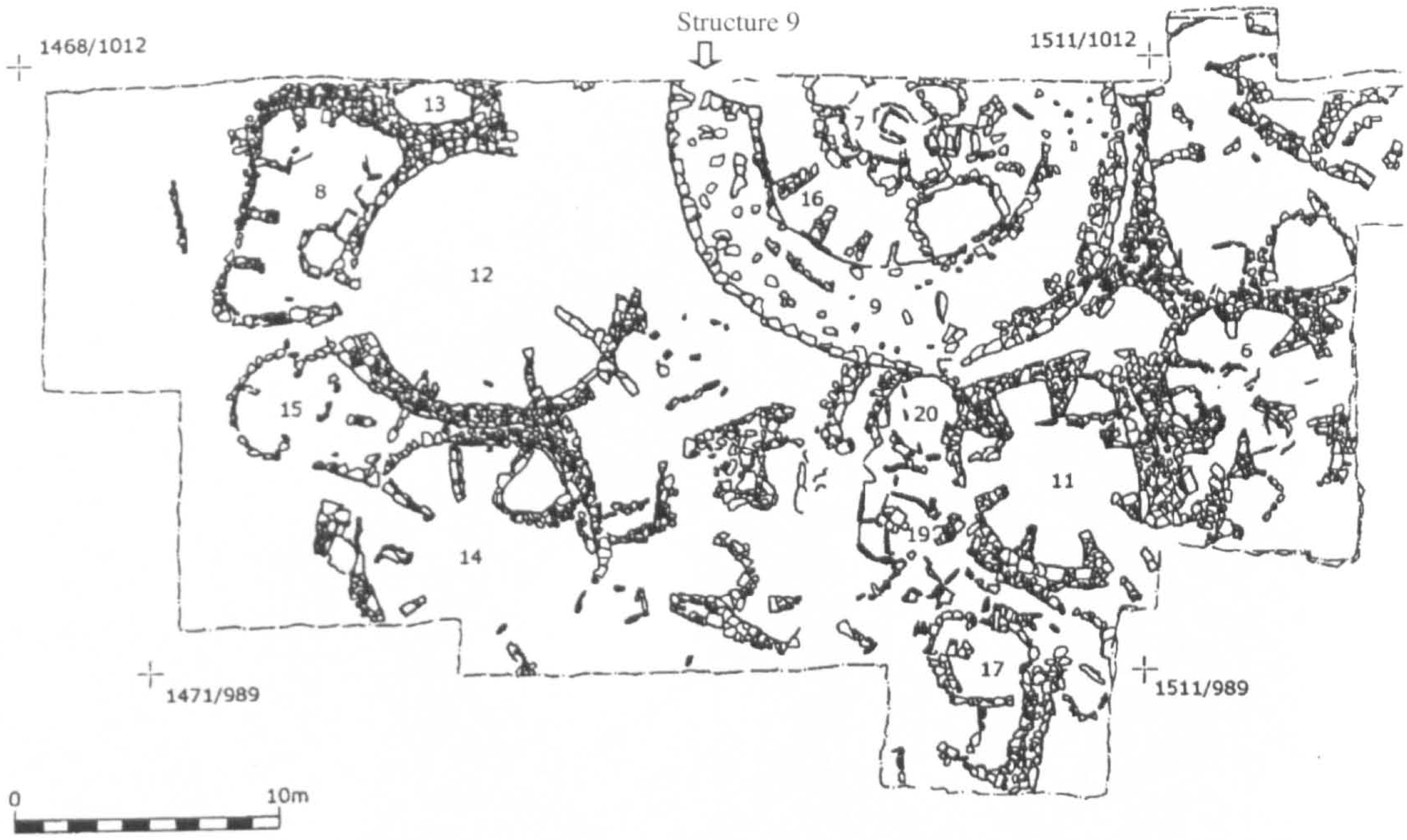



Figure 7.2: Site plan of Old Scatness, showing structures

*Phase I: Neolithic to Bronze Age*

An anthropogenic arable soil was developed on the (probably marine deposited) quartz sand. Ard marks which were cut into the underlying sand and filled by the soil show that the horizon was cultivated (Plate 19). Neolithic pottery was recovered from the soil, and a TL date of 2500-2000 BC was obtained from material within the layer. An OSL date of 2449±791 BC is in fairly close agreement.

*Phase II: Middle Iron Age*

A broch (Structure 9, Plate 20) was constructed in this phase, but it has not been fully excavated. The upper part of the tower is 18m in diameter but it will be larger at the base of the wall, which will be exposed when the excavation reaches ground level (Dockrill et al 2000).

Plate 19: Neolithic/Bronze Age ard marks. Photo by Val Turner.

Plate 20: Aerial photograph of the site under excavation. (Photo by S. Dockrill).

*Phase III: Middle Iron Age(post-broch)*

A substantial roundhouse (Structure 12) was built to the south-west of the broch, with five or six abutting, secondary structures including a sub-rectangular structure (8). OSL dates from the midden material which infilled Structure 12 produced dates of 42BC-AD216 (95% confidence. GU-8379) and 86BC- AD127 (95% confidence. GU-8380). The broch was still standing in this phase, and the internal walls which were added as a secondary feature may have been built at this time. There were also structures to the south and east of the broch.

*Phase IV: Pictish/ Early Norse Interface and Norse Settlement*

To the south of the broch was a large structure with radial walling (Structure 11) and a wheelhouse (Structure 6), which was probably the later of the two buildings. To the north of the wheelhouse was a multi-cellular 'figure-of-eight' structure, a shape which is characteristic of Pictish architecture (shown to the left of the broch in Plate 20). The Pictish building (Structure 5) overlay and re-used parts of an earlier structure. The Pictish Structure 5 was infilled with material containing Norse artefacts, including a steatite line sinker which probably dates to the Late Viking period, AD900-1000. The deposits also contained native pottery types. Large amounts of six-row hulled barley were recovered, and also flax. Norse artefacts and native ceramics were also found together in the upper fill of the building predating the wheelhouse, to the south of the broch. There were no definite Early Norse structures, but a flagged surface and part of a wall were stratigraphically placed and on the right level to suggest that they were of this date. It may be that the Norse structures were removed by later, post-medieval activity.

*Phase V: Post medieval*

Settlement is believed to have been continuous from the Norse into the post-medieval period (S. Dockrill, pers. comm.) Features include a 17th century corn drier and midden deposits, and a soil TL dated to *c.* AD 1800 was identified (the OSL date of AD1802$\pm$ 27 was in close agreement). The 1st edition O.S. map (1878) shows crofting buildings and a kaleyard, but by the time of the second edition map (1900) the buildings had been removed, and only the kaleyard survived (Dockrill 1998). This was re-used in the 20th century, when an adjoining building and cattle byre were built (*ibid.*).

Head Dykes divided the arable area of the Scatness township from the rough grazing areas to the north and south (Fig. 7.1). The northern Head Dyke ran from a point immediately to the south of Toab to the Pool of Virkie, and the southern dyke ran between Sanblister and Sand Point (Brian Smith, pers. comm.) (Fig. 7.1). The township area that these boundaries demarcate was an area of good agricultural land before the 17th-18th century sand blows, but the present soils of the Fraserburgh Association are suited only for use as improved grassland or rough grazing (Dry and Robertson 1982). The rough grazing areas to the north and south are on less fertile peaty and gleyed soils of the Skelberry association, which overlie boulder clay (*ibid.*).

### 7.1.3 The soils

Analysis of the soils surrounding the settlement mound was carried out during earlier phases of the Bradford excavation (Simpson et al 1998b). The work included an auger survey to establish the extent of the buried soils, thin section micromorphology, total phosphate analysis, particle size distribution and loss on ignition (LOI). Six test pits were examined, and samples were taken from the Bronze Age, Iron Age and post-Iron Age soils. The soil horizons in the different test pits were correlated by Munsell colour, the Neolithic soils being reddish brown and the Iron Age soils very dark greyish brown. Control samples were taken from the 19$^{th}$ century kaleyard and from an ash midden on site.

The Neolithic soils contained animal bone and Ca-Fe-phosphate accumulations. The animal bone indicates the addition of cultural material, and the phosphate accumulations were thought to derive from the animal bone (*ibid.*). The stratigraphically later Neolithic or Bronze Age soils contained fine red material, rubified mineral material and fine charcoal, indicating the addition of burnt material. The soil also contained bone fragments, indicating the addition of domestic waste. The loss on ignition range was 0.9%-3.2% and the phosphates measured 711-1516 mgP/100g soil.

The earliest Iron Age soils were similar to the Neolithic/Bronze Age soils, in that they contained fine red material, fine charcoal, rubified stone and animal bone (*ibid.*). The Iron Age soils also contained fish bone.

The later Iron Age soils also contained reddened material, but had larger amounts of both lignified and amorphous organic material than the earlier soils (the loss on ignition range was 2.9-5.9%). Although this could be a factor of differential preservation, the higher organic content in the deposit is reflected in the higher concentration of phosphates, which measured 1125-1782 mgP/100g soil. The LOI, the observable organic material in thin section and the phosphate levels were higher than in the Neolithic/Bronze Age, which suggests that animal manure was added to the soil in larger amounts than in the earlier phases (*ibid.*).

There was an increase in the deposition of blown sand in the Norse, medieval and post-medieval periods (*ibid.*). The episodes could be very severe; in the early part of the 20$^{th}$ century a village on the Bay of Quendale was buried. The soils reflect this increase, but still contain rare animal bone and some rubified mineral material. The numbers of fish bone increase at this time. The loss on ignition range was 2.0-4.9%, lower than in the Iron Age but higher than in the Neolithic. The phosphate range was 567-1107mgP/100g soil, lower than in both of the earlier periods. The Norse manuring practices are believed to have remained the same as in the Iron Age, however, and the arable area was also expanded in this period.

## 7.2 Results

### 7.2.1 Fieldwork

The aim of the fieldwork at Scatness was to sample the dated midden deposits, in order to compare material in the middens with material in the buried soils. The work also aimed to sample a complete profile through the buried soil and sedimentary sequence in a test pit which was being sampled for OSL dating. This will provide more secure dating for the soils and link them more closely to the settlement deposits. A column of samples was taken from a test pit (Area H), *c.* 25 m west of the broch and adjacent to the previous season's Area D, where Neolithic ard marks were recorded. The section in Area H was the most complete single profile of the site stratigraphy. Samples were also taken from Later Iron Age midden deposits cut by the Pictish structure (Structure 5) and from Middle Iron Age midden deposits infilling the Iron Age Structure 12. Control samples were taken from areas of differing underlying geology, at Toab (NGR HU385 115), Hestingott (HU385 124) and the Scat Ness peninsula (HU3865 0920) (Fig. 7.1). All sample and context numbers are cross referenced in Table 7.1.

### 7.2.2 Soil Micromorphology

*Results: Area H*

The sequence of thin section samples from Area H (Fig. 7.3) is shown in Table 7.2. The sand at the base of the sequence is composed of nearly equal amounts of lithic clasts and quartz, with a slightly higher proportion of lithic clasts. The mineralogical composition of the control samples from Toab and Hestingott is similar to that of the Area H sand, both samples having 5-15% quartz and 15-30% lithic clasts. In the control sample from Scat Ness, by contrast, quartz makes up 90-95% of the mineral component and lithic clasts make up <2%. Feldspars, hornblende and other minerals together make up <5% in all three of the control slides and in the basal sands.

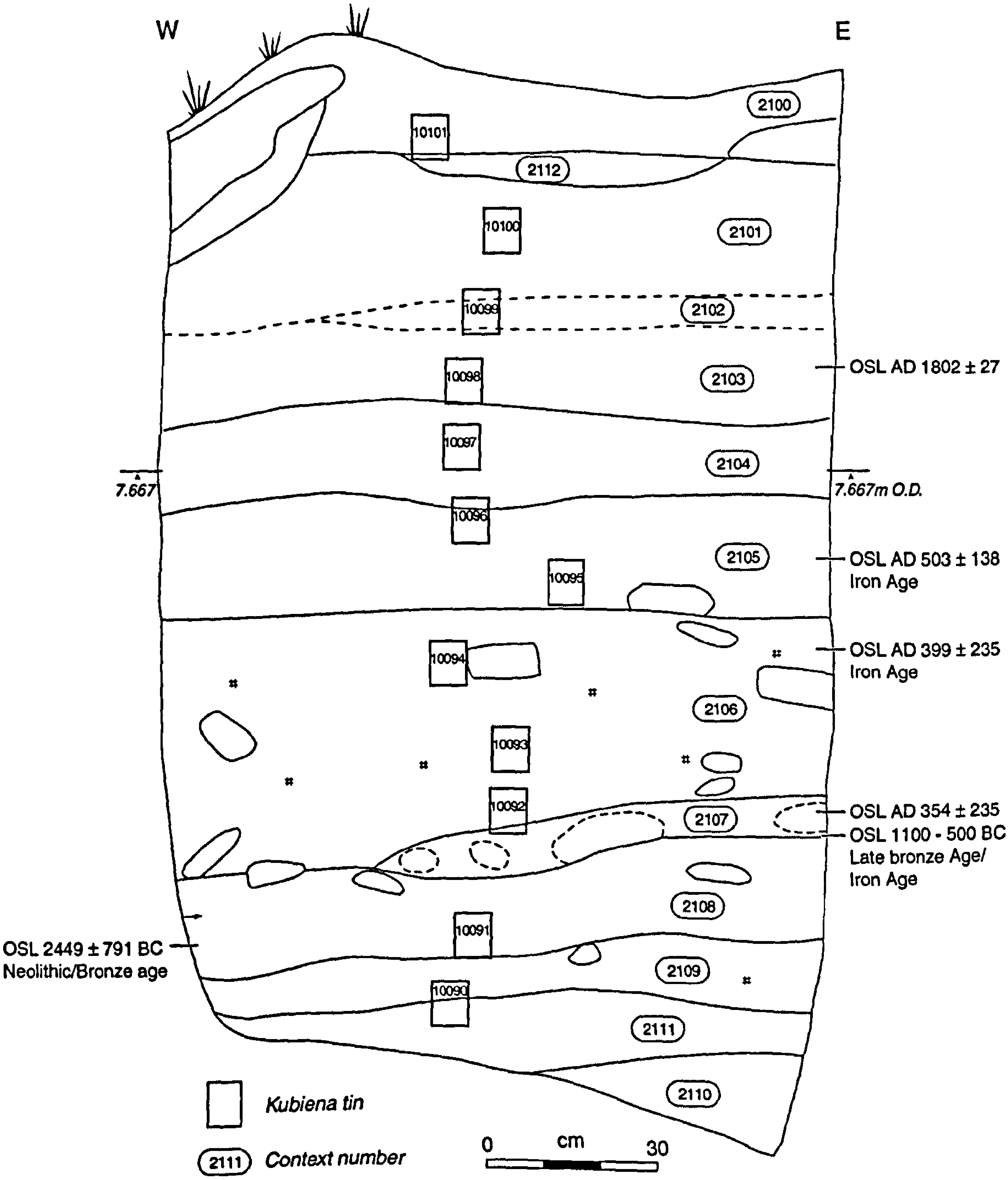



Figure 7.3: Section, Area H. (See Table 7.1 for context descriptions)

Table 7.1: Scatness context descriptions

| Context | Samples | Description and phase |
|---|---|---|
| 2111 | 10090 | Glacial sand, cut by ard marks (non-calcareous sand, 10YR 4/3) |
| 2109 | 10090 | Neolithic/Bronze Age arable soil (sandy silt, 5YR 4/3) |
| 2108 | 10091 | Neolithic/Bronze Age soil (OSL date 2449 $\pm$ 791 BC) (sandy silt, 5YR 3/3) |
| 2107 | 10092 | Soil or midden (sand with midden material, 5YR 4/3)<br>Disparity of dates: 1100-500 BC and 354 $\pm$ 235 AD |
| 2106 | 10092;10093;<br>10094 | Middle to Late Iron Age soil or midden (OSL date 399 $\pm$ 235 AD)<br>(sandy silt loam 7.5YR 4/4 and 10YR 3/2, with sandy lenses 10YR 4/3) |
| 2105 | 10095; 10096 | Middle to Late Iron Age (503 $\pm$ 138 AD) and (200 AD) (sand, 10YR 5/4) |
| 2104 | 10097 | Undated dark soil, <2% shell (sandy silt loam 10YR 3/3) |
| 2103 | 10098 | Shelly soil, AD 1802 $\pm$ 27 (sandy silt, 10YR 3/2) |
| 2102 | 10099 | Shelly soil, 19$^{th}$ century or later (sand 10YR 6/4 and 3/2) |
| 2101 | 10100 | Shelly soil, 19$^{th}$ century or later (sandy loam, 10YR 4/4) |
| 2100 | 10101 | Shelly soil, modern soil (sandy loam, 10YR 3/3) |
| 1728 | 10113; 10114 | Middle Iron Age midden (orange) |
| 1729 | 10112 | Middle Iron Age midden (silty clay, 7.5YR 4/1) |
| 1730 | 10111 | Middle Iron Age midden (silty clay, 10R 4/8) |
| 1731 | 10110 | Middle Iron Age midden (silty clay, 5YR 4/3) |
| 1732 | 10109 | Middle Iron Age midden (sandy silt loam 10YR 3/1) |
| 512 | 10103 | Late Iron Age midden (sandy loam, 2.5YR 3/4) |
| 512 | 10106 | Late Iron Age midden (sandy loam, 2.5YR 3/4) |

Both horizons of the Neolithic soil (Contexts 2108 and 2109) contained 2-5% bone. The horizon above (2107) had slightly less, and the samples from the Iron Age Context 2106 contained between 2-5% and (in the uppermost sample) between 5-15%. In all the horizons above there were only very rare fragments, <0.5%.

Shell fragments first appeared in small quantities (<0.5%) in the base of Context 2106, but were absent from the uppermost sample from the context and from both samples in the layer above. Small amounts were present in both samples from Context 2104 (Samples 10096 and 10097), and increased markedly in the 18th /19th century and later deposits (2103 and above).

Table 7.2: Thin section analysis of Area H

| (Context) and Sample | Depth (metres) | Date | Quartz | Lithic clasts | Bone | Shell | Fine Fabric (PPL) | Fine Fabric (OIL) | Charcoal (peat/turf) | Charcoal (wood) | Coal ash | Red fibrous material | Phytoliths | Diatoms | Fungal spores | Porous excrement | Dense excrement | Earthworm/slug granule | Amorphous organo-min | Microstructure | Related Distribution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (2100) 10101 | .12 | 20th cent. | •• | •• | + | • | Yellowish red, dark red | Reddish brown | ++ |  | + | ++ | + |  | + | • | •• | + | +++ | Complex: spongy, with channels & chambers, blocky | Porphyric |
| (2101) 10100 | .28 | 18th or later | • | •• | + | • | Yellowish red, dark red | Yellowish red | ++ |  |  | +++ | + | + |  | • | • |  | +++ | Complex: intergrain microaggregate and subangular blocky | Porphyric, areas of enaulic |
| (2102) 10099 | .43 | 18th or later | •• | •• | + | •• | Dark reddish brown | Reddish brown | + |  |  | +++ | + |  |  | • | • | + | +++ | Intergrain microag. with areas of sub-angular blocky | Enaulic |
| (2103) 10098 | .55 | 18th cent. | •• | •• | + | • | Dark red | Brown. One area of bright orange. | ++ |  |  | ++ | + | + |  | • | • | + | ++ | Intergrain microag., with areas of angular blocky | Enaulic |
| (2104) 10097 | .67 | undated | •• | •• | + | ++ | Dark reddish brown | Yellowish red | ++ |  |  |  | + | + |  | • | ••• |  | ++ | Spongy | Close porphyric |
| (2104) 10096 | .77 | undated | •• | •• | + | + | Brown, dark brown | Reddish yellow | ++ |  |  |  | + | + |  | • | •• |  | +++ | Spongy; areas of intergrain microag./ crumb | Porphyric |
| (2105) 10096 | .81 | Iron Age | •• | •• | + |  | Dark brown, dark reddish brown | Reddish yellow | ++ |  |  | + | + |  |  | • | • |  | + | Intergrain microag.; grains partly coated w/ fine fabric | Chitonic, partly enaulic |
| (2105) 10095 | .90 | Iron Age | •• | ••• | + |  | Dark reddish brown | Reddish yellow | ++ |  |  |  | + |  |  | ++ | ++ |  | ++ | Complex. Bridged, w/ intergrain microaggregates | Chitonic, partly enaulic |

KEY: + Very Rare (<0.5%), ++ Rare (0.5-2%), +++Very Few (2-5%), • Few (5-15%), •• Frequent (15-30%), ••• Common (30-50%), •••• Dominant/Very Dominant

Table 7.2: Thin section analysis of Area H

| (Context) and Sample | Depth (metres) | Date | Quartz | Lithic clasts | Bone | Shell | Fine Fabric (PPL) | Fine Fabric (OIL) | Charcoal (peat/turf) | Charcoal (wood) | Coal ash | Red fibrous material | Phytoliths | Diatoms | Fungal spores | Porous excrement | Dense excrement | Earthworm/slug granule | Amorphous organo-min | Microstructure | Related Distribution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (2106) 10094 | 1.05 | Iron Age | •• | •• | • | | Dark brown | Reddish yellow | ++ | + | | | + | + | | •• | ••• | | + | Complex: spongy and intergrain microaggregate | Close porphyric |
| (2106) 10093 | 1.19 | Iron Age | •• | •• | +++ | + | Dark brown | Reddish yellow and light red | +++ | + | | + | + | + | + | •• | ••• | | + | Intergrain microaggregate and spongy | Close porphyric |
| (2106) 10092 | 1.30 | Iron Age | •• | •• | +++ | + | Dark brown | Reddish yellow | +++ | | | | + | + | | • | • | | ++ | Spongy | Close porphyric |
| (2107) 10092 | 1.35 | LBA or Iron Age | •• | •• | ++ | | Dark brown, strong brown | Reddish yellow | + | | | | + | + | | +? | | | + | Predom. single grain w/ fine fabric bridges coatings & microags | Ensulic, w/ gefuric/ chitonic |
| (2108) 10091 | 1.52 | Neo/BA | •• | •• | +++ | | Dark brown | Reddish yellow, light red | • | + | | | + | + | + | ++ | • | | +++ | Spongy, with channels and vughs | Close porphyric |
| (2109) 10090 | 1.62 | Neo/BA | •• | •• | +++ | | Reddish brown to dark reddish brown | Light red | +++ | + | | | + | + | | ++ | •• | | + | Spongy, with channels and vughs | Close porphyric |
| (2111) 10090 | 1.66 | Glacial | •• | •• | | | Reddish brown to dark reddish brown | Light red | ++ | | | | + | + | | +++ | ••• | | ++ | Bridged | Gefuric, small areas porphyric |

KEY: + Very Rare (<0.5%), ++ Rare (0.5-2%), +++Very Few (2-5%), • Few (5-15%), •• Frequent (15-30%), ••• Common (30-50%), •••• Dominant/Very Dominant

Charcoal from burnt peat or turf occurred in small amounts throughout the sequence, with the largest amount (5-15%) in the upper horizon of the Neolithic soil (2108). Wood charcoal occurred in both Neolithic horizons and was present in the upper sample of the Iron Age Context 2106. A fragment of partially burnt coal was found in the modern topsoil (2100). Fibrous red material, interpreted as unburnt peat, occurred in the $18^{th}/19^{th}$ century and later deposits (2103 and above) (Plate 21). The contexts from the base of the sequence up to Sample 10096 (the lower sample from Context 2104) were within the range of colours identified in reflected light as the colours of peat or turf ash; the Neolithic soil (2109, Plate 22) was so bright as to be identical to the Iron Age midden material (Plate 23) in OIL. The contexts above this layer were yellowish red or reddish brown under reflected light, apart from Context 2103 (Sample 10098) which was brown with one small area of bright orange fabric.

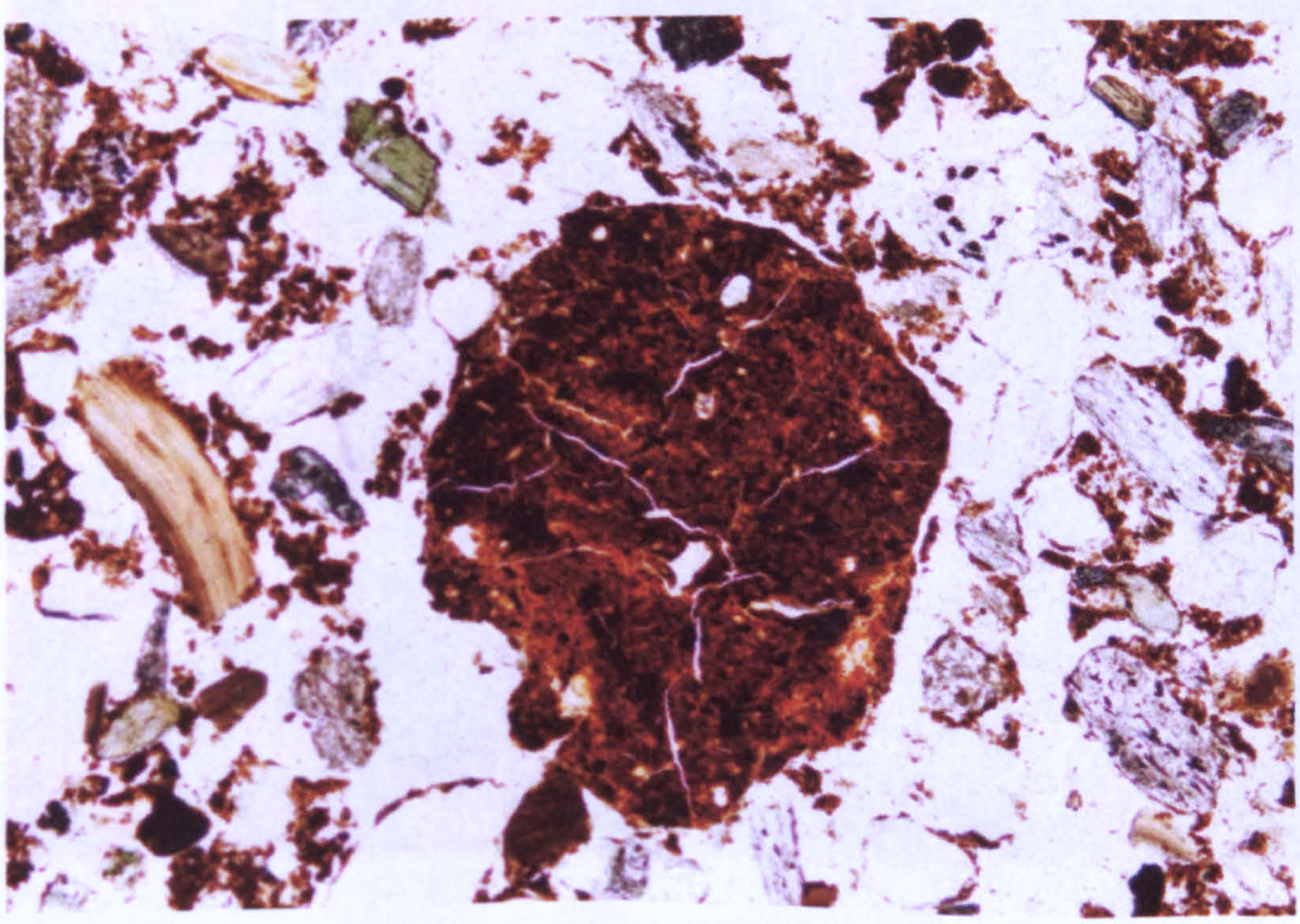


Plate 21: Peat fragment in the $18^{th}$ /$19^{th}$ century soil (Magnification x 40, PPL)

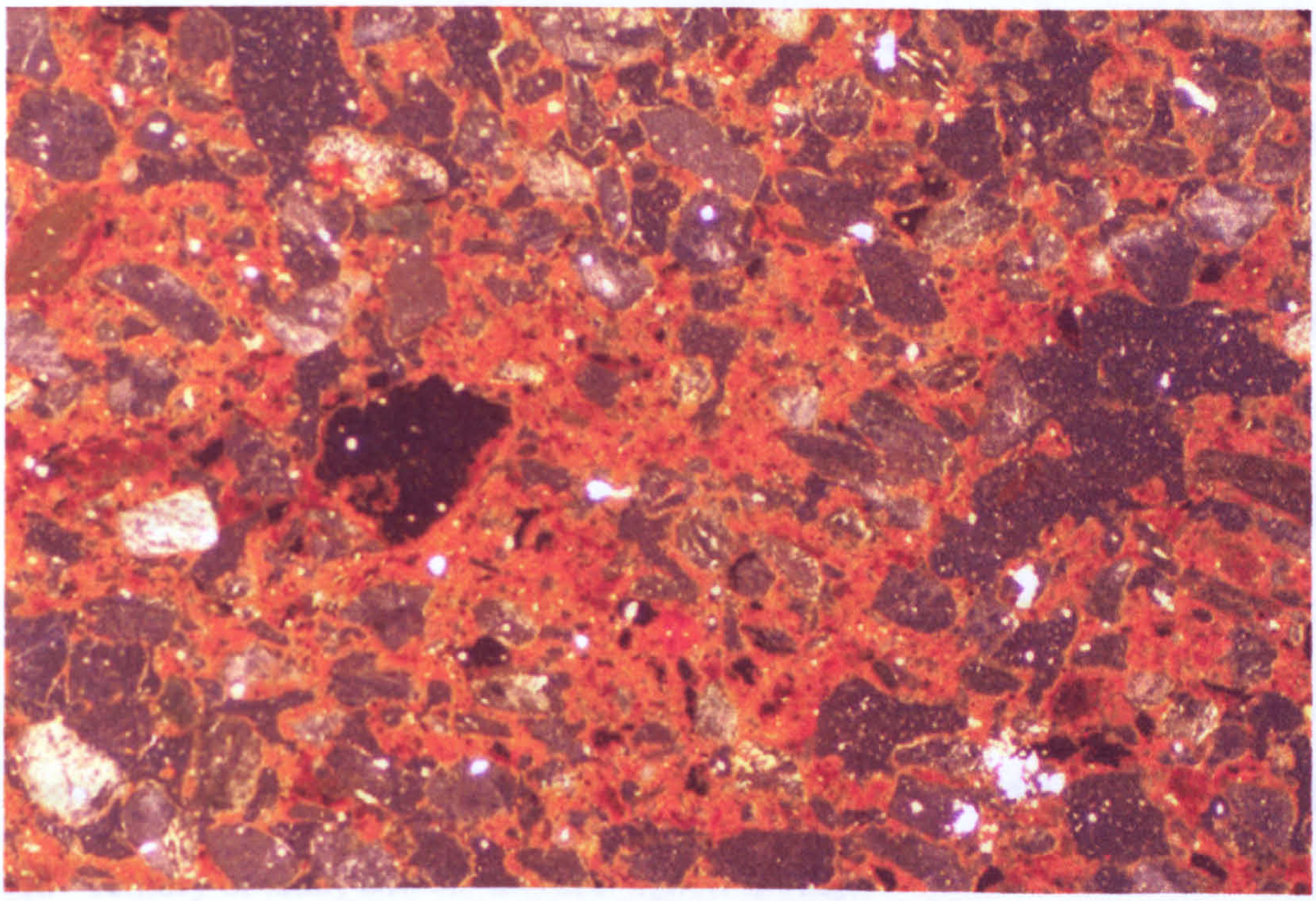


Plate 22: Neolithic/Bronze Age soil (Magnification x 25, OIL)

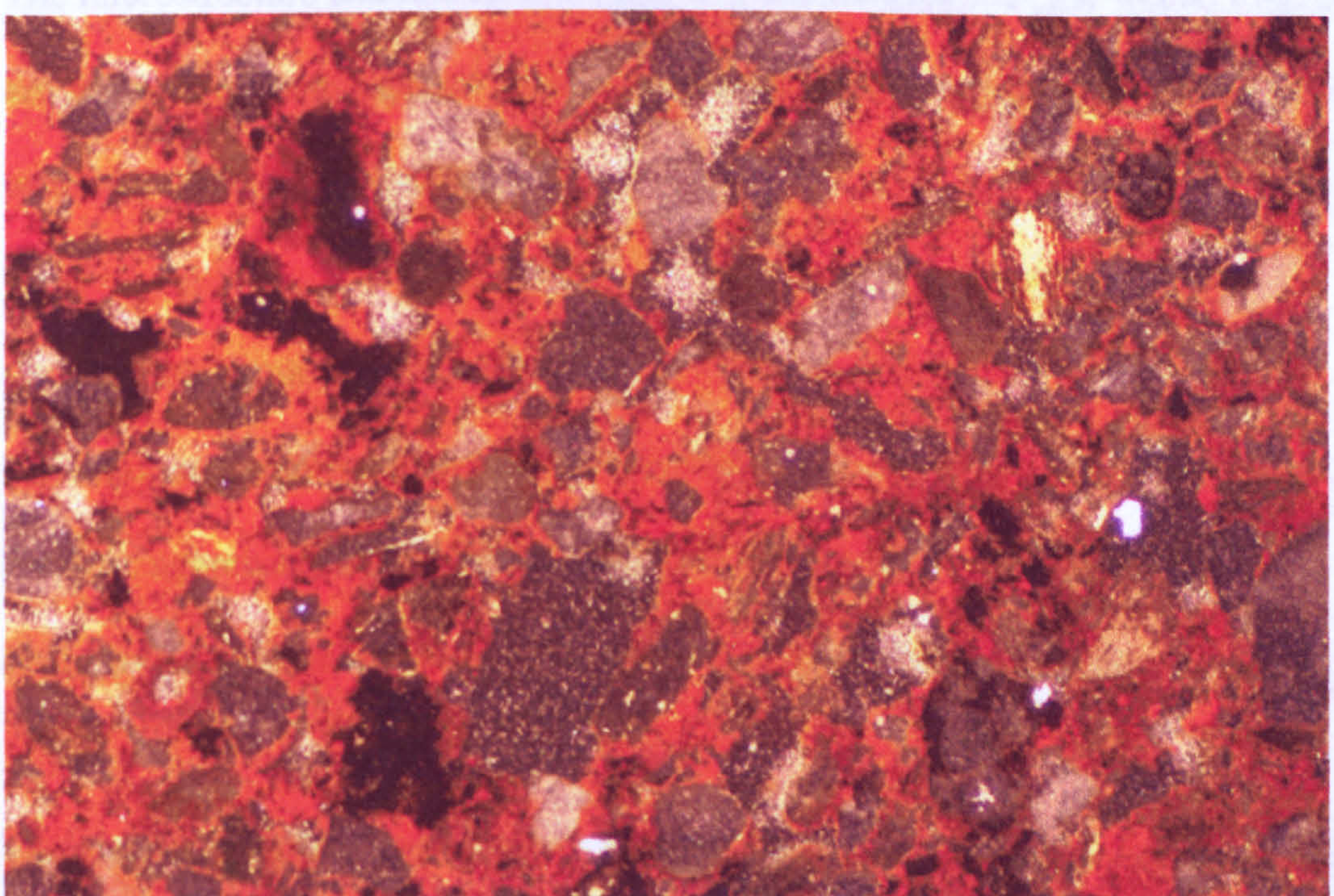


Plate 23: Iron Age midden deposit (Magnification x 25, OIL)

All of the deposits apart from Context 2107 (Sample 10092) had areas of excremental fabric, often having what appeared to be wholly excremental fabric. Context 2107 may also be affected by biological activity (the fabric contained intergrain microaggregates) but this was not as clear as in the other deposits. Earthworm/slug granules were recorded in the 18$^{th}$ /19$^{th}$ century and later deposits (2103 and above). Very rare thin discontinuous yellow, white and orange coatings occurred on a small proportion of mineral grains in all of the contexts. Amorphous organo-mineral material occurred in all of the contexts. The fine fabric in all of the deposits was speckled and all had a low birefringence. Phytoliths were present in all deposits except in the lower horizon of Context 2107 (Sample 10092). Diatoms occurred in all contexts apart from 2105, 2102 (18$^{th}$ century or later) and the modern topsoil (2100).

The microstructure and related distribution of the samples indicate whether the deposits are sand-based or composed of more equal parts of sand and fine fabric. Four types were identified at Old Scatness:

*Gefuric*: sand grains are linked by braces of finer material.

*Chitonic*: sand grains are coated by finer material.

*Enaulic*: aggregates of fine material occur in the spaces between sand grains.

*Porphyric*: sand grains occur in a dense groundmass of fine material.

The first three fabric types are dominated by sand grains, whereas in a porphyric structure there is a larger amount of fine fabric. The deposits with gefuric, chitonic and enaulic related distributions can be classed as sediments in early stages of alteration, either by natural means or by the intentional addition of materials. The five deposits which were recorded as sand-based in the field (2102, 2103, 2105, 2107, 2111) were also recorded as sand-based in thin section.

*Results: Middens*

The samples from the Middle and Late Iron Age Middens (Table 7.3) had a similar mineralogy to the soils and sediments of the Area H sequence, apart from two of the MIA samples (Contexts 1728 and 1729) which had higher percentages of quartz. Small amounts of bone were present in all of the midden samples. Shell sand was present in very small amounts (<0.5%) in the LIA contexts and one of the MIA contexts (1730). Charcoal from burnt peat/turf was more common in the middens than in the Area H sequence, making up 15-30% of three of the MIA contexts and 5-15% of a further four (Plate 24). The fine fabric of all of the contexts but one was within the same Munsell colour range as the experimental peat and turf ash samples under reflected light (yellow, reddish yellow and light red). Phytoliths were present in six of the ten midden samples and diatoms were present in all but one sample of the LIA Context 512. Excremental fabric was recorded in three of the midden deposits (including both LIA samples) and may be present in a further three, but the bright orange ashy fabrics did not appear to have been reworked. Earthworm channels occurred in some of the deposits and very rare earthworm/slug granules were recorded in the LIA Context 512 (Sample 10106).

Table 7.3: Thin section analysis of the midden deposits

| (Context) and Sample | Date | Quartz | Lithic clasts | Bone | Shell | Fine Fabric (PPL) | Fine Fabric (OIL) | Charcoal (peat/turf) | Charcoal (wood) | Coal ash | Red fibrous material | Phytoliths | Diatoms | Fungal spores | Porous excrement | Dense excrement | Earthworm/slug granule | Amorphous organo-min | Microstructure | Related Distribution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (512) 10103 | Late Iron Age | • | • | + | + | Dark reddish brown | Light red, bright orange | +++ | | | | + | | | •• | +++ | | ++ | Spongy, with channels | Porphyric |
| (512) 10106 | Late Iron Age | •• | •• | ++ | + | Dark reddish brown | Light red | +++ | | | | | + | | •• | +++ | + | +++ | Spongy and intergrain microaggregate | Close porphyric |
| (1728) 10114 | Middle Iron Age | •• | •• | + | | Reddish brown to yellowish red; dark reddish brown | Light red and bright orange | •• | | | | + | + | | | ? | | + | Spongy | Close porphyric |
| (1728) 10113 | Middle Iron Age | •• | • | + | | Reddish brown | Light reddish brown and yellow | • | + | | + | + | + | | ++ | •• | | ++ | Spongy | Close porphyric |
| (1729) 10112 | Middle Iron Age | •• | • | + | | Brown | Light brown and reddish yellow | •• | + | | | + | + | + | | ? | | | Spongy | Porphyric |
| (1729) 10111 | Middle Iron Age | •• | •• | + | | Black, brown, strong brown | Reddish yellow, bright orange | • | + | | | + | + | | | | | ++ | Spongy | Close porphyric |
| (1730) 10111 | Middle Iron Age | +++ | • | ++ | + | Black | Bright orange | +++ | | | | | + | | | | | | Spongy | Porphyric |
| (1730) 10110 | Middle Iron Age | • | • | + | | Black, dark brown, yellowish red | Light red, red and bright orange | • | | | | | + | | | | | ++ | Spongy | Porphyric |

KEY: + Very Rare (<0.5%), ++ Rare (0.5-2%), +++Very Few (2-5%), • Few (5-15%), •• Frequent (15-30%), ••• Common (30-50%), •••• Dominant/Very Dominant

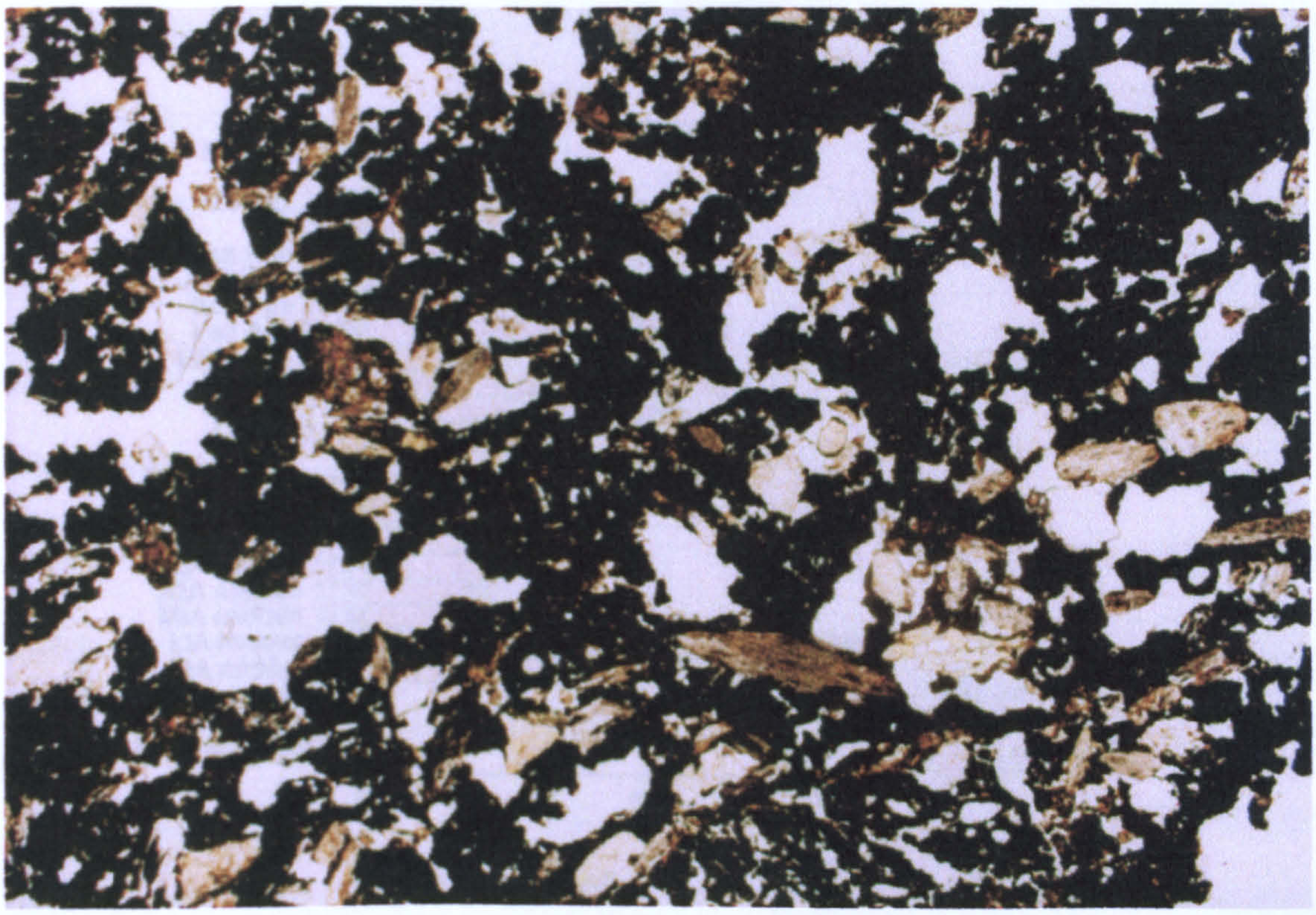


Plate 24: Charred peat in the Iron Age midden (Magnification x 40, PPL)

The interpretations of the thin section analysis are presented in the discussion, below. The complete thin section descriptions are in Appendix 2.

### 7.2.3 Phosphates

*Results*

The 1999 results differ from the earlier work (Simpson et al 1998b) in that the levels of phosphates in the Neolithic horizons (with levels between 13 and 38 times the levels of the controls from Scat Ness, Toab and Hestingott) were slightly higher than levels in the Iron Age

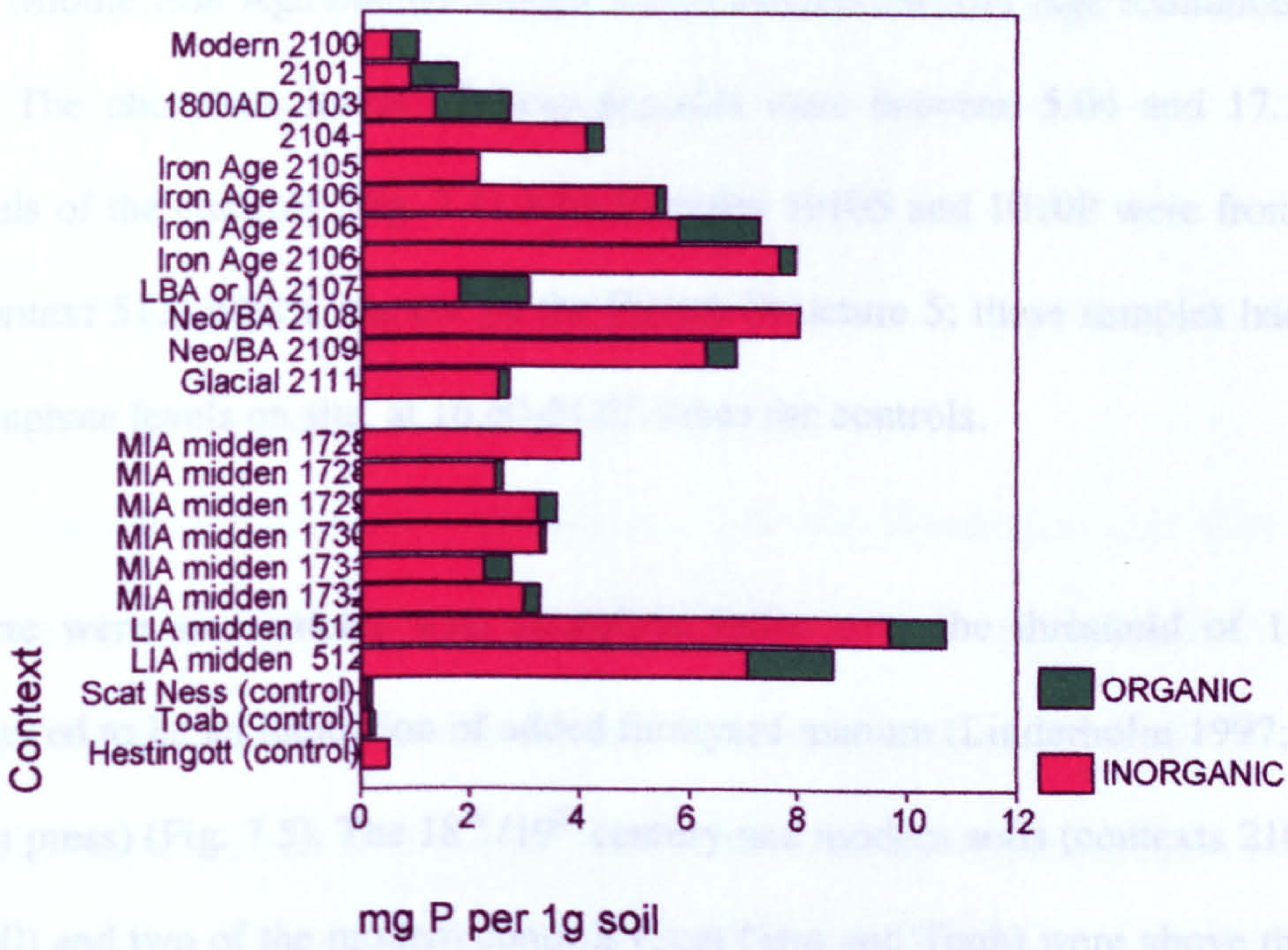



Figure 7.4: Organic and inorganic phosphates

deposits (2107, 2106, 2105) (Fig. 7.4). The phosphates in the upper Neolithic horizon (2108) were entirely inorganic, and the lower horizon (2109) was 91.39% inorganic. The phosphates in the samples from Iron Age Context 2106 were between 10.77 and 37.95 times the controls. Above this heterogeneous deposit was a layer of blown sand (Context 2105), dated to *c.* AD 200, with between 4.14 and 10.24 times the controls; the phosphates from this deposit were entirely inorganic. The phosphate level in the undated dark soil (2104) above the blown sand rose to between 8.48 and 21 times the level of the controls, and levels declined from this time to the present day soil, which has levels only 2-5 times that of the controls.

The samples from Contexts 1728-1732 (Samples 10102 and 10115-10119) were from the Middle Iron Age midden dumps which infilled the Iron Age roundhouse, Structure 12. The phosphate levels of these deposits were between 5.04 and 17.10 times the levels of the controls (Fig. 7.4). LIA Samples 10105 and 10108 were from the midden (Context 512) which was cut by the Pictish Structure 5; these samples had the highest phosphate levels on site, at 16.60-51.05 times the controls.

There were six samples with phosphate ratios over the threshold of 1.5, the level believed to be an indication of added farmyard manure (Linderholm 1997; Macphail et al in press) (Fig. 7.5). The 18th /19th century and modern soils (contexts 2103, 2101 and 2100) and two of the modern controls (Scat Ness and Toab) were above this threshold. The only other context to pass this threshold was the midden deposit 2107, dating to the Bronze Age or Iron Age.

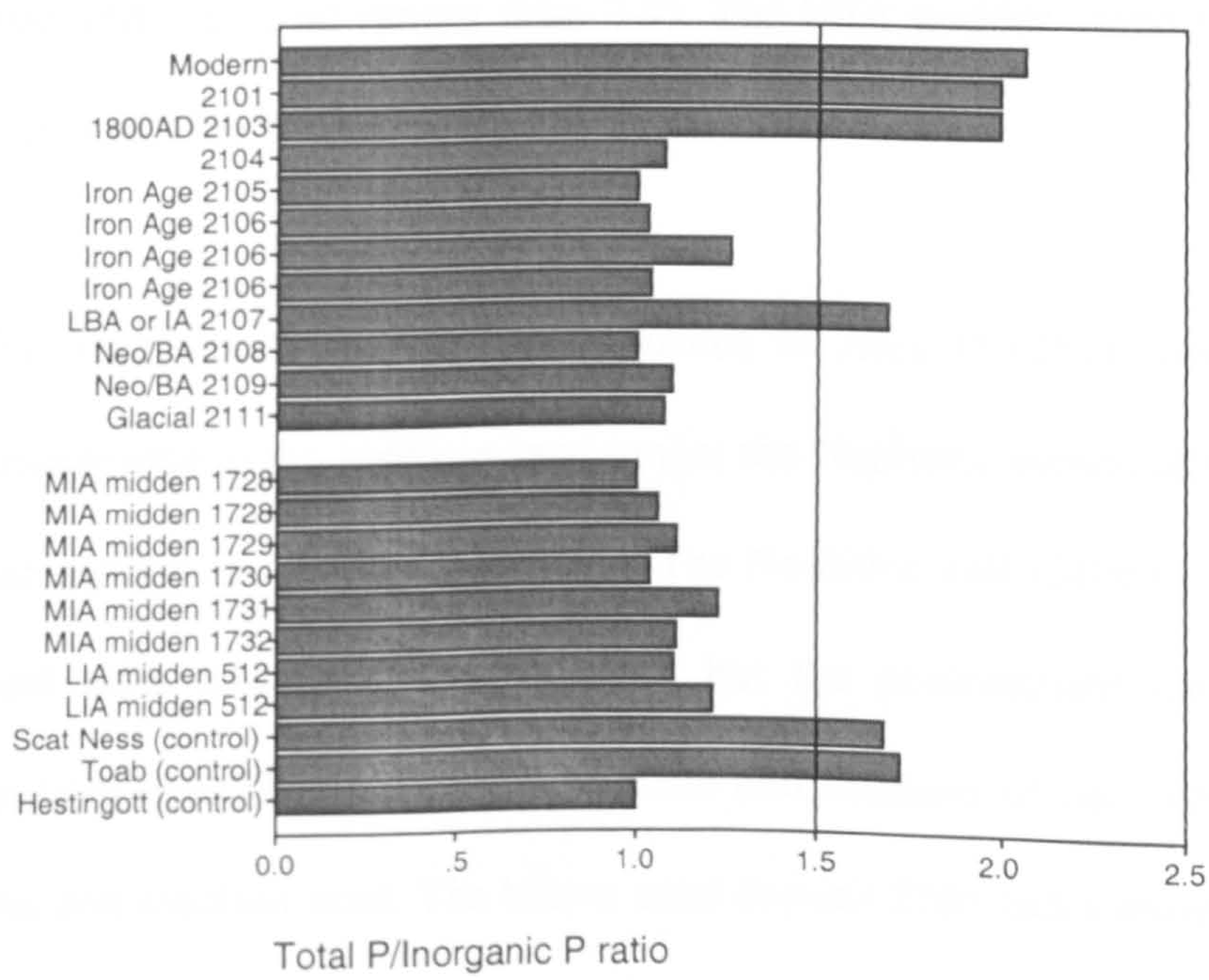



**Figure 7.5: Phosphate ratio**

The interpretations of the phosphate analysis are presented in the discussion (Section 7.3). The raw phosphate data is in Appendix 3.

### 7.2.4 Particle Size Distribution

*Results*

The soils and sediments, including the controls (Hestingott and Scat Ness), have multiple peaks, but the predominant particle size is in the medium sand range (200-500 μm). The particle size distribution plot for the Area H profile (Fig. 7.6) shows very similar curves for all of the soils and sediments in the sequence apart from the upper horizon of the Neolithic soil (Context 2108). This horizon has a smooth curve with two peaks around the fine sand/medium sand size classes. The midden samples generally had lower levels of sand, with the mean and median particle sizes in the silt, very fine sand and fine sand ranges (Fig. 7.7). The MIA midden samples from Contexts 1729, 1730 and 1732 peaked in the silt range.

The sand which underlay the sequence in Area H (2111) had a mean and median particle size in the medium sand range; the Neolithic subsoil above (2109) had a mean and median in the very fine range. The Neolithic soil (2108) was sealed by a layer of sand with midden material (2107), but the predominant component of 2107 was medium sand. The samples from 2106 had medians of silt to fine sand and means of fine and medium sand. The blown sand deposit 2105 had a mean in the fine sand range and a very fine median, unlike the other sand-based deposits which had means and

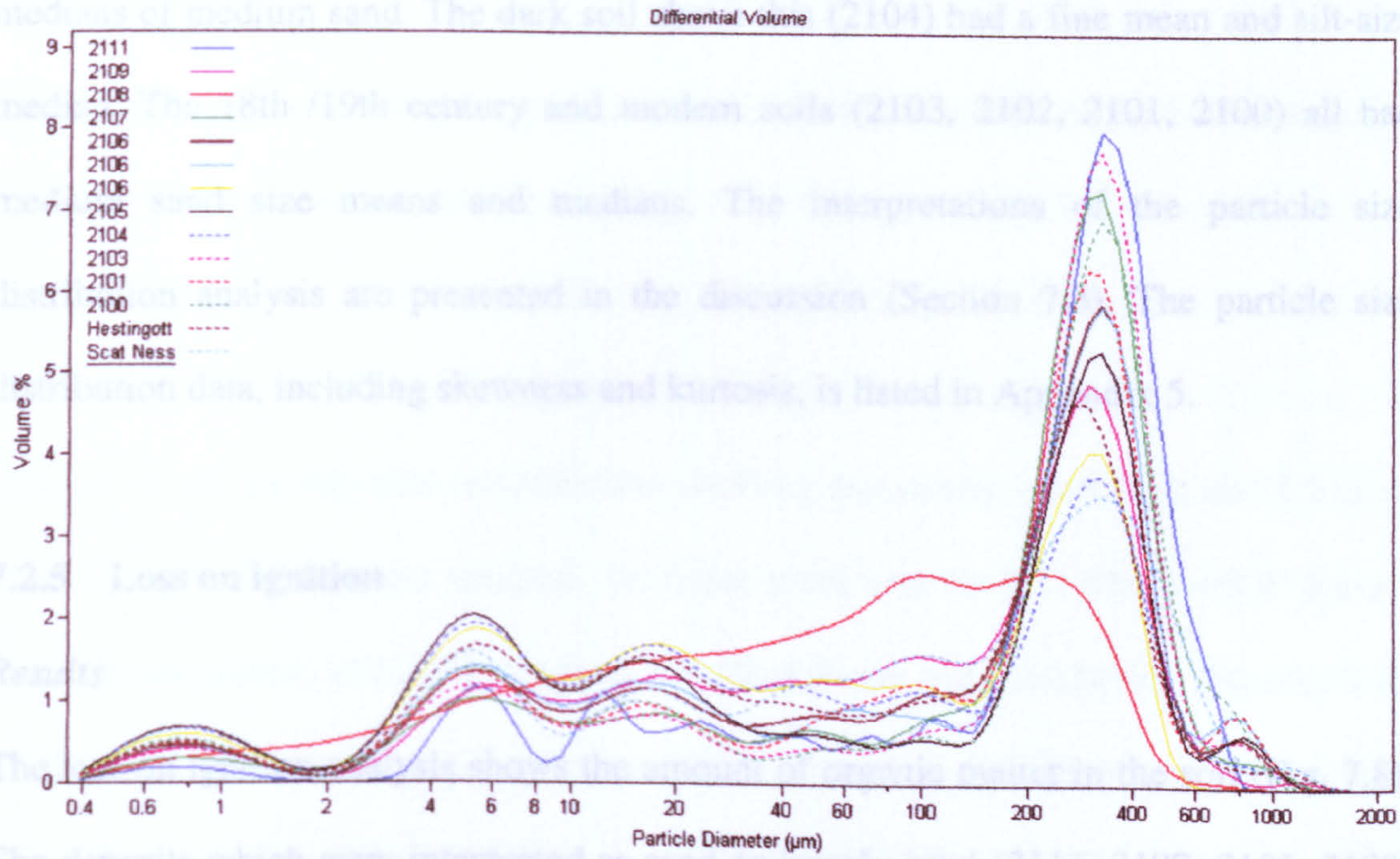



Figure 7.6: Particle size distribution in Area H

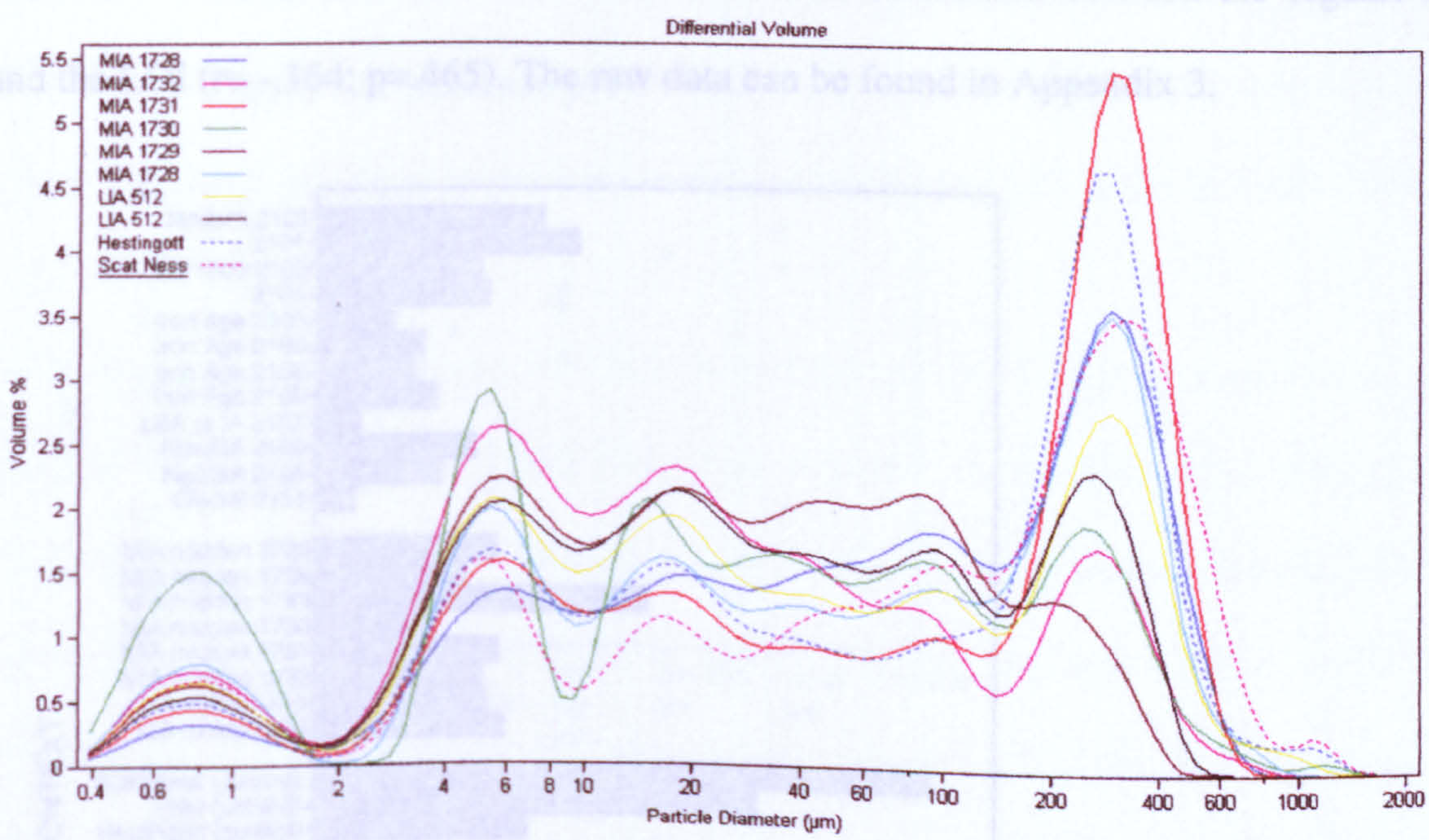



Figure 7.7: Particle size distribution in the midden deposits

medians of medium sand. The dark soil above this (2104) had a fine mean and silt-size median. The 18th /19th century and modern soils (2103, 2102, 2101, 2100) all had medium sand size means and medians. The interpretations of the particle size distribution analysis are presented in the discussion (Section 7.3). The particle size distribution data, including skewness and kurtosis, is listed in Appendix 5.

### 7.2.5 Loss on ignition

*Results*

The loss on ignition analysis shows the amount of organic matter in the soil (Fig. 7.8). The deposits which were interpreted as sand or largely sand (2111, 2107, 2105, 2103) contained between 0.91% (2111) and 3.96% (2103) organic matter. The Neolithic horizons contained 2.96 and 3.79%. There was no correlation between the organic P and the LOI (r= -.164; p=.465). The raw data can be found in Appendix 3.

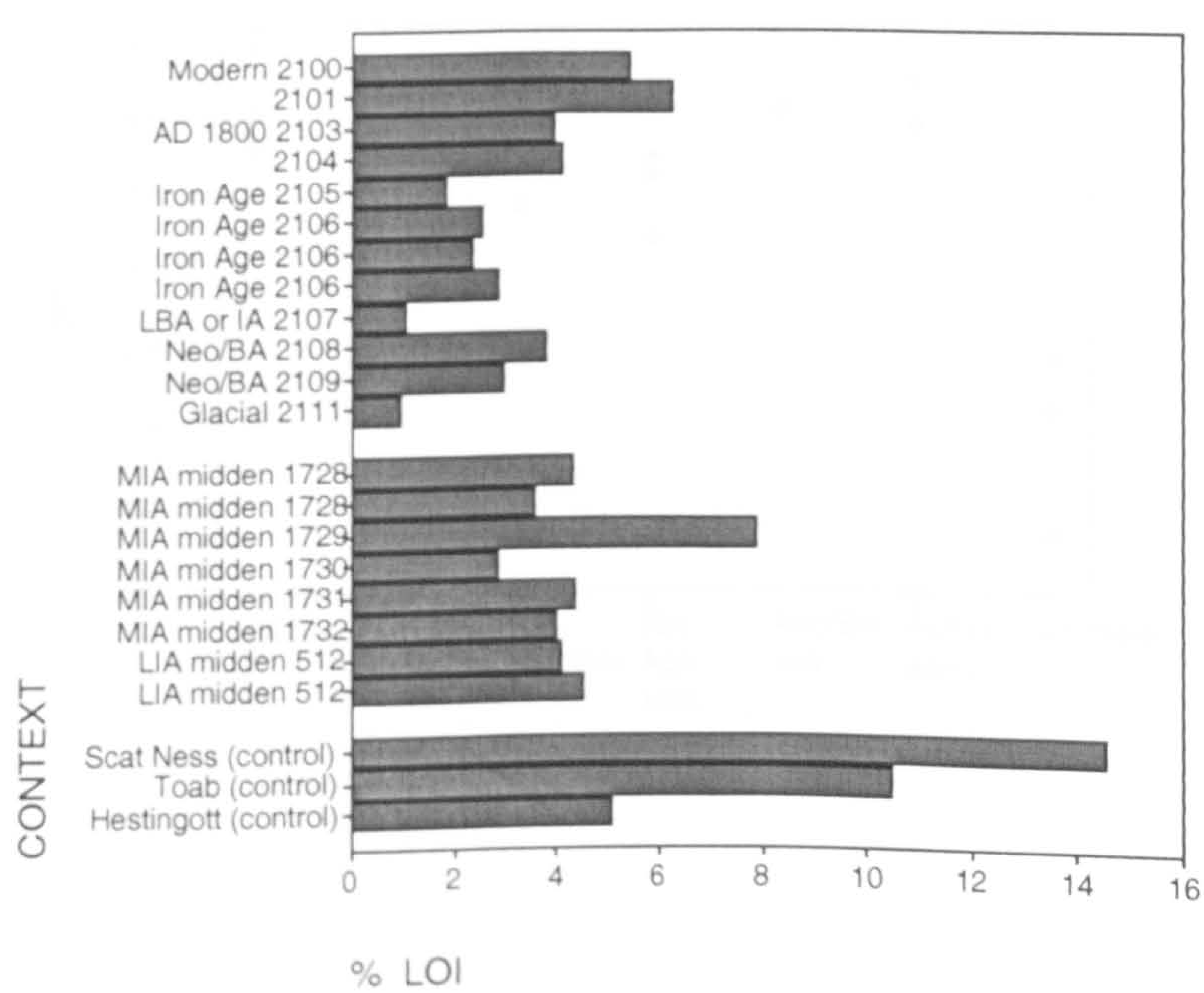



Fig. 7.8: Loss on ignition

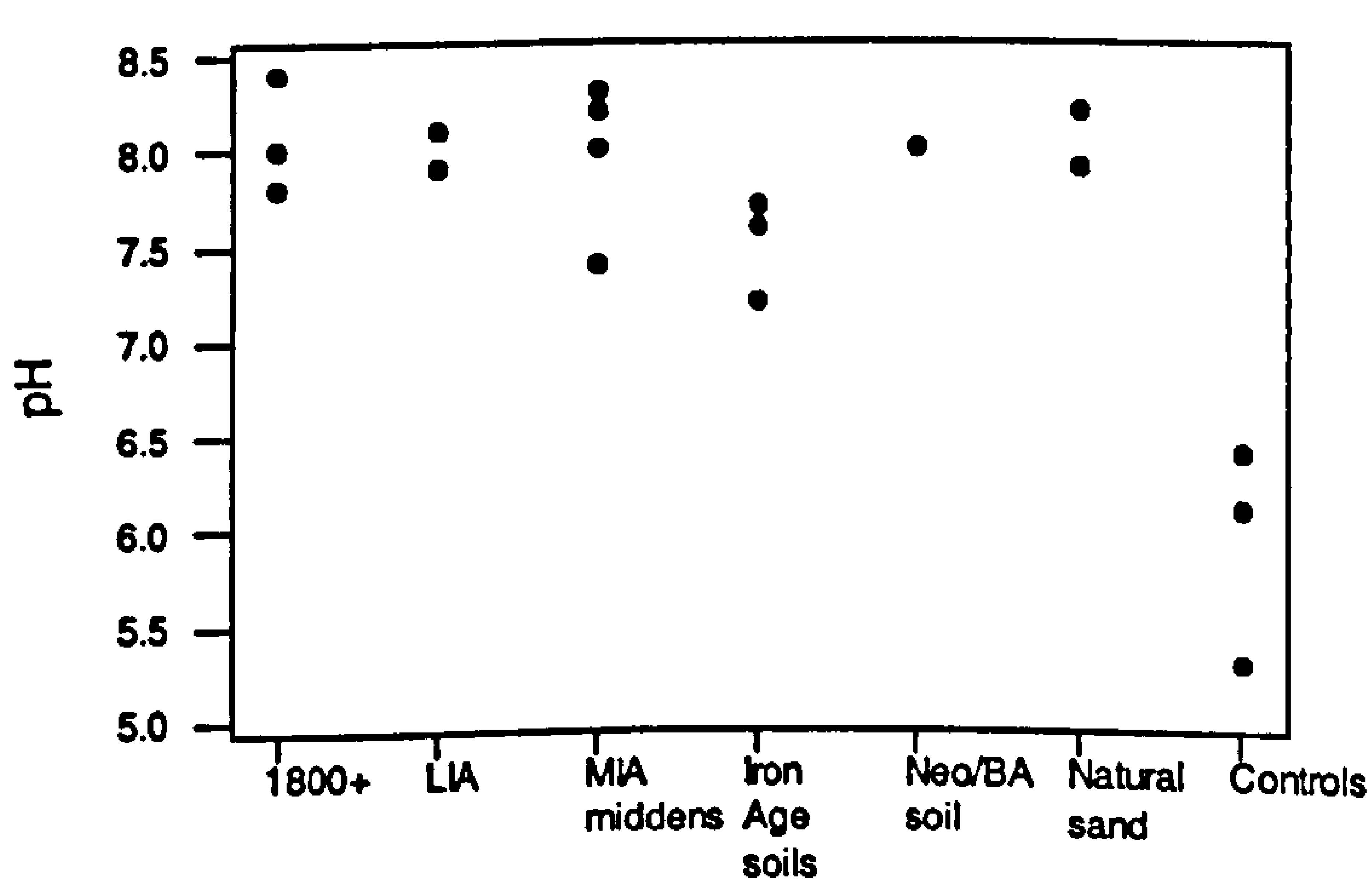
*Interpretation*

The controls had a very high organic content because they were derived from topsoils; the Scat Ness soils were particularly peaty.

### 7.2.6 pH

The pH of all the deposits sampled was alkaline, measuring between 7 and 8.5 (Fig. 7.9). The pH of the parent material, the basal sand, was 7.9-8.2. The control topsoils were circumneutral, at 5.3 (Hestingott), 6.1 (Scat Ness) and 6.4 (Toab). The alkalinity of the soils reflects the input of blown shell sand and the marine deposited sand probably also contained shell fragments which would affect the pH of the soils which developed upon it.

Figure 7.9: Scatness pH



### 7.2.7 Taphonomy

The soils on site were very alkaline, and the deposits in Area H can be seen in thin section to have undergone some mixing by soil biota. The midden deposits show a much lesser degree of biological mixing, and individual worm channels through the deposits were easily identified in thin section. The chemical composition of the middens may have inhibited earthworm activity; wood ash is high in potassium which is toxic to earthworms (Courty et al 1989), and this may also be the case with peat ash. Further evidence for low biological evidence was noted in the course of the excavation: the excavations at Pool, Sanday uncovered 'pea-grit' layers on top of solid surfaces such as stone flagging, but such layers were not found on similar surfaces at Old Scatness (Dockrill, pers. comm.). Pea-grit layers are formed by the downward movement of pea-sized stones which make up the aestivation chambers of earthworms; the stones accumulate on solid surfaces which are impenetrable to earthworms. The absence of these layers at Old Scatness suggests limited biological activity in the soils.

Different species of earthworms can tolerate different pH levels, and although the range of most species is between 4.2 and 8, the high alkalinity at Old Scatness is unlikely to have been a deterrent (Hannah Bishop, pers. comm.). A more probably limiting factor for earthworms is the lack of organic material in the very sandy soils (which is demonstrated by the low LOI) and also the abrasive texture of the very sandy soils (*ibid.*).

## 7.3 Discussion

### 7.3.1 Origins of the mineral components

The mineralogy of the slides and controls was recorded in order to trace possible sources of peat/turf and peat/turf ash which was added to the soils and middens. Peat contains varying numbers of mineral grains which can be seen by x-raying the sample (e.g. James and Guttmann 1992) or by thin section analysis (e.g. Carter 1998). More minerogenic turves are obtained nearer the surface of the parent material or in lake or stream beds where sediment may accumulate (*ibid.*) The similar lithology of the basal sand in Area H and the Toab and Hestingott controls suggests that the control soils were derived from the same parent material or from a sand derived from the same source. The similarity in the composition and particle size of the basal sands and the sand-based deposits which were interleaved with the soils in Area H suggests that both derive from the same local beach sand. Both may be aeolian, as the particle size range of both the basal sands and the sand-based deposits is within the parameters of blown sand size ranges, i.e. 64 µm – 2mm.

The midden samples 10112 and 10113 contain a higher proportion of quartz than the other soils, deposits and controls, and the peat ash within these deposits may derive from the quartz-dominated peat soils on the Scat Ness peninsula.

The upper Neolithic horizon has a particle size distribution which is completely different from the other deposits in Area H, having both a mean and median particle size in the very fine sand size range. This distribution resembles those of the fine grained midden samples and suggests that the soil either contains a great deal of midden material or that it may be a cultivated midden deposit.

### 7.3.2 Domestic waste

Peat was the dominant fuel source at Old Scatness from the Neolithic to the present. Small amounts of wood charcoal were present in the Neolithic and LBA-EIA deposits, and coal appeared for the first time in the modern topsoil. Peat ash occurred in the earlier deposits (2111-2104 lower sample) in such quantities that the colour of the fine fabric in reflected light was in the same colour range as the pure peat ash samples. The upper sample from 2104 and the samples above contained peat ash but not in the same quantities. All of the midden samples but one were predominantly made up of peat ash, but wood charcoal was also found in four of the Iron Age deposits.

Animal bone generally made up between 2-5% of the earlier deposits (Neolithic through LBA-EIA [2106]), and occurred in very small quantities in 2105 (AD 200) and the later contexts. The deposits with greater quantities of bone correspond roughly to the deposits with the greatest amounts of ash, although Deposits 2105 and lower 2104 have large ash components but small amounts of bone. Peat ash and animal bone derive from household, as opposed to byre waste.

### 7.3.3 Animal manure

All of the archaeological soils and sediments have enhanced phosphate levels, but the phosphates are predominantly inorganic. The inorganic P is in part derived from the animal bone which was present in all of the samples apart from the basal sand. The lack of organic P in the upper horizon of the Neolithic soil could indicate either that farmyard manure was not applied to the soil, or that the organic P has entirely mineralised due to biological activity in the soil. The fact that organic P was found in the horizons above and below the deposit suggests that its absence in Context 2108 may not be due to taphonomic factors. The evidence suggests that the Neolithic soil was not manured with animal dung, but this will be further tested by analysing the soil lipids. The inorganic phosphate level in the Neolithic soil is higher than 6 out of the 8 midden deposits and all of the other samples, which suggests that the Neolithic soil may be a cultivated midden, rather than a manured agricultural soil. This is supported by the particle size distribution data and by the identical colours of the Neolithic soil and the ash middens (Plates 22 and 23).

Two Iron Age horizons (in Area H) and five Iron Age midden deposits (infilling Structure 12) were examined. Deposit 2106 in Area H was 0.45 m deep, with generally around 2-5% charcoal and phosphate values of 560-797 mgP/100g soil. The midden deposits, by contrast, generally contained larger amounts of charcoal (5-30%) and lower P values (279-402 mgP/100g), which suggests that Context 2106 was comprised predominantly of organic waste while the middens in Structure 12 were predominantly fuel ash. Deposit 2106 could be either a midden or an agricultural soil containing added midden material, but if it is a soil (which the high level of biological activity suggests) and if the deposits are contemporary (which is more difficult to prove) then the evidence suggests that either the organic manures and fuel ash were dumped in separate middens, or that the organic waste was being used preferentially on the arable fields while fuel ash was mostly dumped in middens within the settlement area (although some still went out onto the fields).

The second Iron Age deposit examined at Scatness was a sand-based horizon with added peat ash (2105), which overlay 2106. There were no ard marks to prove that this was an agricultural soil, but the evidence for biological activity and the enhanced phosphate levels suggest that the horizon may have been an amended soil similar to the earlier Iron Age sand-based soil at Tofts Ness. The Tofts Ness soil contained both charred material, suggesting that the practice of adding fuel ash to soils continued into the Iron Age, and spherulites, indicating that animal (or human) manure was added.

The high P ratios of the control samples around Scatness (and the Papa Stour controls) and the low P ratios for the soils and middens at Scatness and on Papa Stour do not fit Linderholm's model for podzolic soils. The grassland and the moorland topsoils in the Northern Isles are rich in organic matter and therefore contain large proportions of organic P, and the threshold ratio of 1.5 is therefore not applicable. This is not to say that the model should be discarded, but rather that it should adapted for different soil types for which new thresholds should be established. The next stage of this work will be to correlate the organic P values of a soil and the lipid biomarkers for dung, in order to test the extent to which the organic P content represents dung in the soil.

### 7.3.4 Environmental indicators and environmental change

The increase in blown sand in the 18th century and later soils is in agreement with the historical evidence and with the findings in the earlier stages of the project (Simpson et al 1998b). The diminution of wood charcoal over time suggests that woodland was not managed to any great extent. Diatoms were found in the earlier soils, from the Neolithic until the Iron Age Context 2106, after which they occurred in the undated Context 2104 (probably Norse or post-medieval), the 18th /19th century deposit 2103 and the 19th century or later Deposit 2101. They were also found in all but one of the midden deposits. Diatoms occur in water or on wet ground, and were noted in some of the unburnt peat fragments. The presence of diatoms in the peat suggests that the turves were brought in from unimproved moorlands or lake-edge environments; the diatoms may have arrived in the middens and soils embedded in peat ash (*c.f.* Plate 11). Phytoliths were present in very small quantities in all of the Area H contexts and most of the midden contexts. These are found in organic material and are usually taken to represent grass or cereal remains.

The very rare thin clay coatings on the mineral grains could be interpreted in several ways. Clay translocation occurs when soils are disturbed by ploughing, but also occurs naturally in a climate of alternating wet and dry conditions in soils with high porosity in which the pH is between 4.5 and 6.5 (McKeague 1983). Wet, acidic conditions would have been prevalent in the peaty areas to the north and south of the settlement, where the pH was 5.3 (Hestingott), 6.1 (Scat Ness) and 6.4 (Toab). The mineral grains could have been brought within turves from these peaty upland areas. The conditions on site are unlikely ever to have been more wet and acidic, given the freely draining nature and high pH of the basal sand. The clay coatings could be the result of cultivation disturbance, but this is unlikely given the incidence of clay-coated minerals in the uncultivated Iron Age midden deposits. The coated mineral grains are therefore likely to have been transported.

### 7.3.5 Anthropogenic soil formation

There are five deposits that are essentially natural sediments, but which contain anthropogenic material. The deposits were described as gefuric, chitonic and enaulic in the micromorphology table, i.e. they were composed predominantly of sand grains with small proportions of fine fabric. The degree of soil development in a sediment is linked with an increase of fine fabric in the deposit as well as with pedogenic processes which result in textural, depletion, crystalline, amorphous, crypto-crystalline, fabric and excremental pedofeatures, identifiable in thin section.

The upper horizon of the basal sand had enhanced phosphate levels, a light red fine fabric indicating a large ash component, areas of dense excremental fabric, diatoms, phytoliths, amorphous organo-mineral material and clay coatings on the mineral grains. These characteristics suggest that the sediment has been amended by anthropogenic means (the addition of ash and enhanced phosphates) and by pedogenic processes (earthworm activity, organo-mineral formation and clay coatings, if these were not transported).

Amorphous organo-mineral material was present in all the deposits, and all of the deposits (with the possible exception of 2107) contained excremental fabric, indicative of biological activity. The four deposits that were tested (2103-2111) all had enhanced levels of phosphates.

Table 7.4

| Context | Date | % Charcoal | OIL colour | % Fine Fabric |
|---|---|---|---|---|
| 2102 | 18th /19th | Very rare | Reddish brown | 10-20% |
| 2103 | 18th /19th | Rare | Brown | 5-15% |
| 2105 | Iron Age | Rare | *Reddish yellow* | 2-10% (base) 10-20% (top) |
| 2107 | LBA | Very rare | *Reddish yellow* | 0.5-2% |
| 2111 | Neolithic | Rare | *Light red* | 10-15% |

The colour of the fine fabric in oblique incident light (Table 7.4) is an indicator of the amount of ash in the deposit; the fine fabric in the lower three deposits (in italics) contains large amounts of ash, whereas the upper two deposits contain little if any.

It has been suggested (Simpson et al 1998b) that Neolithic/Bronze Age agricultural soils were fertilised with domestic waste (ash and animal bone), while in the Iron Age, when stock were raised more intensively, fields were fertilised with animal manure as well as domestic waste. The current work at Scatness confirms that the earliest soils contained large amounts of domestic midden material. The upper horizon of the Neolithic/Bronze Age soil had a finer particle size distribution than the other soils and sediments in the profile, with a mean and median particle size closer to those of the midden deposits. The layer had 5-15% charcoal, which was far higher than levels in the other soils in the profile but typical of the amounts noted in the middens. The colour of the Neolithic/Bronze Age soil in OIL was identical to that of the midden deposits. The phosphate levels were higher than in all of the later soils and most of the midden deposits, excepting only the LIA midden deposit 512 and the MIA or later midden deposit 1728. All of the evidence suggests that the Neolithic/Bronze Age soil was a midden deposit which was cultivated, rather than an arable soil which was manured.

Unburnt peat occurs for the first time in the Iron Age Context 2106, and was noted again in the Middle to Late Iron Age Context 2105. It occurs consistently and in larger amounts in the $18^{th}$/$19^{th}$ century and later deposits. Unburnt peat was also found in the Bragasetter samples, where (according to the historical sources) it was used as animal bedding before being spread onto the fields. The historical sources are further confirmed by the reference samples from the byre floor at the Shetland Croft Museum, which was composed of trampled, unburnt peat. At Scatness the use of unburnt peat corresponds with a decrease of ash in the soil, and may indicate a change in fertilising materials from domestic waste to stable manure and bedding. Although this suggestion is not supported by increases in total phosphates in the soil, it is strongly supported by the leap in the proportion of organic P (the P ratio), which is higher in the $18^{th}$ /$19^{th}$ century and later soils than in any other deposit sampled on the site.

# CHAPTER 8: DISCUSSION AND CONCLUSIONS

The results from the three sites were discussed separately at the end of Chapters 5, 6 and 7. In this chapter the evidence from the sites will be drawn together and the hypotheses will be revisited. This will be done by first summarising the changes in land management practices that took place over time, and subsequently reviewing the success of the methods in discerning these practices. This will be followed by a discussion of further issues which arose in the course of the work (Sections 8.2 - 8.4) , followed by a summary of the key research issues which could be addressed in the future (Section 8.5). A summary list of conclusions completes the chapter (Section 8.6).

## 8.1 Addressing the hypotheses

### 8.1.1 Settlement in the Neolithic

Chapters 6 and 7 established that enriched arable soils surrounded the Neolithic settlements at Tofts Ness and Old Scatness. The soils on both sites were fertilised with domestic waste including animal bone and peat ash; at Tofts Ness there was also evidence for organic manures, which could derive from either humans or animals. The lipid analysis for the Neolithic soil at Tofts Ness is still awaited, but may show that human manure was used in the Neolithic soils as well as those of the Bronze Age. The Neolithic/Bronze Age soil at Old Scatness had a different signature, with predominantly inorganic phosphates; this soil may have been exposed for longer and thus had the organic manures transformed into the inorganic form, or it may never have contained much organic material. This will be established when the lipid samples are processed.

Perhaps the most interesting discovery was that at both Tofts Ness and Scatness the Neolithic midden heaps were cultivated. The material which infilled the ard marks was clearly the same as that which overlay them, which demonstrates that the arable soils were not stripped away and replaced by dumped midden deposits. The thin section analysis, phosphate analysis and particle size distribution demonstrated that the arable soils were composed of the same material as the midden heaps and were not simply soils with added midden material. At Tofts Ness the cultivated area also extended beyond the midden and midden material was added to these soils; at Old Scatness this may have been the case but this can only be established by further excavation and analysis.

A review of the archaeological literature suggests that the cultivation of midden heaps in the Neolithic took place on a number of other sites in the Northern Isles and on at least one site in England. At Pool, Sanday, Orkney there were ard marks beneath the Neolithic midden, and the excavator suggested that the agricultural soil was removed prior to the midden dumping (Hunter et al in press), which was clearly not the case at Tofts Ness or Scatness, and in light of this research may not have been the case at Pool either. At Knap of Howar, Westray, Orkney both the upper and lower midden deposits had level surfaces, and the excavator suggested that they might have been cultivated (Ritchie 1983). The evidence from this project suggests by analogy that she was probably right. Links of Noltland, Westray is another site with an extensive area of possibly cultivated midden, measuring at least 210 by 70 metres (Clarke et al 1978).

The cultivation of middens may also have taken place on a number of sites in the Western Isles, where large amounts of midden material have been identified interleaved between the machair sands. Gilbertson et al (1999) established that buried soils in the machair contained large amounts of midden material and represent anthropogenic activity rather than periods of natural dune stabilisation; it is possible that some of these deposits were cultivated middens rather than natural soils with added midden material. At Hornish Point, South Uist a possible cultivated midden was recognised and interpreted as such by the excavator (Barber, forthcoming). Cultivation of a midden in the Neolithic was suggested by Macphail (1990) at Hazleton North, Gloucestershire, where small, shifting plots which were recorded beneath a long cairn and one of the plots was placed on top of a midden heap.

The fact that the middens were cultivated suggests that the occupants recognised the fertility of their own domestic waste. Although peat ash on its own is not a particularly effective fertiliser, it nevertheless provides some nutrients and would have improved the soil to some degree (Romans 1986). It is much more effective when combined with other domestic waste such as animal bone (which is present at both sites) and food residues. Early prehistoric houses in the Northern Isles were typically excavated into mounds of ash, and ash was also used on some sites in the house walls, possibly as insulation. Domestic waste therefore had several functions, and was used both in the settlements (for structural purposes) and in the fields (as fertiliser).

The evidence from this research demonstrates that arable soils were amended in the Neolithic. The creation of more productive soils supports the hypothesis which stated that settlement in the Northern Isles was neither temporary nor mobile. The discovery of enriched arable soils around the settlement indicates that the absence of field boundaries does not mean that there was an absence of intensive cultivation. The cultivation of midden heaps on both sites and the addition of midden material to the arable soils at Tofts Ness are indicative of a more sustainable land management system than slash and burn, as well as a more intensive one. The literature review suggests that the practice may have been widespread, but has largely remained undetected because of the novelty of the methods used to detect the practice.

*Hypothesis:*

*The Neolithic in the Northern Isles is characterised by long-lived settlements and fields. The fields may not necessarily have physical boundaries but may be identified by the amended soils where they have been preserved by burial.*

*Conclusion:*

*The amended soils were a resource which would have greatly benefited the settlements which they supported. This is not conclusive proof for long-lived, year-round settlement* *but it tends to support rather than to disprove the hypothesis that settlement in the Neolithic was not temporary or mobile.*

### 8.1.2 The Bronze Age

There was continuity of occupation from the Neolithic into the Bronze Age at both Tofts Ness and Scatness. The earliest soil at Scatness was probably in use from the Neolithic into the Bronze Age, and above this a Bronze Age or Iron Age horizon was sampled, but it is uncertain whether it was a heavily fertilised agricultural soil or a midden deposit. At Tofts Ness the Bronze Age soil was deepened significantly and the area of arable soil was expanded. Domestic waste continued to be used as fertiliser and the high levels of organic phosphates continued, indicating the addition of organic waste. The lipids from the Bronze Age soils show that there was a large amount of added human manure, which probably accounts for the organic P enhancement. There was no evidence for pig or herbivore dung in the soils, and it has been suggested that the herbivore dung was burnt for fuel because of the shortage of peat on the island (Bond 1994b and Simpson et al 1998a). The fertility of the Bronze Age soil is demonstrated by the large size of the barley grains, which were as big as the grains grown in the Norse period at Pool (Bond 1994a).

At Tofts Ness the Neolithic soil was in places sealed by a thin layer of blown shell sand, which continued to accumulate throughout the Bronze Age. The sand may have accumulated steadily, or it may have been deposited during storms and subsequently been ploughed into the soil. The manures could have been added either to stabilise large episodes of sand blow, or to combat a steady accumulation. Manuring was used to combat similar environmental constraints in the Bronze Age and Iron Age at Cill Donain in the Western Isles (Gilbertson et al 1999), and ard ploughing of a 10 cm thick sand layer is known from a Beaker period site at Rosinish, Benbecula (Shepherd and Tuckwell 1977). The ard marks at Rosinish were filled by midden material, which suggests that manure was added to consolidate the sand (*ibid.*). The use of manure for consolidation may also have been used in the Netherlands, where manured Bronze Age soils with ard marks are interleaved with layers of wind-blown sand (Bakels 1997).

The similarity of Neolithic and Bronze Age settlements in the Northern Isles was discussed in Chapter 2 (Section 2.3.1). The domestic structures of both periods in this region are oval shaped and are associated with field boundaries delineating small, irregularly shaped fields, e.g. Ness of Gruting (Calder 1958) which was occupied in both the Neolithic and the Bronze Age. Stone ard points and saddle querns continued to be used in the Bronze Age and the economic evidence (also in Section 2.3.1) suggests a subsistence economy which was similar to that of the Neolithic. A possible difference in the economies of the two periods is that trade in luxury items may have declined in the Bronze Age (Øvrevik 1985).

The literature review led to the conclusion that the economies of the Neolithic and Bronze Age in the Northern Isles were similar, which led to the formulation of the hypothesis that the anthropogenic arable soils would contain similar fertilising materials which would reflect similar landscapes and similar land management systems. The thin section analysis from the Tofts Ness soils showed that peat ash and organic manures were used in both periods. Analysis of the soil magnetism (*xfd*) demonstrated that there was a significant difference between the quantities of materials added to the soils of the different periods, although the phosphates did not differ significantly. The most significant difference was that of scale; the Bronze Age soil was deeper and more extensive than the Neolithic soil, and in the Neolithic the midden was used as an arable plot surrounded by amended but not especially deepened soils. Differences in manuring materials may become apparent when the lipid analysis of the Neolithic soil is completed and it can be compared with the Bronze Age soil.

At Scatness the evidence is equivocal because of the longevity of the earliest soil, which was OSL dated to the Neolithic but which contained both Neolithic and Bronze Age pottery. The phosphates from this soils were very dominantly inorganic, which could reflect either an absence of organic manures in the soil or an active microbial community which has transformed the organic into inorganic P.

*Hypothesis:*

*The Bronze Age had the same economy and land management system as the Neolithic and should therefore have similar amended soils which reflect a similar landscape.*

*Conclusion:*

*The Scatness evidence is equivocal, and the evidence from Tofts Ness suggests that similar materials were used to amend the soils in the Neolithic and Bronze Ages. This* *supports the hypothesis that the economy of these two periods was based on similar resources, but the evidence is not conclusive until the lipid analysis of the Neolithic soil is undertaken.*

### 8.1.3 The Iron Age

Childe's (1946) suggestion that the Iron Age economy was based on arable production is supported by finds of grain and quernstones, but also by evidence from the agricultural soils at Scatness (Simpson et al 1998b). Thin section analysis of the Late Iron Age soil produced evidence (silty-clay textural pedofeatures) which suggests that cultivation may have intensified during this period (*ibid.*) The area of arable soils may have expanded, and the work also established that there was an increase in phosphate levels (Table 8.1) and soil organic matter in the Iron Age, which suggests that more animal manures were used than in earlier periods (*ibid.*).

Table 8.1: Comparison of phosphate values

| **Description** | **mg P per 100g soil** |
|---|---|
| Iron Age soils (Simpson et al 1998b) | 1125-1782 |
| Deposit 2106, Area H (Iron Age soil or midden) | 560-797 |
| Middle Iron Age middens in Structure 12 | 279-402 |
| Late Iron Age midden (Context 512) | 863-1072 |

The high degree of biological activity in Deposit 2106 (identified in thin section) suggest that this deposit is more likely to be a soil with added midden material than a midden, but this is not certain. The charred peat content in 2106 was lower than all but one of the middens in Structure 12, although it was comparable to the LIA middens cut by Structure 5 (Context 512). The phosphate levels overlap with the LIA midden values and are lower than those of the soils. This deposit highlights the difficulties of distinguishing heavily fertilised soils from middens, and ard marks remain the most unequivocal indicator for cultivation.

Comparison of the Iron Age soils with the Iron Age middens at Scatness showed a higher concentration of phosphates in the soil than in the middens, which were composed predominantly of peat ash. This suggests that animal dung was not deposited in the same midden heaps as the domestic waste and may have been spread directly onto the fields.

In historical times all of the household waste was deposited together with the waste from byres into middens prior to deposition on the fields, and this may also be the case at Tofts Ness. The EIA midden at Tofts Ness contained spherulites, which indicate that dung was added to the deposit along with the peat ash. The sandy EIA soil at Tofts Ness also contained spherulites, which indicate that dung was added to the soil. The accumulation of middens containing organic waste could mean that either the middens were never used because arable agriculture ceased to be practised, or that some of the organic material was deposited in the middens and some in the soils, i.e. there was a certain amount of waste.

The phosphate values in the EIA soil at Tofts Ness were lower than those of the earlier soils, and the sand-based soil was not heavily fertilised. Rather than showing an intensification of arable production, settlement and cultivation ceased in the EIA or shortly after. Animal manures can only be used intensively if the animals are stabled or corralled, and the use of organic manure in the fields suggests that the animals may have been confined (if the use of human manure can be ruled out by analysis of the soil lipids).

The collection of organic, possibly animal manures at both Tofts Ness and Scatness could represent an early plaggen system but this is still a tentative suggestion. The analysis of the cultural soils at Bragasetter established that unburned peat fragments in the arable soils are a key indicator for the plaggen system, and such fragments were found in very low levels in the Iron Age soils (Contexts 2105, 2106 and in Test Pit B, unpublished data from Simpson's preliminary study) and in one of the Iron Age middens from Structure 12 (Context 1728). Fragments of unburned peat can be expected to survive in fuel ash residues, and in such low levels they may not represent the remains of animal bedding. Unburned peat fragments occurred in two of the EIA midden deposits at Tofts Ness, but they also occurred in three of the Neolithic middens. The more obvious and unequivocal evidence for plaggening appears at Scatness around AD1800 in Context 2103, where peat fragments make up 0.5-2% of the thin section slide. The two soil horizons above 2103 contain 2-5% unburned peat, providing even clearer substantiation.

A distinctive feature of the Iron Age middens at Tofts Ness was the quantity of wood charcoal, which was very rare in the Neolithic middens, and the presence of wood ash, which was absent from the Neolithic middens. It has been suggested that the woodland which survived into the Iron Age in Orkney was largely cleared at that time for use in ironworking (C. Dickson, unpub.). By contrast, wood charcoal was very rare or absent from all of the soils and sediments which were analysed at Scatness.

*Hypothesis:*

*There was an intensification in arable production and stock keeping in the Iron Age, which may be reflected by increased animal manures in the soil.*

*Conclusion:*

*The Iron Age deposits in Area H at Scatness could have been middens or soils with added midden material. They could not, therefore, be considered in the analysis. The analysis of the middens at Scatness demonstrated that these deposits were actually lower in phosphates than the soils, however, and this suggests that waste material was used differentially on this site. This does not prove that stock keeping was intensified but it suggests an increased organisation in the way that fertilising materials were used. At Tofts Ness, by contrast, organic waste including spherulites indicative of dung was found in the midden heaps. It appears then that organisation increased on some Iron Age sites and decreased on others.*

### 8.1.4 The Norse period

At Scatness the area of arable land was expanded in the Norse period, and the use of animal manures as fertiliser continued (Simpson et al 1998b). The Norse soils contained fish bone, animal bone and charcoal, which indicates that domestic waste continued to be added to the soils. No Norse deposits were analysed during this project, apart from possible Norse horizons or additions to the lower levels of the Bragasetter soils. These still await radiocarbon dating results.

The efforts to improve agricultural production in Shetland may have been either a response to the changing climate or to increased production for trade. In the Viking period the average summer temperatures were slightly warmer than today's, but from around 1200 the northern ice sheets began to advance and agriculture in the North Atlantic became difficult. Grain ceased to be grown in Iceland around 1200, many of the farms in the North of Norway were abandoned by 1300, and the settlements in Greenland had both failed by 1500 (Lamb 1995). The intensification of agriculture in Orkney may have been for export to the more northerly Norse colonies (Simpson 1993), which were suffering from the climatic deterioration; there are references to the exportation of grain from Orkney to Iceland in the Sturlunga Sagas, a collection of contemporary Icelandic histories written in the $13^{th}$ century, and the Bandamanna Saga (Also known as The Saga of the Confederates).

*Hypothesis:*

*There was a further intensification of arable production in the late Norse period, which will be reflected by deeper and more extensive anthropogenic soils.*

*Conclusion:*

*Inconclusive. The hypothesis can not be addressed without the radiocarbon dates from the lower soils at Bragasetter and the OSL dates from the post-Iron Age soils at Scatness.*

### 8.1.5 Plaggen soils in the wider context

It is clear from the literature review and from the research that soils which are classed as plaggen soils on the basis of depth were developed by different methods. The traditional plaggen soil was created by a complex land management system which divided up the area around a township into infield and outfield, and in which the use of resources was regulated. Although field boundaries survive in some regions, there is not evidence to suggest that the landscape in the Neolithic and Bronze Age was divided up with the same complexity, and the inefficient use of waste material suggests that fertiliser was not regarded as so valuable a commodity that its use and distribution had to be regulated. Midden material was used for different functions, and the priority may not have been as fertiliser. The material would have given off warmth as it decomposed, and its use as building insulation may have had a practical function as a source of heat. This may have made it as valuable in construction as it was in the fields.

In the Iron Age there is evidence for increasing social complexity and for trade in subsistence products (Wells 1984; Cunliffe 1991), but the use of manuring resources was still somewhat inefficient on some sites. Organic waste continued to be deposited together with fuel ash in the middens within settlements. Ethnographic research has demonstrated that the dumping of waste material in abandoned buildings and within settlement areas is typical of many sedentary societies (Murray 1980), which suggests that the inefficient use of fertiliser was widespread in pre-industrial societies.

Carrying materials out onto the fields required a great deal of hard labour, and arable agriculture only became more efficient when there was some incentive to make it so. In Ireland the widespread sand plaggening developed as a response to population pressure (Conry and Mitchell 1971); in the Netherlands the traditional plaggen system may have developed in response to market incentives (Groenman-van Waateringe and Luijen 1995; Mücher et al 1990). In both regions the practice of fertilisation had been around for some time before it was intensified. In the Netherlands there is evidence for stabling of animals and manuring with animal dung and domestic waste from as early as the Neolithic. In Ireland the historical evidence suggests that manuring was used at least as early as AD 500 (Conry and Mitchell 1971). In the Western Isles manuring was used in the Bronze Age or possibly earlier, and in the Northern Isles fertilising with organic (Tofts Ness) and inorganic waste (Tofts Ness and Scatness) is evident from the Neolithic. It is possible that the development of the plaggen system may have developed independently from indigenous practices in the Netherlands and the Northern Isles.

*Hypothesis:*

*Methods of manuring have changed over time, and although deep topsoil horizons may appear similar in the field, they were created by different means at different times.*

*Conclusion:*

*The cultivation of midden heaps, demonstrated in the Neolithic at Tofts Ness and Scatness, is a practice which is distinct from adding midden material to arable soils. Iron Age soils were not positively identified in these investigations, but the evidence for the middens together with the soils from the earlier study (Simpson et al 1998b) suggest higher levels of organic manures were used at this time. The phosphate analysis showed differences in the organic/inorganic proportions in the waste material. The hypothesis is confirmed by the investigation.*

### 8.1.6 Discussion of the investigative methods

The value of thin section analysis in identifying manuring materials has been demonstrated in a number of studies (e.g. Simpson et al 1998a and b; Davidson and Carter 1998; Carter and Davidson 1998). One of the shortcomings of the method is the time and expense of processing the samples, which prohibits the collection of large numbers of samples and replicates. Collection of limited replicates makes accurate quantification difficult, and to address this problem it is considered best practice to use thin section analysis in conjunction with other methods which can aid in quantification of the materials (Macphail et al in press). Secondary methods can also be used to identify materials in greater detail on a molecular level (e.g. Simpson et al 1998a). The thin section analysis at Papa Stour, Tofts Ness and Scatness has identified peat/turf fragments, peat/turf ash, charred peat/turf fragments, wood charcoal, charred coal fragments (in the post-medieval period) phytoliths, diatoms and fungal spores. *This has confirmed the hypothesis that soils will retain such evidence, and has demonstrated* *that soils dating back as far as the Neolithic may retain the evidence despite reworking by soil biota and microbes.*

The organic/inorganic phosphate fractionation method, shown to be successful on acid soils, was tested on calcareous soils with differing results. The Tofts Ness soils, with pH between 7.3 and 8.5, retained a signature dominated by organic phosphates, whereas the Scatness soils pre-dating *c.* AD 1800 contained predominantly inorganic P. The signature at Scatness could be a true representation of inputs, or may reflect high biological activity which has transformed the organic into the inorganic fraction. The shortcoming of the method is that the absence or low levels of organic P cannot demonstrate the absence or limited levels of organic inputs, but the strength of the method is that rapid burial enables the organic proportion to be retained even in calcareous conditions. Soil magnetism was used to quantify the deposits at Tofts Ness, and was successful in distinguishing the soils from the midden deposits, and was to some degree successful in distinguishing the cultural soils from one another. The soil magnetism results at Bragasetter successfully distinguished the cultural soils from the unenhanced control soils but did not distinguish them from one another. They nevertheless showed differences in the levels of enhancement in the different functional areas, which corresponded with the historical and ethnographic information.

Reference and control samples were obtained in order to identify the materials used in manuring and to identify the source of the materials. The control samples for the phosphates and soil magnetism provided unenhanced samples against which the archaeological samples could be compared and the degree of enhancement established. The control samples from the relatively undisturbed soils near the archaeological sites demonstrated where the geology differed, e.g. at Scatness where the proportions of lithic clasts and quartz grains were different to the north and south of the site. The control samples also demonstrated that diatoms and phytoliths were present in the undisturbed peat.

The thin section reference samples for peat and peat ash were particularly useful as these materials were still recognisable even in the Neolithic contexts. The samples from the byre floor at the Corrigall Farm Museum demonstrated that raw peat was still recognisable after trampling, compaction and aerobic exposure over *c.* 80 years. The reference samples of animal dung contained spherulites, which are extremely useful indicators. *The hypothesis which stated that sources of material could be identified using reference samples was partially correct, but interpretation was difficult where there were several possible sources, e.g. diatoms can be present in peat, water, lake sediments and animal dung.*

Despite these uncertainties, links between the local soils, settlement deposits and arable fields could be established to some degree by identifying the sources of the manures. The key indicator was raw or unburned peat, which was found in the rough grazing and moorland areas near the settlements, in the midden deposits on site and in the arable soils surrounding the settlements. The settlements were on freely draining parent materials, where peat was unlikely to have formed in prehistory. Peat is therefore a key indicator for plaggen manuring on these sites, although this interpretation has to be applied cautiously given that small amount of uncharred peat will probably survive within fuel ash. Charred peat or turf also provided a link between moorland, the settlement where the peat was burned, the middens where the ash was stored or deposited and the fields where much of the material was finally spread.

*Hypotheses:*

- *Soils can retain evidence for manuring, and some of the materials used can be identified using thin section and chemical analysis: Confirmed.*
- *Links between local soils, settlement deposits and arable fields can be established by identifying the sources of the manures: Confirmed, but sources cannot be precisely defined.*
- *Sources of manuring materials can be suggested using reference and control samples: Confirmed, but caution must be exercised where materials appear similar in thin section and suites of indicators must be considered.*

## 8.2 Recycling of materials

The historical and ethnographic research on land management in the Northern Isles describes a system in which little was wasted. Kitchen refuse, nightsoil, byre waste and fuel ash were deposited together in middens which were subsequently spread onto the fields, and material did not accumulate within the settlements. Research into the traditional land management system in the Western Isles has demonstrated a similar efficiency in the recycling of waste materials in recent times (Smith 1994). The research in the Western Isles also showed an inefficient use of midden material in prehistory, when rubbish was allowed to accumulate within the settlements (*ibid.*). This pattern is also evident in the Northern Isles, where peat ash is found in vast quantities within the settlements from the Neolithic into the Pictish or Late Iron Age period, and organic waste was also allowed to accumulate in middens. The land use system in the Norse period was probably more efficient, but the limited excavation which has been carried out on Norse settlements is insufficient to address the question. The introduction (or the intensification) of the plaggen system in the Norse period may have coincided with more efficient recycling of waste materials.

## 8.3 Origins of the plaggen system

It has been suggested that the plaggen system was introduced to Scotland by monks, based on the discovery of anthropogenic soils at the ecclesiastical sites of Iona and Fearn Abbey (Barber 1981). More particularly, it has been suggested that the plaggen system was introduced into the Northern Isles by the monks at Birsay, Orkney (Simpson 1993). The Birsay monastery was part of the archbishropic of Hamburg-Bremen, an area with a history of plaggening, and monasteries are known to have introduced innovations in farming methods to the different regions where they became established. It is worth noting the language which is used to describe the different functional areas of farms and townships which employed the plaggen system. The rough grazing land (*hagi* or *scattald*), arable infield (*tounmal* in Orkney), animal enclosures (*quoys*) and the different types of arable fields have names derived from the Norse. The nomenclature would be more likely to be German or Dutch if the system was brought from north-western Europe, even if it were introduced in the late Norse period. This suggests that the system was taken over from the indigenous population and developed by the Norse settlers, or that it was developed independently by the Norse. The resolution of this issue will depend on further dating evidence and continued work on Late Iron Age settlements in the region.

## 8.4 Continuity of settlement location

A key feature of the archaeology of the Northern Isles is the longevity of some of the settlements. Both Tofts Ness and Scatness were occupied in the Neolithic, Bronze Age and Iron Age, and occupation at Scatness continued into the Pictish, Norse and post-medieval periods. Jarlshof had Bronze Age and Iron Age phases and was re-occupied in the Pictish, with settlement continuing into the Norse and post-medieval periods (Hamilton 1956). Some early prehistoric sites are believed to have been abandoned and re-occupied in the Iron Age; Pool, Sanday (Hunter 1990), Pierowall, Westray (Sharples 1984), Howe, Orkney (Ballin Smith 1994) and Quanterness, Orkney (Renfrew 1979) all belong to this category (Hunter 1990). Several Iron Age brochs continued to be occupied in the Pictish period; Gurness (Hedges 1987), Scatness (Dockrill 1998), Howe (Ballin Smith 1994) and Minehowe (Card et al 2000) all have Pictish structures. Sites with both Pictish and Norse occupation include Scatness (Dockrill 1998), Pool (Hunter et al in press), Brough of Birsay (Donaldson et al 1981) and Buckquoy (*ibid.*)(which had Norse style buildings but Pictish artefacts). The Vikings buried their dead in Pictish cemeteries at Westness, Rousay (Graham-Campbell and Batey 1998), Point of Buckquoy and probably at Pierowall, Westray (Sharples 1984). Medieval farm mounds on Sanday are thought, because of the Norse place name evidence, to predate the Norse period (Davidson et al 1986).

The longer-lived sites may owe their longevity to their proximity to the better agricultural land and their situation below the more marginal uplands. Abandoned Neolithic and/or Bronze Age farmsteads and field systems are widespread between the 30 and 60m contours of Shetland. These sites are generally believed to have been abandoned because the worsening climate towards the end of the Bronze Age forced the population down onto the lower slopes in the face of encroaching blanket peat (Turner 1998), but there may have been other factors which caused the shift. The multi-phased Jarlshof and Scatness are both on the South Mainland of Shetland, where the soils are more suited to agriculture than the land further north—especially where the soils have been amended. It has been suggested (Dockrill 2000) that one of the factors that caused some settlements to remain for so long in one place was the value of the heavily fertilised infield soils around the settlements. The value of good arable soils was certainly recognised in the Norse period, when townships with plaggen soils were subject to higher taxes (Simpson 1994).

Another possibility is that in the Iron Age the settlements on the best arable land began to specialise in cereal production. Trade in the Neolithic and Bronze Age was in luxury items, but in the Iron Age subsistence products began to be traded as social complexity grew. A rapid field survey was carried out on the broch at Clevigarth, *c.* 3 km NNE of Old Scatness. The survey identified an oval structure set within and intersected by irregular field boundaries, which suggest that the site was occupied in early prehistory. The soils were thin and are probably acidic, and an auger survey demonstrated that there were no deepened soils associated with the site. The broch was built adjacent to the prehistoric fields for some reason other than the proximity of good arable land, and it is suggested here that the brochs on the poorer quality soils of the Shetland uplands were trading in subsistence goods with the broch sites on the better quality soils.

## 8.5 Recommendations for future work

The hypothesis that many broch sites did not practice arable agriculture might be tested by a survey of the soils around the sites on the good arable land on the Fraserburgh soils of the South Mainland and the sites on the more marginal uplands to the north of this area. A preliminary survey of five Iron Age settlement sites has established that deepened soils occur around Jarlshof and also the broch at Eastshore, *c.* 1.5 km ESE of Old Scatness. A more detailed survey with radiocarbon dating and thin section analysis, phosphate analysis and analysis of soil magnetism on these sites and on the 13 other Iron Age sites on South Mainland Shetland may support the preliminary findings that deepened soils are limited to the areas of better land.

Unburnt peat fragments appear to be the best indicators for the plaggen system, but in future work this could be tested using microprobe. Microprobe can be directed at particular features in thin section slides, and will provide an elemental analysis of the materials which have been added to the soil. Samples have been taken of unburnt, dried peat which was collected for fuel for the Shetland Croft Museum, and samples have also been taken from the byre floor at the museum. Microprobe of the unburnt peat will serve as a control, to compare with the peat in the byre floor. This will test the hypothesis that the enhanced P in the bulk samples from the floor layer will be reflected in the peat fragments. The peat fragments from the Bragasetter kaleyard samples will then be analysed in order to confirm that the peat fragments are enhanced in phosphates, proving the link with the byre floor. Having established the links on a recently abandoned system, the samples from the arable fields at Iron Age Scatness will be analysed.

Bulk samples for lipid analysis were taken alongside each context which was sampled for thin section analysis. The samples have been sent to Bristol University but have not yet been processed. The indicators for animal manure will be compared with the organic phosphate levels to see if there is a correlation and under what conditions it occurs, and the identification of other materials will add to the results of this work. Research into a potential lipid biomarker for seaweed is currently underway.

## 8.6 Summary of conclusions

- Anthropogenic soils may appear to be similar in the field, but they were developed by a number of different methods. The variety of different manuring methods is greater than was previously supposed.
- Large numbers of unburned peat fragments in anthropogenic soils may be an indicator for the traditional plaggen system.
- Organic phosphates can survive in calcareous soils under anaerobic conditions.
- In the Neolithic at Tofts Ness and Scatness the midden heaps were cultivated. This may have been a common practice at the time, and it demonstrates that intensive arable agriculture can take place without physical field boundaries. The soils surrounding Tofts Ness were also enriched with midden material.
- In the Bronze Age at Tofts Ness the anthropogenic arable soil was deepened and expanded, i.e. production was intensified.
- A cultivated layer of wind-blown sand at Tofts Ness was consolidated by the addition of midden material, which was probably applied in order to enhance the fertility and stability of the sand. A number of parallels for this practice were noted.
- The Iron Age midden heaps at Scatness contained lower levels of P than the arable soils which surrounded the site, which suggests that organic-rich waste was used selectively as fertiliser.
- In the Early Iron Age at Tofts Ness organic material was added to the arable soils as fertiliser, but was also deposited in the middens on site. The deposition of organic waste in middens rather than on the fields suggests that it was not used as efficiently as it could have been.
- The development of the plaggen system in the Norse period may have brought about a more systematic and efficient use of waste materials at this time.
- In the post-medieval period arable agriculture was intensified further, and waste material was used more systematically.
- These changes reflect greater organisation of resources and an intensification of arable production over time.

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## APPENDIX 1: Soil profile descriptions

### A1.1 BRAGASETTER, PAPA STOUR

Prepared by Paul Adderley, University of Stirling
SSEW terminology (Hodgson, 1976)

Key to soil profile names:

| Functional Zone | Replicate profile |
|---|---|
| K = Kaleyard | 1,2,3,4 |
| P = Planticrue | |
| R = Rigged | |
| G = Grazing | |

| Profile K1 | Site details: | Gently sloping site (ca. 3°) straight<br>Near centre of Kaleyard<br>Profile face - N facing<br>Surface vegetation – annual weeds and grasses (no nettles)<br>Total depth of profile – 55 cm<br>Bone fragment – 18 cm |
|---|---|---|
| **Horizon (SSEW)** | **Depth (cm)** | **Features (SSEW notation)** |
| Ap1 | 0-30 | 10 YR 3/1 very dark grey; sandy silt loam/ sandy loam; weak sub-angular blocky fragments breaking to small granular; many fine fibrous roots throughout horizon; smooth gradual boundary |
| Ap2 | 30-47 | 10 YR 3/2 dark greyish brown; sandy loam/ sandy silt loam; weak sub-angular blocky fragments breaking to granular; many fine fibrous roots throughout; small sub-angular and sub-rounded stones; smooth clear boundary |
| B(x) | 47-55 | 7.5 YR 5/4 brown and 7.5 YR 6/3 light brown (1:1); loamy sand/sandy loam; massive breaking to fine platy peds occasional fine fibrous root; many small angular and occasional large stones;<br>Drift material at base of profile |

| Profile K2 | Site details: | Lower part of Bragasetter kaleyard<br>Gently sloping<br>8 m away from main dwelling of farm buildings<br>Currently used as a small ca.15 m * 10 m hay meadow<br>Total depth of profile – 44 cm |
|---|---|---|
| **Horizon (SSEW)** | **Depth (cm)** | **Features (SSEW notation)** |
| Ap | 0 – 28 | 10 YR 3/1 very dark grey; silty (organic?) clay loam; weak medium subangular blocky fragments breaking to weak granular peds; many fine fibrous roots; earthworms present throughout horizon; concentration of angular and sub angular stones at depth - many small, common large stones; smooth clear boundary |
| Bx | 28-44 | 10 YR 4/3 brown – 10 YR 5/6 yellowish brown at depth; sandy loam; massive breaking to subangular blocky with some evidence of platy peds in parts of profile; common small angular/subangular stones; common fine fibrous roots; bottom of profile shattered (?) drift material |

| Profile K3 | Site details: | Lower part of Bragasetter kaleyard<br>Gently sloping<br>12 m away from main dwelling of farm buildings<br>Currently used as a small ca.15 m * 10 m hay meadow<br>Total depth of profile – 46 cm |
|---|---|---|
| **Horizon (SSEW)** | **Depth (cm)** | **Features (SSEW notation)** |
| Ap | 0 - 26 | 10 YR 3/1 very dark grey; silty (organic?) loam; weak medium subangular blocky fragments breaking to weak granular peds; many fine fibrous roots; many small, few large stones subangular stones at base; smooth clear boundary |
| B(h)x | 26 - 46 | 7.5 YR 5/6 Strong brown with 10 YR 3/1 very dark grey coatings; yellowish brown at depth; sandy loam; massive breaking to platy; many small angular/subangular stones; many fine fibrous roots; bottom of drift material |

| Profile K4 | Site details: | Gently sloping site<br>2.5 – 3.0 m away from edge of kaleyard (stone walls)<br>Edge of plot used for potato cropping<br>Total depth of profile – 70 cm |
|---|---|---|
| **Horizon (SSEW)** | **Depth (cm)** | **Features (SSEW notation)** |
| Ap | 0 - 48 | 5 YR 3/1 very dark grey; silty (organic?) clay loam; weak subangular blocky fragments breaking to granular; many fine fibrous roots in upper 20-25 cm of horizon, common fine fibrous roots below this depth; charcoal 5 YR 2.5/1 black throughout horizon to 40 cm; few small subangular stones in lower parts of horizon (35 – 48 cm); smooth abrupt boundary |
| Bh | 48 – 58 | 5 YR 3/2 dark reddish brown – 7.5 YR 4/2 dark brown; silty loam; subangular blocky fragments breaking to weak granular peds; few fine fibrous roots; many small subangular stones; few large stones; smooth clear boundary |
| Bx | 58 – 70 | 5YR 3/3 dark reddish brown with few (ca. 5%) 5 YR 3/1 very dark grey mottles; sand; massive breaking to fine platy peds; occasional (<1%) thick fibrous root; drift material at base of profile |

| Profile R1 | Site details: | Rigged land associated with Bragasetter<br>Profile on centre of slope below Whirlie farmhouse<br>Moderately to strongly sloping site<br>S aspect<br>Centre of rig (rig "width" – 5.2 m)<br>Periodicity of adjacent rigs 2.0 – 2.5 m<br>Profile face facing S<br>Total depth of profile – 64 cm |
|---|---|---|
| **Horizon (SSEW)** | **Depth (cm)** | **Features (SSEW notation)** |
| Ap | 0 - 46 | 10 YR 3/1 very dark grey; sandy silt loam; moderately developed subangular blocky fragments breaking to weakly developed granular peds; many small subangular and subrounded stones quantity and size of stones increasing with depth (40 cm); no distinct orientation of stones; many fine fibrous roots; earthworms present; smooth clear boundary |
| Bx | 46 - 66 | 10 YR 5/4 yellowish brown - 10 YR 4/3 brown; sand/sandy loam; infilled channels (faunal?) with coarse sandy material, darker (7.5 YR 3/2 dark brown) than matrix; massive breaking to weakly developed fine platy peds, occasionally breaking to weak subangular blocky peds; few fibrous roots; many small, medium and large subangular and subrounded stones of distinctly mixed lithology including red sandstone and quartzose, consolidated (?) drift material at base of profile |

| Profile R 2 | Site details: | Rigged land associated with Bragasetter<br>Profile on centre of slope below Bragasetter farmhouse and midden<br>Moderately sloping site<br>S aspect<br>Centre of rig (rig "width" – ca. 3 m)<br>Profile face facing SE<br>Total depth of profile – 74 cm |
|---|---|---|
| Horizon (SSEW) | Depth (cm) | Features (SSEW notation) |
| Ap1 | 0 – 40 | 5 YR 2.5/1 Black; sandy silt (organic ?) loam; weakly developed subangular blocky fragments breaking to moderately developed fine granular peds; few small angular stones; many fine fibrous roots; gradual smooth boundary |
| Ap2 | 40 – 56 | 5 YR 2.5/1 – 3/1 black – very dark grey; sandy loam; weakly developed subangular blocky fragments breaking to smaller sub-angular peds; many large stones angular/subangular occasionally subrounded with no distinct orientation; common fine fibrous roots; smooth clear boundary |
| B(w?) | 56 – 74 | 5 YR 4/2 dark reddish grey – 7.5 YR 5/2 brown; sandy loam; massive breaking to very weak sub angular peds; common medium large subangular/subrounded stones (NB fewer stones than Ap2 horizon); relict faunal (?) channels infilled with coarse sand material 7.5 YR 4/4 dark brown |

| Profile R3 | Site details: | Rigged land around Bragasetter farm<br>Moderate/gently sloping site facing E (towards shoreline)<br>Rig "width" – 10.0 m<br>Nearest rig boundary - 2 m<br>Less prominent rig boundary – 8 m<br>Permanent pasture<br>Profile face facing E<br>Total depth of profile - 34 cm |
|---|---|---|
| **Horizon (SSEW)** | **Depth (cm)** | **Features (SSEW notation)** |
| Ap | 0 – 18 cm | 7.5 YR 4/2 dark brown; sandy loam/loamy sand; moderately developed medium subangular blocky fragments breaking to fine granular; many small subrounded stones in upper part of horizon; many medium angular/subangular stones in lower part of horizon; earthworms present; many fine fibrous roots; clear wavy boundary |
| Bx | 18 – 34 cm | 10 YR 4/6 dark yellowish brown; sandy loam; massive breaking to fine platy peds; common fine fibrous roots; many large angular stones; drift material at base of profile |

| Profile R4 | Site details: | Rigged land around Bragasetter farm<br>Gently sloping site facing E (towards shoreline)<br>Rig "width" – 9.5 m<br>Nearest rig boundary – 2.5 m<br>Permanent pasture<br>Profile face facing E<br>Nearer shoreline than BR3 profile<br>Total depth of profile – 40 cm |
|---|---|---|
| **Horizon (SSEW)** | **Depth (cm)** | **Features (SSEW notation)** |
| Ap | 0 – 30 | 10 YR 3/2 very dark greyish brown; sandy silt (organic?) loam; weak subangular blocky breaking to granular peds; many fine fibrous roots; few large stones; few fleshy roots; clear smooth boundary |
| B(g)x | 30 – 40 | 10 YR 4/3 brown; sandy silt; massive breaking to subangular blocky and occasionally fine platy peds; common fine fibrous roots; few large stones; drift material at base of profile |

| Profile P1 | Site details: | Planticrue on upper slopes near to Bragasetter and Whirlie<br>Nearest building ca. 50 m away<br>Size of planticrue 2.4 m * 3.7 m<br>Profile pit 50 cm away from walls of planticrue<br>Surface of planticrue large fallen stones and boulders from walls, otherwise permanent grass<br>Planticrue open to grazing sheep<br>Total depth of profile – 24 cm |
|---|---|---|
| **Horizon (SSEW)** | **Depth (cm)** | **Features (SSEW notation)** |
| Ap | 0 – 17 | 7.5 YR 3/2 – 4/2 dark brown; silty loam; moderate to weakly developed medium granular; common subangular and subrounded small stones including coal? (2.5 Y 2/0); many fine fibrous roots; clear irregular boundary |
| AC | 17 – 24 | Clear fine mottling (1:1) 7.5 YR 4/4 brown along with 10YR 3/1 very dark grey; sandy loam; massive with matrix (20-30 % /vol) around abundant/extremely abundant large and very large stones; many fine fibrous roots; |

| Profile P2 | Site details: | Planticrue situated between Bragasetter and School buildings<br>Planticrue open to sheep grazing<br>Size of planticrue 6.5 m * 5.5 m<br>Nearest planticrue wall 1.5 m<br>Permanent pasture<br>Total depth of profile – 30 cm |
|---|---|---|
| Horizon (SSEW) | Depth (cm) | Features (SSEW notation) |
| Ap | 0 – 16 | 7.5 YR 3/2 – 4/2 dark brown; silty clay loam; weakly developed subangular blocky fragments breaking to very weak fine granular peds; common subangular and subrounded small and medium – stones increasing with depth; many fine fibrous roots; few fleshy roots; gradual wavy boundary |
| AC | 16 - 30 | 10 YR 5/4 – 6/4 yellowish brown – light yellowish brown with frew clear fine mottles 7.5 YR 5/6 strong brown; sandy loam; massive breaking to angular/subangular blocky peds; common small angular and subrounded large and very large stones; many fine fibrous roots; "rotten rock" fracturing at base of profile to reveal coarse sandy 5 YR 4/6 yellowish red material |

| Profile P3 | Site details: | Planticrue on upper slope above profiles BR 3 and BR 4<br>SE aspect<br>Planticrue open to sheep grazing<br>Permanent pasture<br>Site gently sloping within planticrue<br>Many large and very large stones scattered within planticrue<br>Planticrue dimensions 3.0 * 3.7 m<br>Nearest planticrue wall 0.7 m<br>Heavy rain preceding sampling and profile description 3 cm standing water in base of profile, suggesting poor drainage<br>Total depth of profile 27 cm |
|---|---|---|
| **Horizon (SSEW)** | **Depth (cm)** | **Features (SSEW notation)** |
| Ap | 0 – 20 | 10 YR 3/2 very dark greyish brown; silty (organic?) loam; coarse sand grains visible; subangular blocky fragments breaking to very weakly developed granular peds; many fine fibrous roots; many small angular stones of mixed lithology in upper part of horizon; many medium mixed (rounded to angular) stones in lower part of horizon; smooth clear boundary |
| AC | 20 – 27 | 7.5 YR 5/6 strong brown; sand; massive breaking to apedal single grains; many large angular stones; few fine fibrous roots; |

| Profile P4 | Site details: | Planticrue nearest Bragasetter farmhouse<br>Planticrue on upper slope above profiles BR 3 and BR 4<br>**No access for sheep**<br>**SE aspect**<br>Recently dug over<br>Site gently sloping within planticrue<br>Planticrue dimensions 4.2 * 2.8 m<br>Nearest planticrue wall 1.0 m<br>Common small mixed lithology stones on surface |
|---|---|---|
| **Horizon (SSEW)** | **Depth (cm)** | **Features (SSEW notation)** |
| Ap | 0 – 9/18 | 7.5 YR 3/2 dark brown; sandy silt loam; moderately developed subangular blocky fragments breaking to fine granular peds; many small angular/ subrounded stones throughout horizon; many large angular stones at base of horizon; common woody and coarse fibrous roots; common fine fibrous roots; irregular broken boundary |
| AC | 9/18 – 20/24 | 7.7 YR 4/6 – 5/6 strong brown; occasional fine bands of (organic?) material very dark grey 10 YR 3/1; sand; massive breaking to single grain occasionally to fine platy peds; few fine fibrous roots; very abundant, very large angular stones; |

| Profile G1 | Site details: | Gently sloping site on lower level permanent pasture near to shoreline<br>Total depth of profile – 42 cm |
|---|---|---|
| **Horizon (SSEW)** | **Depth (cm)** | **Features (SSEW notation)** |
| Ah | 0 – 29 | 7.5 YR 3/2 - 4/3 brown/ dark brown; sand – coarse sand grains visible; very weakly developed granular peds/single grain; many fine fibrous roots; few small rounded stones in lower part of horizon; gradual wavy boundary |
| Bx | 29 – 42 | 10 YR 4/3 brown; sandy loam; massive breaking to single grain; few fine fibrous roots; common medium/large angular stones; relict root channels (or faunal burrows?) infilled with sandy material throughout horizon; different material at base; |

| Profile G2 | Site details: | Grazing land near shoreline<br>Distance to cow-dyke – ca. 30m<br>Level/gently sloping site<br>Permanent pasture (unimproved)<br>Total depth 28 cm |
|---|---|---|
| **Horizon (SSEW)** | **Depth (cm)** | **Features (SSEW notation)** |
| Ah | 0 – 18 | 7.5 YR 3/2 dark brown; sandy silt loam; coarse sand grains visible; weakly developed medium granular peds; common small/medium angular/subrounded stones few coarse fleshy roots; many fine fibrous roots; clear smooth boundary |
| Bx | 18 - 28 | 7.5 YR 5/3 brown matrix with 7.5 YR 3/2 dark brown infilling into (relict root?) channels; sandy loam; massive breaking to weakly developed medium angular peds; common medium angular stones; common fine fibrous roots; drift |

| Profile G3 | Site details: | Strongly sloping site<br>Waterlogged at 12 cm<br>Distance to nearest burn – 3 m<br>Total depth of profile – 25 cm |
|---|---|---|
| **Horizon (SSEW)** | **Depth (cm)** | **Features (SSEW notation)** |
| Ah | 0 – 16 | 10 YR 2/2 very dark brown; silty (organic?) loam; visible sand grains; very abundant fine fibrous roots; many medium fleshy roots; discontinuous |
| BC | 16 – 25 | 10 YR 5/3 brown; sand; single grain; few fine fibrous; many large and very large angular/ subrounded stones; |

| Profile G4 | Site details: | Gently sloping site<br>Between school house and Bragasetter<br>Total depth of profile – 28 cm |
|---|---|---|
| Horizon (SSEW) | Depth (cm) | Features (SSEW notation) |
| Lf | 0 – 2 | Clear wavy boundary |
| Ah | 2 – 16 | 10 YR 2/2 very dark brown; silty (organic?) loam; visible sand grains; very abundant fine fibrous roots; many medium fleshy roots; discontinuous |
| AC | 16 – 28 | 10 YR 2/2 very dark brown; silty (organic?) loam; visible sand grains; few fine fibrous roots; very abundant subangular/ subrounded large/ very large stones; |

## A1.2 TOFTS NESS

| *Context* | *Area* | *Description* | *Munsell colour* | *Interpretation* |
|---|---|---|---|---|
| 5000 | J | Grey, sandy silt | 10 YR 3/1 | Topsoil |
| 5001 | J | Black, slightly clayey, sandy silt | 10 YR 2/1 | Midden deposit |
| 5002 | J | Very pale brown, sand | 10 YR 7/3 | Animal disturbance |
| 5003 | J | Dark brown, clayey silt | 10 YR 4/2-4/3 | Midden deposit |
| 5004 | J | Black, slightly sandy, clayey silt | 10 YR 2/1 | Midden deposit |
| 5005 | J | Dark brown, sandy, silty clay | 10 YR 3/1 4/2-4/3 | Midden deposit |
| 5006 | J | Black, sandy, clayey silt | 10 YR 2/1 | Midden deposit |
| 5007 | J | Dark brown, sandy, clayey silt | 10 YR 4/2-4/3 | Midden deposit |
| 5008 | J | Greyish brown, sand, with humic lenses | 10 YR 5/2 | Midden deposit |
| 5009 | J | Very dark greyish brown, silty clay | 10 YR 3/2 | Midden deposit |
| 5010 | J | Greyish brown, sand | 10 YR 5/2 | Buried soil |
| 5011 | J | Very dark brown, sandy, silty clay | 10 YR 3/1 | Buried soil |
| 5012 | J | Black, sandy, silty clay | 10 YR 2/1 | Buried soil |
| 5013 | J | Very dark greyish brown, sandy clay | 10 YR 3/2 | Buried soil |
| 5014 | A | Mid brown, very sandy silt | Unrecorded | Topsoil |
| 5015 | A | Very pale brown, sand | 10 YR 6/2 & 7/3 | Windblown sand |
| 5016 | A | Very dark brown, sandy, clayey silt | 10 YR 2/1-2/2 | Upper buried soil |
| 5017 | A | Very dark grey, silty clay | 10 YR 3/1 | Midden deposit |
| 5018 | A | Very dark greyish brown, clay | 10 YR 3/2 | Midden deposit |
| 5019 | A | Very dark greyish brown, clayey silt | 10 YR 3/1-3/2 | Midden deposit |
| 5020 | A | Brown, clay | 7.5 YR 4/2-4/3 | Midden deposit |
| 5021 | J | Black/very dark brown, sandy, clay silt | 10 YR 2/1-2/2 | Midden deposit |
| 5022 | J | Very dark greyish brown, silty clay | 10 YR 3/2 | Midden deposit |
| 5023 | J | Very dark grey slightly sandy, silty clay | 10 YR 3/1 | Midden deposit |
| 5024 | A | Very dark brown, clayey silt | 10 YR 2/2 | Midden deposit |
| 5025 | A | Very dark grey, silt | 10 YR 3/1 | Midden deposit |
| 5026 | A | Very dark grey clayey, silt | 10 YR 3/1 | Midden deposit |
| 5027 | J | Very dark grey, slightly sandy, silty clay | 10 YR 3/1 | Midden deposit |

| *Context* | *Area* | *Description* | *Munsell colour* | *Interpretation* |
|---|---|---|---|---|
| 5028 | A | Very dark grey, silty clay | 10 YR 3/1-3/2 | Midden deposit |
| 5029 | A | Dark brown, clayey silt | 7.5 YR 3/2 | Midden deposit |
| 5030 | A | Black, silty clay | 10 YR 2/1-2/2 | Lower buried soil |
| 5031 | A | Dark grey, clay | 10 YR 4/1 | Midden deposit |
| 5032 | A | Very dark grey, clayey silt | 10 YR 3/1 | Midden deposit |
| 5033 | A | Very dark brow, silty clay | 10 YR 2/2 | Midden deposit |
| 5034 | A | Mottled, brown/strong brown, silty clay | 7.5 YR 4/4-4/6 & 10 YR 3/2 | Midden deposit |
| 5035 | A | Dark greyish brown, silty clay | 10 YR 3/2 | Midden deposit |
| 5036 | 4 | Brown, sandy soil | Unrecorded | Turf |
| 5037 | 4 | Brown soil, grey and white sand | Unrecorded | Topsoil |
| 5038 | 4 | White, sand | Unrecorded | Windblown sand |
| 5039 | 4 | Light brown, sand | Unrecorded | Windblown sand |
| 5040 | 4 | Black, sandy silt | 10 YR 2/1 | Buried soil |
| 5041 | 4 | Black, sandy silt | 10 YR 2/1 | Buried soil |
| 5042 | 4 | Black, sandy silt | 10 YR 2/1 | Buried soil |
| 5043 | 4 | Black, sandy silt | 10 YR 2/1 | Buried soil |
| 5044 | 5 | Brown sandy soil | Unrecorded | Turf |
| 5045 | 5 | Brown soil, grey and white sand | Unrecorded | Topsoil |
| 5046 | 5 | White, sand | Unrecorded | Windblown sand |
| 5047 | 5 | Very light brown, sand | Unrecorded | Windblown sand |
| 5048 | 5 | Black, sandy silt | 10 YR 2/1 | Buried soil |
| 5049 | 5 | Grey, sand | Unrecorded | Sand below buried soil |
| 5050 | 5 | Dark grey, sand | Unrecorded | Sand below buried soil |
| 5051 | 5 | Grey/brown, sand | Unrecorded | Sand below buried soil |
| 5052 | 5 | Black, sandy silt | 10 YR 2/1 | Buried soil |
| 5053 | 3 | Brown soil, grey and white sand | Unrecorded | Topsoil |
| 5054 | 3 | Light grey, medium to coarse sand | 10 YR 7/2 | Windblown sand |
| 5055 | 3 | Grey/brown, sand | 10 YR 6/2–5/2 | Buried soil |
| 5056 | 3 | Black, sandy clay loam | 10 YR 2/1 | Buried soil |
| 5057 | 3 | Very dark grey, sandy clay loam | 10 YR 3/1 | Buried soil |
| 5058 | 3 | Very dark grey, silty clay | 10 YR 3/1 | Buried soil |
| 5059 | 3 | Dark greyish brown, silty clay | 10 YR 4/2 | Buried soil |
| 5060 | 6 | Grey brown, sand | Unrecorded | Turf |
| 5061 | 6 | Light brown soil | Unrecorded | Topsoil |
| 5062 | 6 | Light brown, sand | 10 YR 6/2 | Lower topsoil |

| *Context* | *Area* | *Description* | *Munsell colour* | *Interpretation* |
|---|---|---|---|---|
| 5063 | 6 | Linear cut | N/A | Probably modern |
| 5064 | 6 | Light brown sand and dark brown soil | 7.5 YR 5/6-5/8 & 10 YR 7/3-7/4 | Fill of F 5063 |
| 5065 | 6 | Grey/white, sand | 10 YR 7/1-7/2 | Upper windblown sand |
| 5066 | 6 | Black, sandy silt | 10 YR 2/1 | Upper buried soil |
| 5067 | 6 | Black, sandy silt | 10 YR 2/1 | Upper buried soil |
| 5068 | 6 | Dark grey, sandy silt | 10 YR 3/2 | Upper buried soil |
| 5069 | 6 | Grey/white, sand | 10 YR 7/1-7/2 | Lower windblown sand |
| 5070 | 6 | Very dark greyish brown, clayey silt | 10 YR 3/3 | Lower buried soil |
| 5071 | 7 | Grey brown, sand | 10 YR 5/1-4/1 | Turf |
| 5072 | 7 | Brown soil, grey and white sand | 10 YR 5/2-4/2 | Topsoil |
| 5073 | 7 | White sand | 10 YR 7/1-7/2 | Windblown sand |
| 5074 | 7 | Black, sandy silt | 10 YR 2/1 | Buried soil |
| 5075 | 7 | Black, clayey sandy silt | 10 YR 2/1 | Buried soil |
| 5076 | 7 | Very dark grey, sandy silt | 10 YR 3/1 | Buried soil |
| 5077 | 7 | Dark grey clayey silt | 10 YR 4/1 | Buried soil |
| 5078 | 8 | Grey brown, sand | 10 YR 5/1-4/1 | Turf |
| 5079 | 8 | Brown soil, grey and white sand | Unrecorded | Topsoil |
| 5080 | 8 | White sand | 10 YR 7/1-7/2 | Upper windblown sand |
| 5081 | 8 | Black, peaty soil | 10 YR 2/1 | Upper buried soil |
| 5082 | 8 | Dark grey, sandy silt | 10 YR 4/1 | Upper buried soil |
| 5083 | 8 | Very dark grey, sandy silt | 10 YR 4/1-3/1 | Upper buried soil |
| 5084 | 8 | Black, clay | 10 YR 2/1 | Upper buried soil |
| 5085 | 8 | Greyish sand | 10 YR 7/1-7/2 | Lower windblown sand |
| 5086 | 8 | Dark grey, clayey silt | 2.5 YR 4/1 | Lower buried soil |
| 5087 | A | Medium flat stones | N/A | Paving ? |
| 5088 | 3 | Greyish brown, loamy sand | 10 YR 5/2&6/2 | Buried soil |
| 5089 | A | Greyish brown, loamy sand | 10 YR 5/2 | Upper buried soil |

# APPENDIX 2: SOIL MICROMORPHOLOGY

## A2.1 BRAGASETTER SLIDE DESCRIPTIONS

### R1.15 (Ap horizon)

**Fabric 1**
Channel and chamber structure with weakly developed sub-angular aggregates
Porosity 10-20%
**Coarse Fraction**
c. 50%. Sub-rounded to angular. 90-95% quartz. 5-10% other, including feldspar, compound quartz grains, glassy mineral (sub-angular, 2° linear weathering, porous)
coarse sand 10%
medium sand 5-10%
fine sand 20%
very fine sand 10-15%
silt 5-10%
**Fine fabric:** Dark brown, speckled, low birefringence
**Coarse Organic**
c. 5% charcoal; 1-2% of the charred material contains mineral grains.
1-2% reddened fibrous material with mineral grains (fragments measure up to 1.2mm).
very rare (<0.5%) parenchymatic tissues
**Fine Organic**
<0.05% fungal spores
<0.05% phytoliths (only noted a few)
<0.05% fine crystalline material
**Groundmass:** close porphyric
**Pedofeatures**
c. 10μm thick coating of very dark red (XPL) material coating 1 or 2 grains; associated fine crystalline material goes slightly sparkly under OIL.
Mammilated excrement <2% of the slide in channels and chambers
Areas of the fabric are formed by densely coalesced excremental fabric. Fabric appears to be wholly excremental.

**Fabric 2**
Channel and chamber structure
5-10% porosity
**Coarse Fraction**
25-30% of the slide
95% quartz. 5% other, including compound quartz grains,
Grains are sub-rounded to angular
coarse sand 2%
medium sand c. 5%
fine sand 5-10%
very fine sand 5-10%
silt 10-15%
**Fine Fabric:** pale brown (PPL); Yellow-brown (OIL); low birefringence
**Coarse Organic**
2-5% charcoal.
<1% reddened fragments with mineral grains
<0.5% phlobaphene containing tissues
1-2% parenchymatic tissues. Parts of the fabric have up to 10%.
**Fine Organic**
Very rare (<0.5%) fungal spores. Very rare (<0.5%) phytoliths
**Groundmass:** close porphyric
**Pedofeatures**
2% reddened material with varying sharpness of outline.
Thin coatings (c. 10μm thick) coatings on one or two grains

<2% mammilated excrement in channels and chambers

**R1.30 (Ap horizon)**

**Fabric 1**
Channel and chamber structure with weakly developed sub-angular blocky aggregates
Porosity c. 30%
**Coarse Fraction**
40% of the slide. 90-95% quartz. 5-10% other, including microcline, other feldspar, sandstone, biotite, compound quartz grains. Grains are sub-angular to angular
coarse sand 2-5%
medium sand 5-10%
fine sand c. 15%
very fine sand 5-10%
silt 2-5%
**Fine fabric:** brown (PPL and OIL), speckled, medium birefringence
**Coarse Organic**
2-5% charcoal up to c. 1 mm
Phlobaphene containing tissues? Red material with fibres and cells
Material contains c. 5% mineral grains
<0.5% parenchymatic tissues
**Fine Organic**
<0.5% fungal spores
<0.5% diatoms
<0.5% phytoliths
<0.5% fine crystalline material
**Groundmass:** close porphyric
**Pedofeatures**
<0.5% grains with heterogeneous orange and white (XPL) coatings c. 4-6 μm thick. One grain has an inner coating of white material c. 4μm thick and an outer, yellowish coating 6-8 μm thick.
One sandstone fragment with depleted stone rim up to 250 μm thick
<5% porous mammilated excrement forming loose discontinuous infills in channels and chambers
Granular soil in channels and chambers
Igneous rock fragment with weathering (darkened area) on the upper side.
Amorphous organic material

**R1.30 Fabric 2**
Small area 2mm x 800 μm, running off the top of the slide. Material forms the infill of a channel and is the same as BR1.45 fabric 1

**R1.45 (Ap/Bx Horizon)**
6 'fabrics', described briefly for reference and then in full:

*Fabric 1*: pale yellow-brown 10YR 6/6
*Fabric 2*: mid brown 10YR 4/4 . Possibly the same as fabric 1, BR1.30
*Fabric 3*: Stoneless brown speckled silt, forming coatings and infilling voids. 10YR 3/4. Forms cappings on excremental infills composed of Fabric 1 or of a combination of fabrics 1 and 2.
*Fabric 4*: Bright orange 5YR 5/8. Actually this is a material, not a fabric. Fragments of this appear in within other fabrics.
*Fabric 5*: Mid orange-brown (2.5YR 5/8 to 7.5YR 5/6)
*Fabric 6*: Chitonic sand with pedofeatures

The slide as a whole has a channel and chamber structure. Chambers are coarse macro (2-5mm)
Porosity: c. 40%

**Fabric 1**
**Coarse component**

c. 20% of the slide. C. 95% quartz, 5% other, including micas,
Grains are sub-rounded to angular—dominantly angular and sub-angular
coarse sand 5%
medium sand 10%
fine sand 5-10%
very fine sand 5-10%
silt 2-5%
**Fine Fabric**: pale yellow-brown (PPL)—10YR 6/6. Yellow-brown (OIL). Speckled. Low birefringence
**Coarse Organic**
<1% parenchymatic tissues
<0.5% phlobaphene containing tissues
<0.5% charcoal (small fragments, up to 40 µm)
**Fine Organic**
<0.5% diatoms
<0.5% fungal spores
1-2% amorphous organo-mineral material
**Groundmass**: porphyric
**Pedofeatures**
1-2% amorphous organic
<5% loose, discontinuous excremental infills
Fabric is mammilated at the edges and probably comprises very dense excremental material
Organo-mineral nodule with distinct edges (slightly serrated at x620)
<0.5% iron accumulations

**R1.45 Fabric 2**
**Coarse Component**
98% quartz. 2% other, including plagioclase, micas. Grains are sub-rounded to angular
medium sand 5%
fine sand 10-15%
very fine sand c. 20%
silt 5-10%
**Fine Fabric**: mid-brown (PPL 4/4), orange-brown (OIL), speckled. Low birefringence
**Coarse Organic**
1-2% charcoal under 200 µm; 1 large fragment (600 µm) contains a quartz grain.
Fragment of material 440 µm, red and slightly fibrous looking; made up of red nodules. Material contains one quartz grain.
**Fine Organic**
<0.5% fungal spores
<0.5% phytoliths
<0.5% fine crystalline material, both in the fabric and in the voids. Forms a coating on some of the grains.
**Groundmass**: close porphyric
**Pedofeatures**
1-2% organo-mineral
Fabric is mammilated around the edges. <5% mammilated fabric.
Fabric 2 forms a small area of dense complete infill in a channel between several other fabric types.
Fabric 2 also forms excrement in other parts of the slide.

Fabric 2 is probably the same as Fabric 1 in BR1.30.

**Fabric 3**
99% fine fabric and c. 1% coarse silt. Coarse component includes silt and micas.
Fine Fabric: brown (PPL) 10YR ¾. Orange-brown (OIL). Speckled. Very low birefringence
Organic: c. 2% amorphous organo-mineral. C. 1% fine charcoal
Fabric forms coatings on mineral grains and on aggregates. Also forms cappings on aggregates and mammilated excrement in channels. Forms void linings and in some cases lines only the bottom of voids. Cappings are up to 120 µm thick
Fragments of former void lining or cappings are incorporated into other fabrics, including fabric 5.
The material is interpreted as silt translocated from Fabric 1, BR1.30

**Fabric 4**
Glassy, bright orange fabric (5YR 5/8) PPL. Red brown (OIL). Moderate birefringence. A material rather than a fabric.

**Fabric 5**
**Coarse component**
40% coarse. 90-95% quartz, 5-10% other, including micas and feldspar . Sub-rounded to sub-angular
coarse sand 5%
medium sand 2-5%
fine sand 10%
very fine sand 10%
silt 15%
**Fine Fabric:** mid orange-brown (PPL) 2.5YR 5/8 to 7.5YR 5/6. Reddish brown (5YR 5/4) in OIL. Speckled limpidity. Moderate birefringence.
**Coarse Organic**
2-5% amorphous organo-mineral
<0.5% charcoal frags <100 µm
<0.5% parenchymatic tissues
<0.5% phlobaphene containing tissues
**Fine Organic**
<0.5% phytoliths
<0.5% fungal spores
<0.5% fine crystalline material
**Groundmass:** close porphyric
**Pedofeatures**
Dusty and limpid yellow and orange birefringent clay coatings up to 10 µm on c. 5% of the grains. Coatings are discontinuous and are sparkly yellow and white under OIL
Fabric is mammilated on the edges and <5% is clearly made up of porous coalesced excrement
Areas and fragments of bright orange fabric 4 occur within the fabric.

**R1.45 Fabric 6**
Channel and chamber structure
Porosity 10-20%
**Coarse Component**
Coarse: fine ratio at 90:10
90-95% quartz, 5-10% other, including biotite, feldspar (including microcline), compound quartz grains. Sub-angular to angular.
coarse sand 2%
medium sand 15%
fine sand 50%
very fine sand 15%
silt 2-5%
**Fine Fabric:** reddish and yellow-brown (5YR 5/6, 6/6, 5/8) (PPL). Speckled. Medium to high birefringence.
**Coarse Organic**
<0.5% parenchymatic tissues
<0.5% charcoal frags, up to 100 µm
**Fine Organic**
1-2% fine crystalline material
<0.5% fungal spores
<0.5% diatoms
**Groundmass:** Chitonic. Few (5-15%) areas of close spaced porphyric.
**Pedofeatures**
V. rare loose discontinuous excrement in channels. Mammilated and spheroidal areas (<5%) of Fabric 4 in and around several voids and channels
Areas of the fine fabric are porous excrement; some areas are comprised of densely coalesced excrement.
Grains have orange and yellow coatings (XPL) which also show up yellow-brown in PPL. Areas of the coatings are limpid; some are dotted. Coatings are up to 100 µm thick but mostly c. 10 µm thick.

V. rare amorphous organo-mineral

R4.15 (Ap Horizon)

**Fabric 1**
Channel and chamber structure
Porosity 25-30%
**Coarse Component**
20-30%
sub-angular to sub-rounded.
85-90% Quartz. 10-15% other, including feldspar (plagioclase), sandstone (with iron depletion around the rim), compound quartz grains.
coarse sand 2%
medium sand 10%
fine sand 10%
very fine sand 5-10%
silt 5-10%
**Fine Fabric:** red-brown (PPL), brown (OIL), speckled. Low birefringence
**Coarse Organic**
v. few (c. 2%) charcoal fragments, up to several mm
2-5% parenchymatic tissue
Fragments of red, possibly burnt material up to 800 μm, containing mineral grains. Material looks like organo-mineral under OIL (i.e. dark red-brown)
**Fine Organic**
<0.5% phytoliths
<0.5% fungal spores (some of which are fragmented)
<0.5% pollen
c. 1% fine crystalline material
**Groundmass:** porphyric
**Pedofeatures**
<5% mammilated porous and very porous excrement and loose discontinuous excremental infills (porous and very porous)
Fabric is mammilated around the edges and is probably comprised of densely coalesced excrement
?Calcium-iron phosphate or plant-derived material, lining several voids
Thin (<10 μm) yellow and white dusty and limpid coatings on <1% of the mineral grains
5% amorphous organo-mineral (red in PPL and OIL)
Stone rim noted on one sandstone

**Fabric 2**
(Paler and more dense than Fabric 1)
Structure is nearly massive: only a few macro-channels
Porosity
**Coarse Component**
20-25% coarse. Sub-rounded to angular—dominantly angular and sub-angular
c. 90% quartz, 10% other, including compound quartz grains, feldspar,
coarse sand 2-5%
medium sand 5-10%
fine sand 5-10%
very fine sand 5-10%
silt 2-5%
**Fine Fabric:** Munsell: 7.5YR 6/6 reddish yellow, PPL. Red-brown in OIL. Speckled, low birefringence.
**Coarse Organic**
c. 5% parenchymatic tissues
<0.5% charcoal frags up to 250 μm
<0.5% phlobaphene containing tissues
**Fine Organic**
<0.5% fungal spores

<0.5%-1% phytoliths
<2% fine crystalline material
**Groundmass**: open porphyric
**Pedofeatures**
c. 2% amorphous organo-mineral, including organo-mineral nodules, rounded, with well defined edges (transported?)
Very thin (10-15 µm) discontinuous limpid yellow and white coatings on <0.5% of the mineral grains
Fabric is mammilated around the edges
<5% loose discontinuous excrement in channels, comprised of the same fabric

**K3.15 (Ap Horizon)**
Angular blocky structure, accommodated aggregates
Porosity 20-30%
**Coarse Component**
20-30% of slide 90-95% quartz, 5-10% other, including feldspar, micas, sandstone, compound quartz grains.
medium sand 10%
fine sand 5%
very fine sand 5%
silt 5%
**Fine Fabric**: dark red-brown (PPL); mottled bright red and brown (OIL). Speckled limpidity. Low birefringence.
**Coarse Organic**
2-5% charcoal
<0.5% red fibrous material
c. 2% parenchymatic tissue
<0.5% fungal spores
**Fine Organic**
<1% phytoliths
fine crystalline material
<0.5% fungal spores
**Groundmass**: porphyric
**Pedofeatures**
Dense coalescence of excrement to create a total excremental fabric.
Very rare (<0.5%) porous mammilated excrement in channels and chambers
V. rare granulated excrements c. 25 µm
<5% amorphous organo-mineral

**K4.15 (Ap Horizon)**
**Fabric 1**
Complex structure: channel and chamber with some angular blocky aggregates and also some rounded aggregates.
Porosity 40-50%
**Coarse Component**
25% coarse. 90% quartz; 10% other, including feldspar, sandstone (very rare. No stone rims).
Compound quartz grains
Sub- rounded to angular; dominantly sub-angular to angular
coarse sand 5%
medium sand 2%
fine sand 5%
very fine sand 5%
silt 2-5%
**Fine Fabric**: Brown (PPL and OIL), speckled limpidity, low birefringence
**Coarse Organic**
5-10% charcoal, containing mineral grains (which don't turn red under OIL—why not?)
<2% red (PPL and OIL) fibrous material up to 1 mm, containing sand inclusions. One fragment contains a diatom.
<0.5% fungal spores
<1% parenchymatic tissue remains

Probable bone fragment
**Fine Organic**
<0.5% diatoms in the fabric
<0.5% phytoliths
<0.5% fine crystalline material
**Groundmass:** porphyric
**Pedofeatures**
Very rare, very thin clay coatings on <0.5% of the mineral grains
1-2% amorphous organo-mineral
Large areas of the fabric (15-30%) are very porous unconsolidated mammilated excrement. Fabric is total excremental—areas are densely coalesced but dominant fabric is porous.

**K4.15 Fabric 2**
Complex structure: Crack structure with channels
Porosity c. 5%
**Coarse Component**
30% coarse material. 90% quartz, 10% other, including compound quartz grains. Grains are sub-angular to angular
coarse sand 1-2%
medium sand 5-10%
fine sand 10%
very fine sand 5%
silt 2%
**Fine Fabric:** pale brown, speckled, low birefringence
**Coarse Organic**
c. 5% charcoal up to 800 μm, including charred material with 5-10% mineral grains
<2% red fibrous material up to 700 μm
<1% parenchymatic tissues
**Fine Organic**
very rare (<0.5%) fine crystalline material
<0.5% phytoliths
**Groundmass:** porphyric
**Pedofeatures**
1-2% organo-mineral. Edges of the aggregates are mammilated—fabric is excremental (but the excrements around the edges could relate to fabric 1)

**K4.15 Fabric 3**
(Small area of fabric, 2.8 x 6.4 mm)
Very small cracks and one channel
Porosity 2%
**Coarse Component**
90-95% quartz. 5-10% other, including feldspar, sandstone? (without stone rim). Grains are sub-rounded to sub-angular
medium sand 5%
fine sand 5%
very fine sand 2-5%
silt 2-5%
**Fine Fabric:** Yellow-brown (PPL and OIL), speckled, low birefringence
**Coarse Organic**
c. 5% parenchymatic tissue
<2% charcoal up to 100μm. 1 fragment of charcoal 700 μm, with mineral grains
**Fine Organic**
<0.5% fungal spores
<0.5% phytoliths
<0.5% fine crystalline material
**Groundmass:** porphyric
**Pedofeatures:** 1-2% amorphous organo-mineral

**K4.15 Fabric 4**
(area c. 3.2 x 2.4 mm)

Spongy structure
Porosity 20%
**Coarse Component**
40%. 55% quartz, Sub-rounded to angular grains.
medium sand 15%
fine sand 10%
very fine sand 5%
silt c. 2%
**Fine Fabric:** yellow-brown, speckled, low birefringence
**Coarse Organic**
10-15% parenchymatic tissue (some with intact phytoliths)
<1% charcoal frags up to 120μm
**Fine Organic**
<0.5% fungal spores
rare (0.5-2%) phytoliths
rare (0.5-2%) fine crystalline material
**Groundmass:** porphyric
**Pedofeatures**
2-5% amorphous organo-mineral
One quartz grain coated with birefringent orange material (XPL and PPL). The coating is pale orange and sparkly in OIL.
Coatings of fine crystalline material and iron?
Fabric is spongy and porous—edges are mammilated. Also mammilated around and in the voids.
Total excremental fabric? Fabric 4 may itself be a dung fragment which has coalesced

**K4.45 (B(h)x Horizon)**
**Fabric 1**
channel and chamber and crack structure
Porosity 10-20%, c. 10% cracks and 1-% channels and chambers. Channels are c. 40-150 μm wide; chambers are up to c. 4mm
**Coarse Component**
10-15% of the slide. 90-95% quartz, 5-10% other, including garnet
Sub-rounded to angular
Coarse sand c. 2%
Medium sand 2-5%
Fine sand c. 10%
Very fine sand 5-10%
Silt c. 5%
**Fine Fabric:** Munsell 10YR 6/6 brownish yellow (PPL). Reddish brown (OIL). Speckled, low birefringence.
**Coarse Organic**
2-5% charcoal, up to 2-3 mm. Larger fragments contain mineral grains (quartz)
5-10% red material; some is slightly fibrous. Red material contains mineral grains; some fragments contain charcoal and fine crystalline material. Fragments are up to 3-4 mm
Bone fragment? C. 130 μm (1 cm from the edge, marked with an arrow)
**Fine Organic**
c. 1% fungal spores
<0.5% diatoms (more frequent than on the other slides but of the same type)
<0.5% pollen (more than on the other slides).
<0.5-1% phytoliths, mostly fragmented
1-2% fine crystalline material, especially coating grains and lining voids. Forms dense continuous infills in some cracks and channels
**Groundmass:** open porphyric
**Pedofeatures**
Rare thin clay coatings (<10 μm thick)
c. 10% amorphous organo-mineral material, including nodules and diffuse areas
Loose discontinuous mammilated infills of the fabric in channels (<0.5%). Edges of the fabric are mammilated
Red mammilated material forms loose discontinuous infills in several (3-5) channels and chambers

**K4.45 Fabric 2**
Darker colour and more amorphous organo-mineral than Fabric 1
Porosity 10-20%
10% channels and chambers with spongy microstructures, 10% cracks
**Coarse Component**
c. 10%. 95-98% quartz, 2-5% other
Sub-rounded to angular
Coarse sand 2-5%
Medium sand 2-5%
Fine sand 5%
Very fine sand 2-5%
Silt 2-5%
**Fine Fabric**
Munsell 5YR 4/4, reddish brown (PPL). Reddish brown (OIL). Speckled. Low birefringence
**Coarse Organic**
Plant organ residues <0.5%, including phlobaphene-containing and parenchymatic tissues
<0.5% parenchymatic tissues
2-5% charcoal (larger fragments contain frequent to common mineral grains)
5-10% reddened material up to 4-5mm (with rare mineral grains)
**Fine Organic**
<0.5% fungal spores
<0.5% phytoliths
<2% fine crystalline material
**Groundmass:** porphyric
**Pedofeatures**
10-20% amorphous organo-mineral
<0.5% mammilated excrement

**G1a.15 (Ap Horizon)**

**Fabric 1**
Intergrain microaggregate structure
Porosity c. 60% Complex packing voids
**Coarse Component**
30% of the slide. 5% quartz. 95% other, including very dominant unidentified brown and sparkly mineral, compound quartz grains, feldspar. Grains are rounded to angular. Very rare shell sand (concentrated at the base of the slide)
coarse sand 15%
medium sand 5-10%
fine sand 2-5%
very fine sand 2-5%
silt <2%
**Fine Fabric:** red brown (PPL and OIL). Speckled. Medium birefringence.
**Coarse Organic:** 2-3% parenchymatic tissues
**Fine Organic**
5% fine crystalline material (forms coatings on mineral grains and occurs in fabric and voids)
<0.5-1% fungal spores
<0.5% phytoliths
<0.5% pollen
1 possible parasite egg?
**Groundmass:** Gefuric
**Pedofeatures**
Fabric is comprised of very dominant (>70%), very porous and porous excremental fabric and frequent dense excremental aggregates up to 800 μm..
Very rare fine blue crystalline material.

**Fabric 2**
( c. 1% of the slide. Distinctive colour, density and lithology)
Porosity 40%

**Coarse Component**
40-50% of slide. Coarse sand has same lithology as Fabric 1. Silt to medium sand is 90% quartz and 10% other, including feldspar, micas,
Grains are subrounded to angular
coarse sand 15-20%
medium sand 15%
fine sand 5-10%
very fine sand 2-5%
silt 2-5%
**Fine Fabric**: pale yellow-brown (PPL and OIL). Speckled. Medium to high birefringence.
**Coarse Organic**: <2% parenchymatic tissues
**Fine Organic**
<0.5% fungal spores
<0.5% phytoliths
2-5% fine crystalline material
**Groundmass**: close porphyric
**Pedofeatures**
Thin (up to 10 μm) coatings on c. 5% of the mineral grains. Coatings are limpid yellow and second order colours.
<2% amorphous organo-mineral
<0.5% calcium-iron phosphate or plant derived material
<5% mammilated excrement

**P1a.15 (Ap Horizon)**
*Fabric 1*: 5YR 4/4 Reddish-brown
*Fabric 2*: 2.5YR 5/8 Red
*Fabric 3*:10YR 7/4 very pale brown
*Fabric 4*: 7.5YR 5/6 strong brown
*Fabric 5*: 7.5YR 6/6
*Fabric 6*: Channel infill comprised of medium and fine sand with coatings in birefringent fabric

**Fabric 1** (dominant fabric)
Channel and chamber structure
Porosity 30-40%
**Coarse Component**
20%. 95-98% quartz, 2-5% other, including feldspar, compound quartz grains, sandstone, micas.
Sub-rounded to angular.
coarse sand 0
medium sand 5-10%
fine sand 5-10%
very fine sand c. 10%
silt c. 5%
**Fine Fabric**: Munsell 5YR 4/4 reddish-brown (PPL). Red-brown (OIL). Speckled; low birefringence.
**Coarse Organic**
<2% charcoal
<2% parenchymatic tissues and ?mineral replaced tissues?
<2% fragments of red material (PPL), burnt soil or organo-mineral? One fragment is distinctly fibrous
**Fine Organic**
c. 10% fine crystalline material
<0.5% phytoliths
<0.5% fungal spores
**Groundmass**: porphyric
**Pedofeatures**
c. 2% amorphous organo-mineral, diffuse and nodules
<0.5% calcium iron phosphate or plant derived material

Large areas of the fabric (15-30%) are comprised of porous and very porous excrement. The remainder is dense and very densely coalesced excrement, with mammilated edges and small vughs surviving to show the original shapes.
Fine crystalline material frequently (15-30%) lines the voids
Stone rim c. 200 µm wide on an unidentified stone

**P1.15 Fabric 2**
Crack structure
Porosity c. 10%: cracks, channels and vughs
**Coarse Component**
20-30%. 95% quartz, 5% other, including compound quartz grains, feldspar, mica, sub-rounded to angular
coarse sand 0
medium sand 5-10%
fine sand 5%
very fine sand 5-10%
silt 2-5%
**Fine Fabric:** Munsell 2.5YR 5/8 red (PPL). Dark red-brown (OIL). Speckled. Moderate birefringence
**Coarse Organic**
1 large charcoal fragment 1.2mm
<0.5% parenchymatic tissue
**Fine Organic**
<0.5% fine crystalline material
<0.5% fungal spores
<0.5% phytoliths
<0.5% pollen
**Groundmass:** porphyric
**Pedofeatures**
Under OIL the whole fabric looks like organo-mineral material.
Thin (10-15 µm) discontinuous yellow and white coatings on <0.5% of the mineral grains
Fabric is very mammilated, but looks more mineral than organic. 5-15% porous mammilated excrement.

**P1.15 Fabric 3**
Fabric 3 forms dense discontinuous infills in channels and chambers of Fabrics 1 and 4. The fabric occurs in small aggregates, c. 500µm –2mm
Porosity <2%
**Coarse Component**
5-10% total. 98% quartz, 2% other. Sub-rounded to angular
Medium sand 2-5%
Fine sand 2-5%
Very fine sand c. 2%
Silt 2-5%
**Fine Fabric**
10YR 7/4 very pale brown (PPL). Very pale yellow-brown (OIL). Speckled. Very low birefringence.
**Coarse Organic**
<0.5% phlobaphene-containing tissues?
**Fine Organic**
<0.5% fungal spores
<0.5% pollen
<0.5% diatoms
<0.5% phytoliths
**Groundmass:** open porphyric
**Pedofeatures**
<0.5% amorphous organo-mineral
2-5% calcium iron phosphate or plant derived material?
Fabric is mammilated around the edges.
<5% mammilated excrement in channels and chambers

**P1.15 Fabric 4**
Fragments of this occur within Fabric 1 and in the lower right hand corner of the slide.
Channel and chamber structure with cracks
Porosity 20-50%
**Coarse Component**
30%. 95% quartz, 5% other, including compound quartz grains, feldspar,
Sub-rounded to angular
Medium sand 5-10%
Fine sand c. 10%
Very fine sand c. 10%
Silt 5-10%
**Fine Fabric**
Munsell 7/5YR 5.6 strong brown (PPL). Reddish brown (OIL). Low birefringence. Speckled
**Coarse Organic**
2-5% charcoal
Unidentified material that I think is organic but may also be mineral. Isotropic.
**Fine Organic**
5% fine crystalline material, concentrated mostly in and around voids.
<0.5% fungal spores
<0.5% diatoms
<0.5% phytoliths
**Groundmass:**
**Pedofeatures**
c. 2% amorphous organo-mineral, including both nodules and areas with diffuse edges
Yellow coatings up to c. 6μm thick on <0.5% of the mineral grains
The fabric forms areas of dense excremental infill in voids. The edges are mammilated. Fabric is mostly very dense, probably coalesced excrement; 10-15% porous excremental fabric.

**P1.15 Fabric 5**
Probably the same as Fabric 4. Forms a dense continuous infill in a channel 2.5mm wide

**P1.15 Fabric 6**
Infill of a channel, also 2.5 mm wide. Comprised of mineral grains (90% quartz and compound quartz grains) in a birefringent clay and iron-rich groundmass. Chitonic/enaulic.

**P2.15 (Ap Horizon)**

**Fabric 1**
Complex structure: angular blocky, with chambers
Porosity 10%
**Coarse Component**
30-35%. 90-95% quartz, 5-10% other, including feldspar, sandstone (with stone rims), compound quartz grains. Sub-rounded to sub-angular
coarse sand 5%
medium sand 5%
fine sand 10%
very fine sand 5-10%
silt 5%
**Fine Fabric**
Munsell 7.5YR 6/6 reddish-yellow to 5YR 5/6 yellowish-red (PPL)
Pale brown (OIL)
Low birefringence. Speckled
**Coarse Organic**
1-2% charcoal
<1% organ residue
<1% parenchymatic tissues
<0.5% fragments of dark red fairly opaque material containing mineral grains. Several paler red fragments, fibrous looking, also with mineral grains
**Fine Organic**
<0.5% fungal spores

<1% phytoliths
**Groundmass**: porphyric
**Pedofeatures**
Bright red and sparkly (OIL) coating on rare grains; coating is brown in PPL (Iron ?)
Very rare (<0.5%) mammilated excrement
Red (PPL) textural feature in and around root (mineral replacement); textural iron features <0.5%?
1-2% amorphous organic
Dense bow-shaped channel infill

**P2.15 Fabric 2**
Dense structure with only 2 voids, both infilled
**Coarse Component**
c. 20%. 95% quartz, 5% feldspar, compound quartz gains, mica. Sub-rounded to angular
coarse sand 2%
medium sand 2%
fine sand 5%
very fine sand 5-10%
silt 5%
**Fine Fabric**
Munsell 7.5YR 6/3 light brown (PPL)
Pale brownish grey (OIL)
Speckled. Medium to high birefringence
**Coarse Organic**
<2% parenchymatic tissues
2% charcoal
**Fine Organic**
<1% phytoliths
<0.5% fine crystalline material
**Groundmass**: porphyric
**Pedofeatures**
2% amorphous organic
Clay coatings on c. 5% of the grains. Coatings are 2-10μm thick.
Fine crystalline material infill in one of the 3 voids (channel)
Organic coating on quartz grain? Red-brown coating in PPL, up to 35 μm thick, but mostly c. 6 μm; coating goes bright red under OIL. Under XPL coating is dark red-brown and partly coated with ?yellow clay 2-3 μm thick
<2% very porous mammilated excrement in voids; excrement is comprised of a different fabric.

**P2.15 Fabric 3**
**Coarse component**
20-30% of the slide. 95% quartz, 5% other. Rounded to angular.
coarse sand 0
medium sand 5-10%
fine sand 5-10%
very fine sand c. 5%
silt c. 5%
**Fine Fabric**
Munsell 2.5YR 4/8 red (PPL)
Red-brown (OIL)
Speckled, medium birefringence
**Coarse Organic**
<2% charcoal
**Fine Organic**
c. 2% phytoliths
<2% fine crystalline material
<0.5% fungal spores
**Groundmass**: porphyric
**Pedofeatures**
c. 2% amorphous organo-mineral
area of burning and fine crystalline material along soil void: reddened in OIL and darkened in PPL

## A2.2 TOFTS NESS SLIDE DESCRIPTIONS

**Sample 100**
**Context 5012** (shelly, upper horizon)
40-50% mineral, 20-30% porosity, c. 30-40% fine fabric
**Microstructure:** spongy, with channels
**Porosity:** c. 15% vughs, 5-15% channels, 2-5% vesicles
**Mineral:**

| | |
|---|---|
| Silt | 15-20% |
| V. fine sand | 5-15% |
| Fine sand | 5-15% |
| Med. sand | 15-25% |
| Coarse sand | 5-10% |

Quartz: 20-25%, dominantly subrounded and subangular.
Shell: 20-30%
Bone: v. rare
Other: feldspars, other, <2%
**Coarse organic:** 5-10% charred material, including 0.5-2% wood charcoal but dominantly peat (charred material with voids and mineral grains). One v. large frag of burnt soil (charred black, with mineral grains and shell sand)
Fine organic: v. rare phytoliths, possible rare pollen, v. rare fungal spores, v. rare diatoms, poorly preserved.
**Groundmass:** close porphyric
**Fine Fabric:** (PPL) 5YR 4/4 and 7.5YR 4/6 strong brown—as 5013 but also areas slightly redder. (OIL) 7.5YR 6/6-7/6 (reddish yellow). Not as strongly coloured as the lower horizon 5013. Speckled. Low birefringence.
Pedofeatures: textural: v. rare birefringent yellow, orange and white discontinuous coatings < 10μ on mineral grains and shell. Depletion: shell sand is decaying around the edges. Crystalline: none. Amorphous and cryptocrystalline: 0.5-2% (c. 2%) amorphous organo-mineral. Rare (c. 2%) orange (OIL) or red (PPL) segregations and hypocoatings. Fabric appears to be wholly excremental: dense with c. 15% porous excrement.

**Sample 100**
**Context 5013**
30-40% mineral, 30-40% porosity, 40-50% fine fabric
**Microstructure:** spongy
**Porosity:** 30-40%, including 2-5% channels, 0.5-2% vesicles, c. 30% vughs
**Mineral:**

| | |
|---|---|
| Silt | 10-15% |
| V. fine sand | 5-15% |
| Fine sand | 10-15% |
| Med. Sand | 5-15% |
| Coarse sand | 5-10% |

Quartz and compound quartz: c. 35% of slide, dominantly sub-rounded.
Shell: 2-5%
Bone: <0.5%
Other mineral (including feldspars) 0.5-2%
**Fine fabric:** PPL: 7.5YR 4/6-5/6 (strong brown). OIL: 7.5YR 6/6-7/6 (reddish yellow). Speckled. Low birefringence.
**Coarse organic:** Rare charcoal, small frags up to 1mm, including material with voids and mineral grains (peat) and material with cellular structure (wood), but dominantly void/mineral material—often still red around the voids, i.e. incompletely burnt.
**Fine organic:** v. rare phytoliths, bordering on rare—many are still spiky. V. rare fungal spores, VERY rare diatoms (just saw one).
**Groundmass:** Porphyric
**Pedofeatures:** Textural: v. rare discontinuous yellow, white and orange clay coatings <10 μm thick on mineral grains. Depletion: shell is decaying slightly. Crystalline: none. Diffuse brown (OIL) amorphous organo-mineral material and organic staining, 2-5%. Rare glassy yellow material and

glassy orange iron lining rare voids (c. 2% segregations and hypocoatings). Possible plant or peat fragment pseudomorphs. c. 15-30% of the slide is comprised of what appears to be dense and very dense excremental fabric. The fine fabric may be entirely excremental but this is not clear. There are fragments of another soil or peat: red brown, with glassy yellow material in the voids, containing c. 20-30% quartz grains, with high birefringence in XPL. Red b-fabric.

**Sample 101**
**Context 5011** (shelly, upper horizon)
Mineral 40-50%, porosity c. 20%, fine fabric 30-40%
**Microstructure**: Spongy, with channels and chambers
**Porosity**: 20%, including 2-5% channels, 2-5% chambers and 5-15% vughs
Mineral

| | |
|---|---|
| Silt | 5-10% |
| V. fine sand | 5-10% |
| Fine sand | 5-10% |
| Med. Sand | 15-25% |
| Coarse sand | 5-15% |

Quartz and compound quartz 15-20%, rounded to angular
Shell 30-40%, fairly well preserved with slightly decaying edges.
Bone: v. rare, in fairly good state of preservation
Other mineral, including feldspars: 2-5%
**Fine Fabric**: PPL: 7.5YR 4/4 and ¾ (brown and dark brown), OIL: 2.5YR 5/4 (reddish brown). Speckled. Low birefringence.
**Coarse organic**: 2-5% charcoal up to 800 μm; this includes wood and peat charcoal. V. dominantly <400 μm. Most of the charcoal is too small to identify as either wood or charcoal, but the larger fragments are mostly (>50%) peat.
**Fine organic**: v. rare fungal spores.
**Groundmass**: close porphyric
**Pedofeatures**: shell fragments are decaying on the edges. Orange staining around shell edges—iron accumulation? C. 2% (2-5%) bright orange nodules (OIL), usually in clusters, 20-60 μm diameter. These occur within the fine fabric. Rare red-brown (OIL) amorphous organo-mineral material, evident as irregular, diffuse areas and diffuse irregular nodules. Areas of diffuse orange fabric (OIL), orange and glassy in PPL. Fabric isn't obviously excremental.

**Sample 101**
**Context 5012**
Porosity 15-20%, Mineral 40-50%, Fine fabric 40-50%
**Microstructure:** spongy, with channels and chambers
**Porosity** 15-20%. 2-5% channels, 10-15% vughs, 2-5% chambers.
**Mineral**

| | |
|---|---|
| Silt | 5-10% |
| V. fine sand | 5-10% |
| Fine sand | 5-10% |
| Med. Sand | 15-20% |
| Coarse sand | 5-10% |

Quartz 30-40%, rounded to angular, dominantly sub-angular
Lithic clasts 2-5%
Other: v. rare feldspars
Shell 10-15%
Bone: v. rare frags <c. 200 μm
**Fine Fabric**: PPL: 7.5YR 4/6 and 5/6 (strong brown), OIL: 5YR 6/4 (light reddish brown) to 5/4 (reddish brown). Speckled. Low birefringence.
**Coarse organic**: 2-5% charcoal, including frags with mineral grains and rare frags with cellular structure. V. rare parenchymatic tissues.
**Fine organic**: nothing obvious. See Pedofeatures.
**Groundmass**: porphyric
**Pedofeatures**: Rare orange nodules (OIL) 20-40μm in dia., bright orange in reflected light and orange or black in PPL. Occurring mostly in clusters, lining one void but mostly occurring within the fine fabric. 2-5% amorphous organo-mineral material, forming diffuse areas of red grading into

brown, often with red edges or diffuse orange areas staining the fine fabric. In PPL the amorphous organo-mineral forms orange segregations, dark orange-brown in OIL. Some of the amorphous organo-mineral forms black or brown nodules (PPL and OIL), usually surrounded by brown (OIL) diffuse material. Rare possible pseudomorphic material, similar to the red fibrous material of the kaleyard or peat reference sample but more broken down. In PPL the orange grades into glassy yellow material in some of the pseudomorphs and areas of nodules. Depletion: shell is decaying around the edges. V. rare discontinuous birefringent yellow, white and orange coatings on <2% of the mineral grains.

**Sample 102**
**Context 5010** (sandy horizon over 5011)
50-60% mineral, 40-50% porosity (c. 40%), 5-15% fine fabric
**Microstructure:** bridged
**Porosity:** c. 40%, including 30-40% simple and complex packing voids and rare channels
**Mineral:**

| | |
|---|---|
| Silt | 0.5-2% |
| V. fine sand | 0.5-2% |
| Fine sand | 2-5% |
| Med. Sand | c. 40% |
| Coarse sand | 5-10% |

10-15% quartz, dominantly sub-round and sub-angular
Shell: 40-50%
<2% other, including lithic clasts, feldspars and other
**Fine Fabric:** 5-15%, increasing towards the top of the slide. Immediately above 5011 is a layer of nearly pure sand. PPL: 2.5YR 4/6 – 5YR 4/4 (red to reddish brown). OIL: 7.5YR 4/4 (brown). Speckled. Low to moderate birefringence.
**Coarse organic:** charred material 0.5-2% at the base of the deposit and 2-5% at the top of the slide (upper 2 cm). Charred material is dominantly composed of non-cellular reflective black material with voids and cracks, with a small proportion (<0.5% of the slide) made up of charred material with a cellular structure.
Fine organic: v. rare fungal spores. V. rare phytoliths (well preserved).
Groundmass: gefuric (bridged)
Pedofeatures: depletion: shell grains are decayed on the edges and often have bright, birefringent rims. Amorphous and cryptocrystalline: 0.5-2% bright orange (OIL) roughly circular nodules, c. 20-60 μm in diameter, sometimes with a reflective, dark, metallic core. Usually occur in clusters, overlapping. 0.5-2% dark brown (OIL) diffuse areas of organic or organo-mineral material. An area in the top left side of the slide is bright orange under OIL; the colour permeates both the shell and the fine fabric. This material is glassy red and yellow under PPL and shows up under XPL as orange coatings on the shell. The fabric is not obviously excremental.

**Sample 102**
**Context 5011**
10-20% porosity, 40-50% mineral, c. 60% fine fabric
**Microstructure:** spongy, with channels
**Porosity:** 5-10% channels, 5-15% vughs. One channel oriented vertically and filled with shell sand.
**Mineral:**

| | |
|---|---|
| Silt | c. 10% |
| V. fine sand | 5-10% |
| Fine sand | 5-10% |
| Med. sand | 20-30% |
| Coarse sand | 10-15% |

Quartz c. 15%, rounded to angular, dominantly sub-rounded.
Shell 20-30%
Bone: v. rare (well preserved frag. 360 μm)
Other (inc. feldspars) <2%
**Fine fabric:** PPL: 5YR 4/4 – 4/6 (reddish brown to yellowish red). OIL: 5YR 5.4 – 4/4 (reddish brown). Speckled. Low to moderate birefringence.
**Coarse organic:** 0.5-2% (c. 2%) charred material up to 600 μm (both peat and wood charcoal).
**Fine organic:** v. rare fungal spores, v. rare phytoliths.

**Groundmass**: close porphyric

**Pedofeatures**: Very rare clay coatings <10 µm on <0.5% of the mineral grains. Rare amorphous organo-mineral, possible plant pseudomorphs. Also rare diffuse staining of fine fabric. Rare bright orange (OIL) nodules, 40-60 µm in diameter, usually in clusters, often merging. Black or reddish under PPL. Area of red cells, probably plant pseudomorph, c. 9.2 mm. Rare iron segregations, possibly organo-mineral. Rare bright yellow (OIL) hypocoatings of voids. B fabric is dotted with bright yellow dots under XPL. Fabric may be wholly dense excremental but is not obviously, unequivocally so. A second microfabric occurs in darker, red brown rounded aggregates.

**Slide 103**

**Context 5006** (EIA midden, Area J)

5-15% porosity, 40-50% mineral, 40-50% fine fabric

**Microstructure**: spongy, with channels

**Porosity**: 5-15%, including 5-10% vughs and c. 5% channels, 200-300 µm wide (larger channels are where shells were scraped out in processing).

**Mineral**:

| | |
|---|---|
| Silt | 15-20% |
| V. fine sand | 5-10% |
| Fine sand | 10-15% |
| Med. sand | 10-15% |
| Coarse sand | 2-5% |

Quartz: 30-40%

Shell: 15-20%

No bone. <2% other, incl. Feldspars

**Fine fabric**: PPL: 7.5YR 5/4 – 4/4 (brown). OIL: 10YR 6/6 – 7/6 (brownish yellow to yellow). Also 2-5% yellow (10YR 8/6 – 8/8) and bright orange. Speckled. Moderate birefringence.

**Coarse organic**: 15-25% charred material, including rare woody frags. V. dominantly peat ash. Two charred cereal grains. Occ. Single cells (v. rare) 75-80 µm across, orange walls, yellow contents.

**Fine organic**: v. rare diatoms (inc. cowrie shaped in addition to the usual oval shaped), v. rare phytoliths, V. rare spherulites, bordering on rare (some areas of the slide have c. 2%). V. rare Ca oxalates.

**Groundmass**: close porphyric.

**Pedofeatures**: V rare v. thin clay coatings on <2% of the mineral grains; discontinuous (although one grain has nearly continuous), <10 µm, yellow, white and orange. Depletion: shell is degrading at the edges and often has a bright birefringent rim. Some frags are degrading in the centre as well. V. rare crystalline void lining, c. 25 µm thick, white in XPL. B. fabric is v. reflective, with areas of pure birefringent fabric, sparkly yellow/orange/white material with frequent spherulites. This material does not stand out in OIL. Areas of amorphous organic and amorphous organo-mineral material, diffuse, red or red-brown under OIL, max. 2-5% of slide. Excremental: rare mammilated fabric around void edges.

**Slide 103**

**Context 5007**

5-15% porosity, c. 40% mineral, c. 50% fine fabric

**Microstructure**: channel

Mineral

| | |
|---|---|
| Silt | 15-25% |
| V. fine sand | 10-15% |
| Fine sand | 5-10% |
| Med. Sand | 5-10% |
| Coarse sand | 0.5-2% |

Quartz 30-35%, mostly sub-rounded to sub-angular

Shell 2-5%, degrading.

Other, including feldspars: <2%

Bone: one frag. 280 µm, fair condition. Another possible fragment at interface with 5006. One frag. 1.2mm. total bone <0.5%.

**Fine fabric**: PPL: 5YR 3/3 – 4/3 (dark reddish brown to reddish brown). OIL: 10YR 7/6 yellow (dominant); rare brighter yellow and orange (10YR 8/8). Speckled. Moderate birefringence.

**Coarse organic:** 5-15% charred material, including 0.5-2% woody charcoal. Most is peaty, with mineral grains and voids. Very rare parenchymatic tissues, in channels.
**Fine organic:** v. rare Ca oxalates, v. rare spherulites (although there are areas with up to c. 2%), v. rare phytoliths, v. rare diatoms.
**Groundmass:** close porphyric
**Pedofeatures:** depletion: shell is decomposing; many frags have a birefringent area around the rim. 2-5% organic or organo-mineral staining. <0.5% porous excrement, in channels.

**Slide 104**
**Context 5004**
15-20% porosity, 30-40% mineral, 50-60% fine fabric
**Microstructure:** vughy
**Porosity:** 10-15% vughs, 2-5% channels
**Mineral:**

| | |
|---|---|
| Silt | 15-25% |
| V. fine sand | 10-15% |
| Fine sand | 5-10% |
| Med. Sand | 5-10% |
| Coarse sand | 0.5-2% |

Quartz: 25-35%, rounded to angular, dominantly sub-rounded and sub-angular
Shell: 2-5%
Other, inc. feldspars: <2%
Bone: v. rare possible bone, very poorly preserved small fragments <c. 500 µm
**Fine fabric:** PPL: 7.5YR 4/4 (brown). OIL: 10YR 7/6 (yellow), 10YR 6/4 light yellowish brown; 2-5% bright orange. Speckled, high birefringence.
**Coarse organic:** 15-30% charred material, including c. 2% (c. 0.5-2%) woody material. Very rare possible charred seeds, cereal and other?
**Fine organic:** v. rare fungal spores, v. rare phytoliths, v. rare (bordering on rare) spherulites, v. rare Ca oxalates. Bright birefringent material with spherulites coats a large organic, possibly slightly charred fragment (which looks more like peat than wood) The birefringent material (probably wood ash) is v. rare in the context, but forms a band with 15-30% shell sand at the base of the context. There is also a band of shell sand above the shelly ash band. Also a cluster of spherulites forming a mass 3.4mm long.
**Groundmass:** close porphyric
**Pedofeatures:** Thin orange coating <c. 10 µm on one grain; white discontinuous coating 10-15 µm on another-- <0.5% of the grains have coatings—they are extremely rare. Shell is in differing states of decay. There are some well preserved grains, some degraded. The don't seem to have the birefringent rims seen in other contexts. The amorphous organo-mineral component isn't obvious; there is diffuse organic staining grading into solid fragments of charred organic material and also areas of possible organo-mineral (reddish brown) around the charred material. One passage feature 2mm wide, with a dense complete infill of darker brown fabric. Very rare porous mammilated excrement in channels.

**Slide 104**
**Context 5005**

**Porosity** 10-15%, mineral 40-50%, fine fabric c. 50%
**Microstructure:** vughy, with channels
Porosity: 5-10% channels with differing orientations, from horizontal to vertical. 5-10% vughs.
**Mineral:**

| | |
|---|---|
| Silt | 15-20% |
| V. fine sand | 5-10% |
| Fine sand | 5-10% |
| Med. Sand | 5-10% |
| Coarse sand | 2-5% |

Quartz: 30-40%, mostly sub-rounded and sub-angular
Shell: 5-15%. One limpet shell.
Other, inc. feldspars and hornblende: <2%

Bone: v. rare frags <2mm
**Fine fabric**: PPL: 10YR 4/4 (dark yellowish brown). OIL: 10YR 7/6 (yellow). 0.5-2% is bright orange in OIL. Speckled. Moderate to high birefringence.
**Coarse organic**: 15-25% charred material, predominantly with voids and mineral grains but 0.5-2% with a cellular structure. V. rare possible seeds (like fungal spores but larger. No obvious cereal grains). Some of the charred peat contains woody fragments. V. rare frags of unburnt or partially burnt peat (red, fibrous material), c. 600 μm. Rare parenchymatic tissues.
**Fine organic**: v. rare phytoliths, v. rare diatoms, v. rare possible pollen, v. rare Ca oxalates and v. rare spherulites. Lens of bright birefringent material with spherulites—may be wholly comprised of spherulites (ash lens? These lenses make up <0.5% of the slide). The ashy lenses also contain a higher proportion of shell sand and are identical to the thin layer that separates 5004 and 5005.
**Groundmass**: close porphyric
**Pedofeatures**: Shell fragments are breaking down; many have birefringent edges and some are stained with iron. Bone is in fairly good condition. Crystalline: 0.5% ash lenses. 0.5-2% amorphous organic and organo-mineral staining. Discontinuous porous excrement in one channel, which crosses into 5004 above. Other channels contain rootlets but only very rare porous excrement.

**Sample 105**
**Context 5001**

10-15% porosity, c. 40% mineral, c. 50% fine fabric
**Microstructure**: vughy
**Porosity**: 5-10% vughs and 2-5% chambers
**Mineral**:

| | |
|---|---|
| Silt | 10-15% |
| V. fine sand | 10-15% |
| Fine sand | 5-10% |
| Med. Sand | 5-15% |
| Coarse sand | 2-5% |

Quartz: c. 30%, rounded to angular, dominantly sub-rounded and sub-angular.
Shell: 10-15%
Bone: c. 2% (Rare)
Other: <2%, inc. feldspars
**Fine fabric**: OIL: 7.5YR 7/6, 6/4 (reddish yellow, light brown); rare areas of bright orange. PPL: 7.5YR 4/4 – 3/4 (brown to dark brown). Speckled. Moderate birefringence.
**Coarse organic**: 10-15% charred material inc. rare woody frags. V. rare seeds, inc. cereal. V. rare parenchymatic tissues, esp. in channels. Fibrous red material grades into the charred material; none looks wholly unburnt.
**Fine organic**: v. rare diatoms. Small cluster of brown cells c. 30 μm across—pos. fungal spores? V. rare spherulites.
**Groundmass**: close porphyric
**Pedofeatures**: v., v. rare coatings on grains, <10 μm. Shells are degraded, some with bright birefringent edges. Bone is in fairly good condition, one frag with iron accumulation. Rare amorphous organic/organo-mineral staining, diffuse, with small nodules c. 25 μm across. V. rare porous excrement in channels.

**Sample 105**
**Context 5003**

Porosity 5-10%, mineral 30-40%, fine fabric c. 60%
**Microstructure**: channel
**Porosity**: c. 5% channels, including a passage feature 1.6mm wide. 2-5% vughs, one chamber (<0.5%). V. rare cracks.
**Mineral**

| | |
|---|---|
| Silt | 15-20% |
| V. fine sand | 10-15% |
| Fine sand | 10-15% |
| Med. Sand | 5-10% |

Coarse sand 0.5-2%
Quartz 30-35%
Shell 5-10% sand size; slide also includes limpet shell frags. Shell is v. degraded.
Bone: v. rare
Other: <2%
**Fine fabric:** PPL: : 7.5YR 4/4 – 3/4 (brown to dark brown). OIL: 10YR 7/6 – 8/8 (yellow); 10YR 7/4 (v. pale brown), 0.5-2% bright orange. Speckled. Low to moderate birefringence.
**Coarse organic:** 10-15% charred material including 0.5-2% woody fragments, mostly thin and twiggy.
**Fine organic:** v. rare diatoms. A few possible phytoliths. V. rare spherulites. V. rare Ca oxalates.
**Groundmass:** close porphyric
**Pedofeatures:** Shell sand is badly degraded. There are some small areas of material that may be remnants of degraded shell. Iron has accreted around some rims, and many have bright birefringent rims. Areas of bright birefringent white, possibly crystalline material, either v. decayed shell or ash—doesn't bear any relation to voids. V. rare coatings on <0.5% of the mineral grains, <10μm, only v. discontinuous. 5-10% dark red-brown (OIL) irregularly-shaped nodules 10-20μm in dia. Passage feature filled by porous loose discontinuous mammilate aggregates (exc. Aggregates make up <0.5% of the slide. Note: 5001 and 5003 look identical in thin section, but were distinguishable in the field.

**Sample 106**
**Context 5003/9**

These two midden deposits were identical in thin section.
50-60% fine fabric, c. 30-40% mineral, 15-20% porosity
**Microstructure:** spongy, with cracks and channels
**Porosity:** rare cracks, 5-10% channels, 5-10% vughs.
**Mineral:**

| | |
|---|---|
| Silt | 15-20% |
| V. fine sand | 5-10% |
| Fine sand | 5-10% |
| Med. sand | 5-10% |
| Coarse sand | 2-5% |

(v. fine, fine and med. sand are all closer to 5%). Dominant material is quartz, with lenses of shell sand which make up 2-5%. Bone: 5-10%, including burnt fragments. Unburnt frags are very decayed. Other: 2-5% lithic clasts and other, inc. feldspars.
**Fine fabric:** PPL: 5YR 4/4 (reddish brown). OIL: 7.5YR 6/4 (light brown) to 7.5YR 7/6 (reddish yellow). Moderate birefringence. Speckled.
**Coarse organic:** 15-20% charred material, inc. c. 2% woody charcoal. Some of the peat ash charcoal is not wholly burnt but there are no wholly unburnt peat frags. Rare parenchymatic tissues.
**Fine organic:** v. rare spherulites, with concentrations (c. 2% or more) in ashy lenses cupped in a large limpet shell. The ashy material has a bright white birefringence. V. rare phytoliths, v. rare diatoms (well preserved).
**Groundmass:** porphyric
**Pedofeatures:** one sandstone clast has a discontinuous red (XPL and PPL) coating on the underside, c. 80μm thick. Shell frags are decaying around the edges. Bone is v. decayed. Rare diffuse red-brown organo-mineral material (OIL), reddish in PPL. Rare black material in PPL which goes v. bright, reflective red in OIL (v. rare). No obvious biological activity; fabric is v. dense and the channels are crack-like and do not contain excrement.

**Sample 106**
**Context 5010**

40-50% mineral, 15-20% fine fabric, 20-30% porosity
**Microstructure:** somewhere between bridged and spongy. Too much fine fabric to be bridged but still too mineral-dominated to be spongy.
**Porosity:** 20-30%, including vughs and complex packing voids.
**Mineral:**
Silt 2-5%

| | |
|---|---|
| v. fine sand | 2-5% |
| Fine sand | 2-5% |
| Med. Sand | 30-40% |
| Coarse sand | 2-5% |

15-20% quartz. 30-40% shell. Bone: v. rare possible bone fragments; very degraded. Other: 2-5% lithic clasts and <2% other.
**Fine fabric:** PPL: 5YR 4/6 (yellowish red). OIL: 7.5YR 6/6 (reddish yellow). Speckled. Moderate birefringence.
**Coarse organic:** 2-5% charred material (c. 5%) dominantly peat ash but including small amounts of wood charcoal.
**Fine organic:** v. rare diatoms, v. rare spherulites and Ca oxalates. V. rare single cells, crumpled, brown, distinct cell wall, c. 20μm dia. No obvious phytoliths. V. rare single cells with orange walls, yellow contents, 60-80 μm.
**Groundmass:** dominantly gefuric (bridged); areas of porphyric.
**Pedofeatures:** iron-stained rims on rare shell frags. Shell is degrading around the edges. Possible very degraded bone. Rare nodules, bright orange in OIL, black in PPL, c. 40-50μm. V. rare organic staining of fine fabric. Fabric isn't obviously excremental but may be dense excremental—some mammilated edges.

**Sample 109**
**Context 5015**

Sand overlying BA soil in Area A. 50-60% mineral, c. 2% fine fabric, 40-50% porosity
**Microstructure:** single grain. Small areas of bridged grain structure.
**Porosity:** 40-50% simple packing voids (one infilled channel 2.4 mm across)
**Mineral:**

| | |
|---|---|
| Silt | <0.5% |
| V. fine sand | <0.5% |
| Fine sand | 0.5-2% |
| Med. Sand | 20-30% |
| Coarse sand | 20-30% |

5-10% quartz, c. 50% shell. Pos. limpet shell 1.8 cm. Quartz is dominantly sub-angular and sub-rounded.
**Fine fabric:** confined to small areas of bridging and the fill of a channel. Channel infill is 5YR 4/6 (yellowish red) in PPL, OIL 5YR 6/8 (reddish yellow), with v. rare charcoal frags up to 120 μm. Bridging fabric is v. pale: 7.5YR 6.4 in OIL (light brown) and 5YR 6/6 (reddish yellow) in PPL; moderate birefringence due to white crystalline material in the fabric.
**Coarse organic:** v. rare charcoal frags <100 μm, v. rare parenchymatic tissue?
**Fine organic:** v. rare single cells with brown walls and contents, c. 20 μm in dia.
**Groundmass:** dominantly monic; gefuric in places
**Pedofeatures:** fine fabric coatings (discontinuous) on the mineral/shell grains in areas of the slide. Shell is generally in good condition with only slight decay on some of the grains. Fine fabric contains calcium carbonate. V. rare excrement, porous, in one concentrated area. No sign of iron accumulations.

**Sample 109**
**Context 5016**

40-50% mineral, c. 10% porosity, 40-50% fine fabric
**Microstructure:** slightly spongy, few voids
**Porosity:** rare channels near the top of the horizon. 5-10% vughs
**Mineral:**

| | |
|---|---|
| Silt | 5-10% |
| V. fine sand | 2-5% |
| Fine sand | 5-10% |
| Med. Sand | c. 20-30% |
| Coarse sand | 2-5% |

Quartz 20-30%, mostly sub-rounded and sub-angular. Shell, c. 20%. Bone: v. rare, with some burnt frags. Other: 2-5%, including lithic clasts, feldspars

**Fine fabric:** PPL: 5YR 3/4 (dark reddish brown) to 2.5YR 4/6 (red). OIL: 2.5YR 5/6 (red). Low birefringence. Speckled.
**Coarse organic:** rare charred material (both peat and wood). V. rare parenchymatic tissue.
**Fine organic:** none
**Groundmass:** close porphyric
**Pedofeatures:** iron rims on >50% of the shell frags. 5-10% of the shells are v. degraded. Rims survive although the shell is nearly completely decayed in some cases. Very, very rare discontinuous yellow, white or orange coatings on <0.1% of the mineral grains. V. rare bright orange nodules c. 10-40μm in dia (OIL). These can mass together. They are also present in hypocoatings and segregations formed by darker red-brown material (OIL), which makes up 0.5-2% of the fabric. Fabric is v. dense; only one small area of mammilated fabric on the edge of the slide where the fabric is thinner. No obvious biological activity but maybe the slide is too thick? Although the quartz grains are grey and white or just slightly yellow.

**Sample 110**
**Context 5028**
15-25% porosity, 15-25% mineral, 50-60% fine fabric
**Microstructure:** crack, with channels and vughs.
**Porosity:** 5-15% vughs, 2-5% channels, 2-5% cracks, <2% vesicles.
**Mineral:**

| | |
|---|---|
| Silt | 5-10% |
| V. fine sand | 5-10% |
| Fine sand | 2-5% |
| Med. sand | 2-5% |
| Coarse sand | 0.5-2% |

Quartz makes up >90% of the mineral fraction: rounded to angular, dominantly rounded and sub-angular. <5% hornblende, feldspars and other. No shell. Bone 5-10%, mostly v. poorly preserved.
**Fine fabric:** PPL: 7.5YR 5/4 (brown), 3/4 (dark brown). OIL: 7.5YR 7.6 (reddish yellow), 5YR 7/6 (reddish yellow, 10YR 8/8 (yellow), bright orange. Speckled. Low birefringence with areas of moderate birefringence, especially in the burnt material (i.e. the material which is bright orange and yellow under OIL).
**Coarse organic:** 2-5% charred material. 0.5-2% fibrous red material, often partially blackened. Some fragments contain mineral material. V. rare parenchymatic tissue.
**Fine organic:** 0.5-2% phytoliths, often still connected. Some are very well preserved and still spiky. V. rare pollen, bordering on rare (0.5%). V. rare diatoms, bordering on rare. V. rare single cells c. 200 μm, with yellow walls.
**Groundmass:** open porphyric
**Pedofeatures:** v. rare thin (<10μm) yellow, white and orange coatings; v. rarely these line the voids. V. rare hypo-coatings of voids up to 200μm thick. Coatings are red and/or brown in PPL. V. rare red-brown quasi-coatings. Areas of bleached stone rim on one large sandstone fragment. Glassy yellow and red material (PPL) lines voids and forms segregations. This material makes up 2-5% of the slide and is brown under OIL; interpreted as amorphous organo-mineral material. V. rare mammilated aggregates in channels.

**Sample 110**
**Context 5030**
5-10% porosity, 20-30% mineral, 60-70% fine fabric
**Microstructure:** v. dense spongy.
**Porosity** 2-5% vughs, 2-5% channels, <2% cracks, <2% vesicles
**Mineral:**

| | |
|---|---|
| Silt | 10-20% |
| V. fine sand | 5-10% |
| Fine sand | 2-5% |
| Med. sand | 2-5% |
| Coarse sand | <2% |

Quartz rounded to angular, dominantly sub-rounded to sub-angular.
No shell.
Bone 2-5%, v. poorly preserved and degraded
**Fine fabric :** PPL: 7.5YR 5/4 (brown) to 7/6 (yellow). OIL: 10YR 7/4 (v. pale brown) to 7/6 (yellow). Speckled/dotted, low birefringence.

**Coarse organic:** 2-5% charcoal, mostly <200 μm; charred material includes incompletely burnt frags of material, reddened around the voids, cracked, with cell structures still visible. Some frags contain mineral material.
**Fine organic:** v. rare single cells 50-60 μm, yellow cell walls. 2-5% phytoliths. V. rare possible pollen grains. 0.5-2% rubified flecks and small areas.
**Groundmass:** porphyric.
**Pedofeatures:** v. rare discontinuous yellow, white and orange coatings <5μm thick on <2% of the mineral grains. Fabric isn't obviously excremental—if it is then it is very dense. Two (v. rare) orange-red hypocoatings c. 30μm thick around voids. 2-5% diffuse amorphous organo-mineral material, glassy yellow and red in PPL and brown in OIL. This is the material making up the segregations, hypocoatings and void linings. The segregations increase towards the surface of the horizon.

**Sample 112**
**Context 5020**
15-25% porosity, 15-25% mineral, 60-70% fine fabric
**Microstructure:** intergrain channel
**Porosity:** 5-15% channels, 5-10% vughs, <2% vesicles
Mineral

| | |
|---|---|
| Silt | 5-15% |
| V. fine sand | 2-5% |
| Fine sand | 2-5% |
| Med. sand | 5-10% |
| Coarse sand | <0.5% |

V. dominant quartz, rounded to angular, dominantly sub-rounded and sub-angular. V. rare bone, poorly and v. poorly preserved. V. rare shell (decaying).
**Fine fabric:** PPL: 7.5YR 4/4 to 6/4 (brown to light brown). OIL: bright orange-yellow. Speckled. Low birefringence.
**Coarse organic:** 2-5% charred material, often red around the voids. V. rare parenchymatic material. Rare fibrous red fragments, including one with visible cell structure and contents (phlobaphene containing tissues) and areas of intact phytoliths.
**Fine organic:** v. rare pollen. V. rare phytoliths, diatoms, fungal spores. Material is v. dominantly made up of yellow rubified yellow and orange material (OIL).
**Groundmass:** open porphyric
**Pedofeatures:** V. rare coatings on <0.5% of the mineral grains, <5μm thick, white, discontinuous. 2-5% amorphous organo-mineral material, brown in OIL and red or glassy yellow in PPL. Forms void linings and hypocoatings on rare voids. Large areas of the fabric appear to be dense excremental micro-aggregates; fabric could be total excremental. Glassy red segregations—areas of fibrous red material with the form of organic material but the colour of iron—these are in varying states of decay, some are more brown, some pure red, some more dispersed.

**Sample 112**
**Context 5033**
c. 20% porosity, c. 30% mineral, c. 50% fine fabric
5033 has a larger proportion of larger mineral material (fine sand size) than 5020, the deposit below. 5020 has a higher ash content (brighter orange in OIL)
**Microstructure:** channel
**Porosity:** 15-20%, including 10-15% channels, 5-10% vughs.
**Mineral:**

| | |
|---|---|
| Silt | 10-15% |
| V. fine sand | 5-10% |
| Fine sand | 2-5% |
| Med. sand | 5-10% |
| Coarse sand | 2-5% |

Quartz c. 25%. Other , 2-5% including feldspars, lithic clasts, rare micas, other. No shell. Bone is rare, in varying states of preservation
**Fine fabric:** PPL: 7.5YR 3/4 (dark brown). OIL: 5YR 7/8 (reddish yellow). V. rare bright orange fine fabric. Speckled. Low birefringence.
**Coarse organic:** 2-5% charred material, including v. rare woody fragments and one possible seed. V. rare parenchymatic tissue.

**Fine organic:** v. rare diatoms, one stained yellow. V. rare possible phytoliths.
**Groundmass:** close porphyric
**Pedofeatures:** v. rare yellow, white and orange coatings on rare mineral grains. V. discontinuous, <10µm thick. Depletion: some of the bone frags are v. decayed. V. rare red (PPL) hypocoatings (red brown in OIL). Rare amorphous red-brown (OIL) staining of the fine fabric, diffuse, often linked with charred peat frags. Rare rubified material, bright red and sparkly in OIL. V. bright orange nodules, spherical, 40-50 µm dia. Rare porous excremental fabric in voids. Fabric is mammilated at the edges and may be composed wholly of very dense excremental fabric.

**Sample 113**
**Contexts 5017 and 5019**
The sample was taken across the context boundary but the two midden deposits are indistinguishable; the only difference was that there was a small amount of shell (0.5-2%) in the upper 2 cm of the slide (Context 5017). The slide has therefore been treated as one context.
20-30% porosity, 30-40% mineral, 40-50% fine fabric
**Microstructure:** dominant channel structure
**Porosity:** 10-15% channels with few (5-15%) vughs and 2-5% compound packing voids in areas of crumb structure (areas of excremental aggregates. Channels are in different orientations.

Mineral

| | |
|---|---|
| Silt | 15-20% |
| V fine sand | 5-10% |
| Fine sand | 5-10% |
| Med. sand | 5-10% |
| Coarse sand | 2-5% |

30-35% quartz, rare shell in upper 2 cm, 2-5% other (nearer to 2%. Bone: rare, small frags mostly under 1mm, including burnt frags.
**Fine fabric:** PPL: 5YR 4/6 (yellowish red), OIL: 5YR 6/8 (reddish yellow). Moderate birefringence (dark reddish in XPL). V. rare areas of bright yellow material (OIL).
**Coarse organic:** 2-5% charred material including wood and peat. Rare parenchymatic tissue in channels. Rare frags of peaty material (red, fibrous), bright orange in OIL, with mineral grains. V. rare partially burn peat frags. One v. decayed pos. unburnt peat frag.
**Fine organic:** v. rare diatoms.
**Groundmass:** porphyric
**Pedofeatures:** 2-5% diffuse amorphous organo-mineral material. Rare segregations and hypocoatings, red or red-brown in OIL, up to c. 40 µm. orange and yellow in PPL. Rare bright orange (OIL) nodules, 25-40µm in dia, black or dark red in PPL. Isotropic. Often in clusters. V. rare fragmented discontinuous yellow and orange coatings (XPL). Orange coatings are also visible in PPL. Much of the fine fabric (15-30 % of the slide, c. 20%) is composed of porous excrement (round aggregates). The remainder of the fine fabric (20-30%) is dense excremental. Excremental infillings (loose discontinuous) in very rare voids (channels).

**Sample 116**
**Context 5043**
20-30% porosity, 40-50% mineral, 30-40% fine fabric
**Microstructure:** channel; fabric is also spongy with small vughs
**Porosity:** 2-5% channels, 2-5% chambers, c. 10-15% vughs, mostly <500 µm.

Mineral

| | |
|---|---|
| Silt | 2-5% |
| v. fine sand | 2-5% |
| fine sand | 2-5% |
| Med. sand | 20-30% |
| Coarse sand | 5-10% |

Shell: 20-30% (med. and coarse sand size grains). Quartz: c. 20%. Other, 0.5-2%, inc. lithic clasts, hornblende, feldspars. Bone: v. rare.
**Fine fabric:** PPL: 5YR 4/6 and 3/4 (yellowish red and dark reddish brown). OIL: 5YR 5/4 (reddish brown). Speckled. Low birefringence.
**Coarse organic:** 2-5% charred peat and wood frags. V. rare reddish material that looks like v. decayed peat in PPL but goes bright orange in OIL (organo-mineral? Ash?) Rare parenchymatic tissues and plant organs.

**Fine organic**. V. rare diatoms. V. rare possible phytoliths.
**Groundmass**: close porphyric
**Pedofeatures**: shell is mostly decaying around the edges; some frags have iron around the rims. 2-5% diffuse areas of bright yellow material (OIL). This may derive from the layer below. V. rare (one small area) of bright red (PPL) mineralised organic material. Doesn't seem to be an amorphous organo-mineral component—no sign of iron movement. Fabric is wholly excremental, with 2-5% porous and 20-30% dense aggregates. C. 10% v. dense excremental fabric.

**Sample 116**
Disturbed till (base of Ap?) Distinct from 5043 above in that it's yellower (looked like till in the field), denser and has only a small proportion of shell sand. Channels from 5043 bring the fine fabric down into the basal deposit. Boundary is very indistinct and irregular, occurring over 2cm.
10-20% porosity, 30-40% mineral, 50-60% fine fabric
**Microstructure**: spongy, with small vughs and channels.
**Porosity**: 5-10% channels, 5-10% vughs

Mineral

| | |
|---|---|
| Silt | 15-20% |
| V. fine sand | 10-15% |
| Fine sand | 5-10% |
| Med. sand | 10-15% |
| Coarse sand | 0.5-2% |

Quartz, c. 30%. Shell 2-5%, Other 0.5-2%, including feldspars. Bone—one possible very decayed frag.
**Fine fabric**: PPL: 10YR 7/6 (yellow), 5YR 4/6 (yellowish red), 7.5YR 5/6 (strong brown).
OIL: 10YR 8/8 (yellow), 2-5%. 10YR 7/6 (yellow) and 10YR 6/6 (brownish yellow) make up most of the fine fabric. Low birefringence. Speckled.
**Coarse organic**: rare parenchymatic tissues. Rare charred material.
**Fine organic**: v. rare single cells and clusters of cells.
**Groundmass**: porphyric
**Pedofeatures**: v. rare orange coatings (both XPL and PPL, discontinuous, <c. 15μm. shell frags are decaying, some with orange rims or bright white birefringent rims. Rare orange staining, diffuse (OIL). Bright yellow fabric in OIL, resulting from Iron? Other? Bright yellow areas in OIL look peaty in PPL: red and fibrous. Rare bright orange nodules (OIL), red in PPL, isotropic. Areas of the fabric are massive, and other areas have a v. poorly developed aggregate structure, rounded, like porous and dense excremental fabric. This is not intrusive. c. 5-10% of the slide is porous and dense excremental fabric.

**Sample 117**
**Context 5042**
15% porosity, 40% mineral, 45% fine fabric
**Microstructure**: slightly spongy, with small (c. 500-1000 μm) vughs and channels
**Porosity**: 2-5% channels, 10-15% vughs

Mineral

| | |
|---|---|
| Silt | 2-5% |
| V. fine sand | 2-5% |
| Fine sand | 5-10% |
| Med. Sand | c. 30% |
| Coarse sand | 2-5% |

Shell, 20-30%. Quartz 10-15%, Other 2-5%, inc. hornblende, feldspars, lithic clasts. Bone, v. rare (1 large frag, c. 5mm).
**Fine fabric**: PPL: 7.5YR 4/6 – 2.5YR 5/3 (strong brown to v. dark brown).
OIL: 7.5YR 4/4 brown. Low birefringence. Speckled.
**Coarse organic**: rare charred material (c. 2%) <500 μm. (V. rare larger frags) including peat and v. rare wood. V. rare parenchymatic tissue
**Fine organic**: v. rare single cells.
**Groundmass**: close porphyric
**Pedofeatures**: shell sand is decaying (v. decayed). >50% have orange stained rims. Rare mineral grains have v. thin fragments of orange, yellow and white coatings. V. rare bright orange (OIL) accumulations, permeating fine fabric to create orange staining or coating shell sand frags. 2-5% dark red (PPL) minerals—dark brown in OIL, v. dark, almost isotropic in XPL. This material

clusters; some areas of the slide have up to 10%, others <2%. V. rare orange/yellow material lining voids (PPL); this has a radial pattern in some cases. Rare porous excremental fabric. 5-10% dense excremental fabric.

**Sample 117**
**Context 5043**
15% porosity, 40-45% mineral, 40-45% fine fabric
**Microstructure:** slightly spongy, with small vughs
**Porosity:** 10-15% vughs, v. rare channels, 1 chamber c. 8 x 5mm.
Mineral

| | |
|---|---|
| Silt | 2-5% |
| V. fine sand | 2-5% |
| Fine sand | 2-5% |
| Med. Sand | 20-30% |
| Coarse sand | 2-5% |

Shell 10-20%. 1 large ?limpet shell frag c. 7mm. 20% quartz, 2-5% other, including lithic clasts, hornblende, feldspars. V. rare bone, well preserved.
**Fine fabric:** PPL: 7.5YR 4/6 – 2.5YR 5/3 (strong brown to v. dark brown).
OIL: 7.5YR 4/4 brown. Low birefringence. Speckled.
**Coarse organic:** 2-5% charred material, dominantly peat with v. rare woody frags. Rare frags are >5– µm. V. rare parenchymatic tissue
**Fine organic:** v. rare phytoliths. V. rare spherulites
**Groundmass:** close porphyric
**Pedofeatures:** v. rare orange, yellow and white discontinuous fragmented coatings on rare mineral grains, up to c. 15 µm thick. >50% of shell has iron accumulation, mostly around the edges. Shell is mostly very decayed. 10-15% orange (OIL) staining of fine fabric; iron accumulation forms segregations several cm across, which would have been mottles in the section face. Small diffuse areas and very diffuse nodules are 20-40 µm across. Rare glassy orange/yellow material (PPL) in voids—doesn't show up in OIL or XPL. This material (or a similar material) is found with a radial pattern within voids. V. rare round yellow and orange nodules (PPL), 40-50µm. V. rare dark red (PPL) mineral, as in 5042. This material can have v. sharp, clear edges—v. rectangular—but this is more evident in 5042 than in 5043. One channel has loose, discontinuous excremental infill. 2-5% porous excremental fabric; 10-15% dense excremental fabric.

**Sample 121**
**Context 5058**
15-20% porosity, 30-40% mineral, 50-60% fine fabric
**Microstructure:** channel and chamber
**Porosity:** 2-5% chambers, 5-10% channels, 2-5% vughs (nearer to 5%)
**Mineral:**

| | |
|---|---|
| Silt | 10-15% |
| v. fine sand | 5-10% |
| Fine sand | 2-5% |
| Med. Sand | 5-10% |
| Coarse sand | 2-5% |

c. 30% quartz, dominantly sub-rounded and sub-angular. 2-5% lithic clasts, feldspars, other (rare micas). V. rare bone, well preserved.
**Fine fabric:** PPL: 7.5YR 4/6 (strong brown). OIL: 5YR 6/6 (reddish yellow). Low birefringence. Speckled.
**Coarse organic:** 2-5% charred material (closer to 2%), dominantly wood with rare peat charcoal, but most frags are <3– µm and difficult to identify. V. rare parenchymatic tissues. Frags of red (phlobaphene containing?) tissue around one large chamber.
**Fine organic:** v. rare phytoliths. V. rare fungal spores (brown cell cluster—wall is missing). V. rare possible pollen.
**Groundmass:** porphyric
**Pedofeatures:** v. rare, v. thin clay coatings <5µm thick, orange, yellow and white on 2-5% of the mineral grains. Iron depleted stone rims. V. rare bright orange (OIL) nodules, 15-50 µm, often in clusters. Round, with a radial pattern. Rare diffuse staining of fine fabric, dark orange in OIL, orange in PPL. V. rare glassy yellow material, usually linked with orange material. Loose, discontinuous

excremental infill in channels. Fabric appears wholly excremental, dense and v. dense. 2-5% is porous.

**Sample 121**
**Context 5059** (till)
15-20% porosity, 30-40% mineral, 40-50% fine fabric
**Microstructure:** spongy, with channels
**Porosity:** 2-5% channels, 5-10% vughs
**Mineral**

| | |
|---|---|
| Silt | 15-20% |
| V. fine sand | 10-15% |
| Fine sand | c. 10% |
| Med. sand | 5-10% |
| Coarse sand | 0.5-2% |

Quartz c. 35%. Rare lithic clasts, feldspars, hornblende. 2-5% micas. No shell. 2-5% Calcium Iron phosphate? V. decayed bone?
**Fine fabric:** PPL: 7.5YR 5/6 (strong brown). OIL 10YR 7/6 (yellow). Moderate birefringence. Speckled.
**Coarse organic:** v. rare charred material up to 600 µm but mostly <300 µm. Rare parenchymatic tissue in voids. 1 frag of fibrous red material—seems to be made up of nodules and glassy orange material, i.e. either mineral replaced organic or pure iron accumulation.
**Fine organic:** v. rare possible pollen. V. rare single cells, orange. V. rare possible phytoliths—one dumbbell shaped—hard to i.d. because the deposit is so micaceous.
**Groundmass:** porphyric
**Pedofeatures:** v. rare, v. thin yellow and white discontinuous coatings, mostly <5µm, on <5% of the mineral grains (2-5%). V. rare bright orange (OIL) nodules, 15-50µm, often in clusters. Rare dark orange (OIL) diffuse staining of fine fabric (orange in PPL). 2-5% calcium-iron phosphate? In voids. Some of the channels contain discontinuous porous excrements. Slide is c. 2-5% porous excrement, concentrated n the areas of glassy bone-like yellow material interpreted as Ca Fe phosphate . The fabric looks like wholly dense and v. dense excremental aggregates.

**Sample 122**
**Context 5057**
20-30% porosity, c. 40% mineral, 30-40% fine fabric.
**Microstructure:** spongy, with channels
**Porosity:** c. 5% channels and c. 25% vughs
**Mineral:**

| | |
|---|---|
| Silt | 5-10% |
| V. fine sand | 2-5% (c. 5) |
| Fine sand | 2-5% (c. 5) |
| Med. sand | c. 25% |
| Coarse sand | 5-10% |

Shell, 20-30%. Quartz 15-20%. Bone: v. rare small frags up to 600 µm. Other, inc. feldspars and lithic clasts: 2-5%
**Fine fabric:** PPL 5YR 3/4 to 4/6 (dark reddish brown to yellowish red—nearer to dark reddish brown. OIL: 5YR 6/6 (reddish yellow). Speckled. Low birefringence.
**Coarse organic:** 2-5% charred material, including predominantly peat ash and <2% wood charcoal; many frags are indeterminate. V. rare parenchymatic tissue, mostly in voids. No uncharred peat.
**Fine organic:** none
**Groundmass:** close porphyric
**Pedofeatures:** v. rare, v. thin(<5 µm) yellow and white coatings on rare mineral grains. Shell is decaying; rims are sometimes bright birefringent. Iron accumulations, esp. around the rims, on >50% of the shell frags. V. rare bright orange nodules c. 15-50 µm, usually in clusters. Amorphous red (OIL and PPL) segregations and diffuse areas 2-5%. 2-5% glassy yellow material occurring as void linings, grain coatings and within the fabric, dominantly in voids. Fabric appears to be wholly excremental—dense and v. dense, grading into areas of porous.
Greater porosity in 5057 and redder fabric than in 5058. Fabric is more clearly excremental because of the greater porosity.

**Sample 122**
**Context 5058**
15-20% porosity, c. 30% mineral, 50-60% fine fabric.
**Microstructure:** spongy
**Porosity:** c. 5% channels, 10-15% vughs
**Mineral:**

| | |
|---|---|
| Silt | 5-10% |
| V. Fine sand | 5-10% |
| Fine sand | 5-10% |
| Med. sand | c. 10% |
| Coarse sand | 2-5% |

Shell 2-5% (decaying), quartz c. 25%, bone v. rare (well preserved). Other: v. rare hornblende, v. rare feldspars.
**Fine fabric:** PPL: 7.5YR 4/4 (brown) to 4/6 (strong brown). OIL: 5YR 6/6 (reddish yellow. Speckled. Low birefringence.
**Coarse organic:** 2-5% charred material including wood, peat and indeterminate. V. rare parenchymatic tissue in voids. V. rare, v. degraded red fibrous material.
**Fine organic:** v. rare diatoms, v. rare phytoliths, v. rare small brown cells in parenchymatic tissue.
**Groundmass:** close porphyric
**Pedofeatures:** v. rare bright birefringent yellow and white coatings on rare mineral grains. (<5 μm). Pale, slightly bleached looking coating of soil lining the channels (includes clay, silt and sand). Shell is weathered on the edges and has iron staining. 2-5% red brown (OIL) organo-mineral material occurring as pigment in the fabric. V. rare bright orange nodules c. 20-50μm dia. One Fe hypocoating, bright orange in OIL, red in PPL. The organo-mineral pigment grades into segregations (rare) at its most minerogenic; these areas are red in PPL. Fe coatings on mineral grains? Red in PPL. Yellow material in voids, some glassy, some speckled, some reticulated—makes up c. 2-5%. Difficult to quantify because it is concentrated in some areas and more sparse in others. Fabric may be wholly excremental—dense and v. dense.

**Sample 123**
**Context 5055**
10-15% porosity, 80-85% mineral, 2-5% fine fabric
**Microstructure:** single grain
**Porosity:** simple packing voids. Occasional complex packing voids. Rare channels.
**Mineral:**

| | |
|---|---|
| Silt | <0.5 |
| V. fine sand | <0.5 |
| Fine sand | 0.5-2% |
| Med. sand | c. 70% |
| Coarse sand | 10-15% |

C. 70% shell, 10-15% quartz.
**Fine fabric:** PPL: 2.5YR 4/4 to 4/6 (reddish brown to red).
OIL: 2.5YR 5/4 (reddish brown). Moderate birefringence.
**Coarse organic:** v. rare fine charcoal flecks, silt and v. fine sand size. 1 frag fine sand size, 1 frag med. sand size. Rare parenchymatic tissues in channels.
**Fine organic:** v. rare single cells
**Groundmass:** dominantly monic; occ. areas of fine fabric and gefuric groundmass.
**Pedofeatures:** shell sand is slightly weathered, but not badly. Iron accumulation forms bright orange and yellow areas; this forms bridges between the grains and cements the fabric. Channels have parenchymatic tissues and no obvious earthworm activity.

**Sample 123**
**Context 5056**
c. 5% porosity, c. 35% mineral, c. 60% fine fabric
**Microstructure:** spongy, with channels
**Porosity:** 2-5% including c. 2% channels and c. 3% vughs.
Mineral

| | |
|---|---|
| Silt | 5-10% (c. 5) |
| V. fine sand | 2-5% (c. 5) |
| Fine sand | 5-10% |

| | |
|---|---|
| Med sand | c. 20% |
| Coarse sand | 2-5% |

Shell: c. 20%, quartz c. 15%, rounded to angular. V. rare bone (1 frag, well preserved), 2-5% other including lithic clasts and feldspars.
**Fine fabric:** PPL: 5YR 4/6 –3/4 (yellowish red to dark reddish brown).
OIL: 5YR 4/4 (reddish brown). Speckled. Moderate birefringence.
**Coarse organic:** 2-5% charred material, mostly <200 μm. Dominantly peat charcoal, with rare wood charcoal. Rare parenchymatic tissues.
**Fine organic:** rare single cells
**Groundmass:** close porphyric
**Pedofeatures**
V. rare thin discontinuous coatings on rare mineral grains. Shell is degraded; many frags. have bright birefringent rims or accumulations of iron around the rims. Rare mineral grains also have orange staining around the rim. Large areas of iron segregation, with shell and mineral grains. Very red area c. 4.5mm across. Hypocoating up to 3mm wide on a channel running vertically from the bottom of the slide. V. red areas make up c. 5% of the area of 5056. Two frags of mineral replaced organic material? c. 1mm across. Deep red coating around several parenchymatic rootlet frags. Areas of porous excremental fabric, c. 2-5% of the slide—the remainder of the fabric may be very dense excremental fabric.

**Sample 126**
**Context 5083**
c. 20% porosity, 50-55% mineral, 20-30% fine fabric
**Microstructure:** spongy crumb structure
**Porosity:** 15-20% vughs, rare channels

Mineral

| | |
|---|---|
| Silt | 2-5% |
| v. fine sand | 2-5% |
| Fine sand | 2-5% |
| Med. sand | 30-40% |
| Coarse sand | 2-5% |

c. 20% quartz, c. 30% shell, 2-5% other, including lithic clasts, feldspars. Bone is v. rare, v. degraded.
**Fine fabric:** PPL: 7.5YR 3/4 - 4/6 (dark brown to strong brown).
OIL: 7.5YR 5/4 (brown). Speckled. Low birefringence.
**Coarse organic:** 2-5% charred material, including wood and peat. Rare parenchymatic tissues.
**Fine organic:** v. rare phytoliths.
**Groundmass:** close porphyric
**Pedofeatures:** shell is decalcifying. Calcitic material speckles the fine fabric. Most shell grains have bright birefringent rims. Many also have iron (red in XPL) staining the grains, especially around the edges. V. rare bright birefringent white and yellow coatings on mineral grains, <10μm thick on 2-5% of the mineral grains. 2-5% dark red mineral grains (PPL), red-brown in OIL, glassy, isotropic. This material can occur in clusters, looking like possible mineral replaced organics. Bright orange and yellow area (OIL), red brown in PPL, some kind of organo-mineral? Fabric is wholly excremental: porous, dense and v. dense. Channels filled by 5086, the deposit below, extend up into this horizon.

**Sample 126**
**Context 5086**
10-15% porosity, 30-40% mineral, 50-60% fine fabric
**Microstructure:** slightly spongy
**Porosity:** 5-10% vughs, 2-5% channels

Mineral

| | |
|---|---|
| Silt | 5-10% |
| V. fine sand | 5-10% |
| Fine sand | 5-10% |
| Med. sand | 10-15% |
| Coarse sand | <0.5% |

Quartz, 30-35%, Other: 2-5%, including lithic clasts, feldspars. No bone or shell.
**Fine fabric:** PPL: 7.5YR 4/6 (strong brown).
OIL: 7.5YR 7/6 (reddish yellow) (slightly browner). Low birefringence. Speckled.

**Coarse organic:** rare parenchymatic tissue. V. rare phlobaphene-containing tissue. Rare charred material, including wood charcoal. V. rare red-brown material (PPL), bright orange in OIL; one area is within a charcoal frag.
**Fine organic:** rare single cells, dark red cell walls, orange contents, 80 μm dia. V. rare possible phytoliths.
**Groundmass:** porphyric
**Pedofeatures:** V. rare, v. thin (<5μm) discontinuous orange and white coatings on v. rare mineral grains. Rare amorphous organo-mineral material,: red nodules in PPL, dark red brown or red in OIL, isotropic. Rare amorphous material, as above but not in nodules—possible partially mineral replaced organics. Channel 1400 μm wide with dense incomplete infill (porous excrement); also a small parallel channel with the same infill. Fabric is v. dense and not obviously excremental.

**Sample 129**
**Context 5068**
Top of horizon: 30-40% porosity, 40-50% mineral, 10-15% fine fabric
Bottom of horizon: c. 40% porosity, c. 50% mineral, 5-10% fine fabric
**Microstructure:** intergrain microaggregate, with some larger aggregates or areas of fine fabric
**Porosity:** 40% complex packing voids. One large crack or channel runs through the horizon.
**Mineral:**

| | |
|---|---|
| Silt | 0.5-2% (c. 2) |
| V. fine sand | 0.5-2% (<2) |
| Fine sand | 2-5% |
| Med. sand | c. 30% |
| Coarse sand | 2-5% |

Shell, 30-40%, quartz c. 10%, other c. 2%. V. rare bone frags.
**Fine fabric:** PPL: 7.5YR 5/4 – 4/4 (brown to strong brown).
OIL: 7.5YR 6/6 (reddish yellow). Speckled. Low birefringence.
**Coarse organic:** 0.5-2% charred material (c. 2%). Rare plant organs. Root frags in channels. V. rare parenchymatic tissues.
**Fine organic:** v. rare single yellow cells 200 μm dia. V. rare phytoliths. One possible spherulite? But not a feature in the fabric.
**Groundmass:** enaulic
**Pedofeatures:** most shell frags are degraded around the edges. Many have a bright birefringent rim, and some are more decayed. V. rare bright orange and yellow material in OIL; some is mineral, but none that looks like ash—one area is bright yellow in OIL and orange in PPL—more like iron accumulation. V. rare yellow and orange nodules (PPL), 50μm dia. These don't stand out bright orange in OIL like the similar nodules in other contexts. Fine fabric is dominantly porous excrement, with areas of very porous and areas of dense.

**Sample 129**
**Context 5069**
c. 40% porosity, 55-60% mineral, c. 5% fine fabric
**Microstructure:** intergrain microaggregate, with areas of single grain and small areas of porphyric fine fabric.
**Porosity:** c. 40% simple and complex packing voids.
Mineral

| | |
|---|---|
| Silt | 0.5-2% |
| V. fine sand | 0.5-2% |
| Fine sand | 2-5% |
| Med. sand | 40-50% |
| Coarse sand | 5-10% (c. 5) |

Shell: c. 50%, quartz 5-10%, Other, 0.5-2% lithic clasts etc.
**Fine fabric:** PPL: 7.5YR 5/4 – 4/4 (brown to strong brown).
OIL: 5YR 7/6 (reddish yellow). Speckled. Low birefringence.
**Coarse organic:** Rare charred material, almost entirely within the fine fabric. V. rare parenchymatic tissue (in channel)
**Fine organic:** 1 fungal spore, v. rare single cells, v. rare possible phytoliths
**Groundmass:** dominantly monic

**Pedofeatures**: channels extend from 5070 up into 5069, bringing fine fabric up into the sandy layer. The fine fabric is mammilate on the edges of the larger areas or is made up of porous and v. porous excrement.

**Sample 129**
**Context 5070**
5-15% porosity, 30-40% mineral, 50-60% fine fabric
**Microstructure**: spongy
**Porosity**: c. 5% channels, c. 5% vughs

Mineral

| | |
|---|---|
| Silt | 5-10% |
| V. fine sand | c. 5% |
| Fine sand | 5-10% |
| Med. sand | 15-20% |
| Coarse sand | 0.5-2% |

Shell content is variable—c. 5-15% but mostly (not entirely) confined to intrusive channels. Rounded to angular quartz, 20-30%. Other, including lithic clasts, feldspars etc. c. 2%. V. rare bone in varying states of preservation; some frags of material look like v. degraded bone.
**Fine fabric**: PPL: 7.5YR 5/4 – 4/4 (brown to strong brown).
OIL: 5YR 7/6 (reddish yellow). Speckled. Low birefringence.
**Coarse organic**: rare charred material, including v. rare wood charcoal. V. rare parenchymatic tissues.
**Fine organic**: v. rare diatoms. V. rare possible phytoliths, v. rare single cells. 1 pos. fungal spore
**Groundmass**: porphyric
**Pedofeatures**: v. rare coatings on mineral grains, yellow and orange, discontinuous, up to c. 20 μm thick. Shell frags are slightly degraded around the edges; iron is accumulating around some of the rims. Rare areas of amorphous organo-mineral staining of fabric, brown and red-brown in OIL, red under PPL. Red material (iron) lines rare voids or forms segregations. V. rare bright orange material, difficult to tell whether this is mineral or fabric. V. rare red (PPL and OIL) nodules <c. 50 μm. Fabric is composed of porous, dense and v. dense excrement.

## A2.3 SCATNESS SLIDE DESCRIPTIONS

**10090**
**Context 2109**
**Microstructure:** spongy
**Porosity:** 40-50%. V. dominant vughs. V. few channels (<5%)
**Coarse component:** 30-40%. c. 60% of the coarse fraction made up of lithic clasts, c. 35% quartz, 5% other including compound quartz grains, feldspars, hornblende
Rare bone (0.5-2%)
Very rare rubified mineral material

| | |
|---|---|
| Silt | <2% |
| V. fine sand | 2-5% |
| Fine sand | 5-10% |
| Medium sand | 10-20% |
| Coarse sand | 2-5% |

Lithic clasts are 90% rounded and sub-rounded. Quartz is rounded to angular, mostly(>50%) angular and sub-angular.
**Fine fabric** (20-30% of the slide)
PPL: 5YR 4/4 to 3/4 (reddish brown to dark reddish brown)
OIL: 10R 7/8 to 6/8 (light red)
Speckled. Low birefringence.
**Coarse organic:** 2-5% charcoal and charred material including turf fragments up to 2mm. V. rare plant tissue and organ residue.
**Fine organic:** V. rare diffuse amorphous organo-mineral. V. rare phytoliths
**Groundmass:** close porphyric
**Pedofeatures**
Very rare, very thin (<2μm) yellow (XPL) coatings on mineral grains.
Fabric is composed of porous (<2%) to very dense mammilated material
Non-birefringent glassy yellow-brown material lines some of the voids (very rare to rare, i.e. <2%)

**Context 2111 (slide 10090)**
**Microstructure:** Intergrain microaggregate
**Porosity:** 50-60%. 95% complex packing voids. 2-5% channels and vughs.
**Coarse component:** 40-50%
Dominant (50-70%) lithic clasts, rounded to angular
Common (30-50%) quartz, rounded to angular
>2% other, including compound quartz, feldspar, hornblende

| | |
|---|---|
| Silt | <2% |
| Very fine sand | <2% |
| Fine sand | 5-10% |
| Medium sand | 20-30% |
| Coarse sand | 5-10% |

No bone, but areas of yellow material may be very decayed bone?
**Fine fabric**
PPL: 5YR 4/4 to 3/4 (reddish brown to dark reddish brown)
OIL: 2.5YR 7/8 (light red). Areas of brighter red.
Speckled. Low birefringence
**Coarse organic**
<2% charcoal fragments
<2% burnt material with mineral grains. One large fragment is 1.9 mm: this goes sparkly black under OIL like charcoal but has cracks and vughs like a soil. 5 diatoms are visible, projecting into the voids.
**Fine organic**
0.5-2% diffuse amorphous organo-mineral material
Some of the reflective black material has reddening around it, often with one sharp edge and one diffuse, so it's hard to tell if its charcoal or organo-mineral material.
Very rare pollen
Very rare phytoliths
**Groundmass:**

**Pedofeatures**
Very rare, very thin (<5µm) incomplete yellow and orange coatings on grains.
The fine fabric is mammilated around the edges; 30-50% could be very dense mammilated excrement. <5% porous mammilated excrement.

**10091**
**Context 2108**
**Microstructure:** spongy
**Porosity:** 30-40%. 5-15% channels, 20-30% vughs.
Coarse fraction

| | |
|---|---|
| Silt | <2% |
| V. fine sand | 2-5% |
| Fine sand | 5-15% |
| Medium sand | 10-20% |
| Coarse sand | <2% |

Quartz 20-30%, rounded to angular—mostly sub-rounded and sub-angular
Lithic clasts c. 20%, rounded to angular—mostly rounded and sub-rounded
Hornblende 0.5-2%
Other 0.5-2% (feldspars)
Bone 2-5%
Shell: none
**Fine Fabric**
PPL: 7.5YR 3/3 dark brown
OIL: 5YR 6/8 (reddish yellow) to 2.5YR 6/8 (light red)
One small area (< 0.5% of the slide) of bright orange (OIL) fabric. <0.5% yellow fabric (OIL)
Speckled. Low birefringence.
**Coarse organic**
5-15% charcoal (one charred fragment contains a diatom)
**Fine organic**
V. rare diatoms, pollen, phytoliths. Pos. fungal spore.
**Groundmass:** close porphyric
**Pedofeatures**
2-5% diffuse amorphous organo-mineral. This shows up red in PPL, red-brown in OIL. V. rare nodules with one sharpish edge and one slightly more diffuse.
2-5% of the mineral grains have discontinuous coatings up to c. 16 µm thick; these are yellow and white, occasionally orange.
Fabric may be v. dense excremental.
0.5-2% porous excrement.
5-10% dense mammilated excrement.
<2% glassy yellow material in the fabric and in voids.

**10092 (contexts 2106 and 2107)**
**Context 2106**
**Microstructure:** Spongy
**Porosity:** 40-50%. 5-10% channels, c. 30% vughs
Coarse fraction

| | |
|---|---|
| Silt | 2-5% |
| V. fine sand | 2-5% |
| Fine sand | 5-10% |
| Medium sand | 10-20% |
| Coarse sand | 5-10% |

Quartz 10-20%, rounded to angular
Lithic clasts 10-20%, v. dominantly rounded
Other 2-5%, including feldspars, hornblende
Shell <0.5%
Bone 2-5%
<0.5% rubified mineral
**Fine fabric**
PPL: 7.5YR ¾ (dark brown)
OIL: 5YR 6/6 to 6/8 (reddish yellow)

Speckled. Low birefringence.
**Coarse organic**
2-5% charred material, including material with mineral grains. Fragments up to c. 3mm, but mostly <200-300 µm. One of these fragments has surviving organics and speckled yellow material in the voids.
**Fine organic**
V. rare pollen, v. rare phytoliths (some very well preserved and still spiky)
v. rare diatoms
**Groundmass:** close porphyric
**Pedofeatures**
0.5-2% amorphous organo-mineral, mostly diffuse with v. rare diffuse edged nodules. V. rare clear-edged nodules but these occur in areas of diffuse organo-mineral (i.e. within a cluster) so they don't appear to be transported, but probably formed *in situ.*
Thin (<10µm) discontinuous yellow and white coatings on <5% of the mineral grains.
5-10% speckled yellow and reddish material, pos. decayed bone? Usually associated with amorphous organo-mineral material. (iron accumulation?)
Rare glassy yellow material lining voids.
Fabric is total excremental, dominantly porous and dense excremental.

**Context 2107**
**Microstructure:** predominantly single grain; fine fabric occurs as grain coatings and bridges and as intergrain microaggregates.
**Porosity:** 50-60%. V. dominant simple packing voids. V. rare complex packing voids.
Coarse fraction

| | |
|---|---|
| Silt | <0.5% |
| V. fine sand | <0.5% |
| Fine sand | 2-5% |
| Medium sand | 30-40% |
| Coarse sand | 2-5% |

Quartz 10-20%, rounded to angular, dominantly sub-rounded and sub-angular
Lithic clasts c. 20%, rounded to angular, mostly rounded and sub-rounded
Other, including feldspars and hornblende, 0.5-2%
Bone 0.5-2%
Shell: none apparent
**Fine fabric**
PPL: 7.5YR 4/6 (strong brown) and 3/4 (dark brown)
OIL: 7.5YR 6/6 (reddish yellow) and 5YR 6/8 (reddish yellow)
Speckled. Low birefringence
**Coarse organic**
V. rare charcoal fragments, under 200µm. One fragment c. 600µm, with mineral grains, vughs and cracks. Reddish and yellow where the fabric is thinner, around the voids. Possible diatoms.
**Fine organic**
V. rare diatoms (two were outside the fragment mentioned above, one between sand grains and one in the fine fabric).
**Groundmass:** Predominantly enaulic. Areas of gefuric/chitonic.
**Pedofeatures**
Most grains (>50%) are coated with fine material, usually discontinuous. This shows up red-brown or yellow-brown under PPL, but as the fine fabric has low birefringence the coatings aren't so clear under XPL. White, yellow and orange discontinuous coatings are evident under XPL (up to c. 25µm thick) on c. 10-20% of the grains.
The fine fabric might be in part excremental—many of the small aggregates are round, but are not clearly excremental. The fine fabric is so sparse (0.5-2%) that it's hard to say.
V. rare diffuse amorphous organo-mineral.

**10093**
**Context 2106**
**Microstructure**: intergrain microaggregate (>70%). Spongy (5-15%)
**Porosity**: 30-50% of the slide.

| | |
|---|---|
| Channels | <5% of total void space |
| Complex packing voids | 60-70% |

Vughs 30-40%
**Coarse fraction:** 40-50%
Silt 2-5%
V. fine sand 2-5%
Fine sand 2-5%
Medium sand 10-20%
Coarse sand 2-5%
Quartz- c. 20% of the slide
Lithic clasts, c. 25%
Other: Feldspars (microcline, plagioclase) <2%
Shell, v. rare
Bone, 2-5%. Varying states of decay; some is sharp edged, some breaking into small fragments which are moving down through the soil.
Rare rubified mineral material
**Fine fabric**
PPL: 7.5YR 3/3 (dark brown)
OIL: 5YR 6/8 (reddish yellow) to 2.5YR 6/8 (light red)
Speckled. Low birefringence.
**Coarse organic**
2-5% charred material, including material with mineral grains.
V. rare parenchymatic tissues
**Fine organic**
V. rare phytoliths.
V. rare organo-mineral accumulations, some diffuse, some with one clear edge and one diffuse.
**Groundmass:** close porphyric
**Pedofeatures:**
Frequent (15-30%) porous and v. porous mammilated excrement.
Common (30-50%) dense and v. dense mammilated excrement.
Fabric appears to be wholly or nearly wholly excremental.

**10094**
Fabric 1: main fabric
Fabric 2: reddish, well defined edges, c. 2.8mm across
Fabric 3: 10YR 5/6 yellowish brown (PPL). V. clear edges. 4 fragments, with another just to the right.
Fabric 4: 10YR 7/6 to 6/6 (yellow to brownish yellow)PPL. One fragment, v. distinct. Also fills a channel in the top right corner.
**Fabric 1**
**Microstructure:** complex—a combination of spongy and intergrain microaggregate.
**Porosity:** 40-50%. Dominant vughs, frequent complex packing voids, v. few channels.
**Coarse fraction:** 30-40%
Silt 2-5%
V. fine sand 2-5%
Fine sand 5-10%
Medium sand 20-30%
Coarse sand 2-5%
Quartz, 20-30% of slide
Lithic clasts 10-20%
Other, inc. feldspars (microcline and plagioclase), hornblende
Shell- none
Bone 5-15%. Very degraded. Some well preserved fragments with sharp edges, some transparent and crumbling into fragments which are moving down through the soil.
V. rare rubified mineral material.
**Fine fabric:** 20-30% of the slide
PPL: 7.5YR 3/3 dark brown
OIL: 5YR 6/8 reddish yellow
Speckled, low birefringence.
Coarse organic
Charred material, including v. cracked fragments with mineral grains.
**Fine organic:**

V. rare amorphous organo-mineral, mostly diffuse. Some nodules, but edges aren't sharp.
V. rare phytoliths.
**Groundmass:** close porphyric
**Pedofeatures:**
Freq. (15-30%) porous and v. porous mammilated excrement.
Common (30-50%) dense and v. dense mammilated excrement.
Fabric appears to be wholly excremental.

**Fabric 2**
Very dense fabric with only a few voids (2-5% void space) which may be where mineral grains were pulled out during thin section manufacture? Contains one large mineral, 1.1mm across, unidentified. Excluding this, the fabric is 15-30% mineral grains and 70-80% fine material. The dominant mineral is mica (50-7-% of the mineral material; c. 10% of the fabric) and c. 5% of the slide is quartz.
**Fine fabric:**
PPL: 10R 3/6 dark red
OIL: 5YR 3/2dark (reddish brown) to 7.5YR 3.2 (dark brown)
High birefringence. Speckled.
The fabric stands out from the surrounding Fabric 1 in all lights. Fabric 1 is much brighter and redder.
**Coarse organic:** c. 2% charcoal (rare)
**Fine organic:** V. rare phytoliths.
**Groundmass:** open porphyric
**Pedofeatures:** rare red material—not clearly nodular—in one void, and in the fabric, especially towards the edge of the fabric fragment. One organo-mineral nodule with clear, sharp edges.
Thin yellow coatings on 10-15% of the mineral grains: one coating 25 μm thick
V. thin (5-10μm) yellow coatings, very discontinuous, in voids.
Glassy yellow material lines the few voids, and adheres to the edges of the fabric fragment.

**Fabric 3**
c. 5 fragments. 2 are 2mm across and very sharp edged; the other 3 are less well defined, one having been reworked by soil biota/microbes. Frags are 40-60% coarse mineral material, including quartz (just a few grains, c. 5-15% of the mineral fraction), lithic clasts (major component, 30-50%), bone (5-15%) well preserved, with sharp edges. Very rare rubified mineral (small grains, <50μm).
**Fine fabric:** mottled yellow and red-brown (PPL). Under OIL looks the same as Fabric 1. Low birefringence, speckled.
**Coarse organic:** rare charcoal.
**Fine organic:** v. rare phytoliths
Pedofeatures: rare amorphous organo-mineral material with diffuse edges. One nodule.

**Fabric 4**
10-20% mineral, including quartz, lithic clasts, micas. Porosity c. 10% (5-15%) cracks and channels.
**Fine fabric:**
PPL: 10YR 7/6 (yellow)
OIL: 10YR 7/4, a paler yellow.
Low birefringence. Speckled.
V. rare charcoal, phytoliths.
2-5% organo-mineral, diffuse.
V. rare organo-mineral nodules, <100μm.

**10095**
**Context 2105**
This deposit was described on site as blown sand. The slide has three fabrics: the dominant fabric is blown sand, and within this are wide channels filled with Fabric 2, a dark brown sandy soil. In the lower left corner is a third fabric, redder than Fabric 2.

**FABRIC 1**
**Microstructure:** complex. Dominantly bridged, with intergrain microaggregates. Variable amounts of fine material.

**Porosity:** 40-50%, dominantly simple and complex packing voids. 25-30% of the slide is taken up by two channels, each 5-6mm wide, or possibly they form one large channel 1.2mm wide and branching off. (pos. root rather than earthworm burrow?)

Coarse fraction

| | |
|---|---|
| Silt | <2% |
| V. fine sand | <2% |
| Fine sand | 5-15% |
| Medium sand | 30-40% |
| Coarse sand | 2-5% |

Quartz 20-30%, rounded to angular, mostly sub-rounded and sub-angular
Lithic clasts 30-35%, mostly rounded and sub-rounded
Other, including feldspars and hornblende, <2%
Bone <0.5%
Shell: none
V. rare rubified mineral material

**Fine Fabric**

PPL 5YR 3/4 (dark reddish brown)
OIL 5YR6/8 (reddish yellow)
Speckled. Low birefringence.

**Coarse organic**

Rare charred material; 1200μm charred frag with c. 20% mineral grains, reflective black under OIL. Charcoal is mostly <500μm, with a few frags around 1mm.
V. rare parenchymatic tissues in channels

**Fine organic**

V. rare phytoliths. One is very well preserved, still having spikes.

**Groundmass:** Dominantly chitonic, with microaggregates

**Pedofeatures**

0.5-2% amorphous organo-mineral, diffuse.
0.5-2% porous excrement. Larger areas of fine fabric (0.5-2% of the slide) may be dense excrement.

FABRIC 2 (Fill of channels)

Dense complete to loose discontinuous channel infill; porosity varies from c. 20% to c. 80%. In the dense areas of fabric the voids are cracks and vughs; in the loose discontinuous areas the voids are complex packing voids (i.e. occurring between single grains and small aggregates).
Mineralogy is the same as for Fabric 1, i.e. quartz, lithic clasts, feldspar, hornblende, bone, BUT with rare shell frags. There is a higher proportion of silt and v. find sand than in Fabric 1. The material is not so well sorted, and there is more fine fabric.

| | |
|---|---|
| Silt | 2-5% |
| V. fine sand | 2-5% |
| Fine sand | 2-5% |
| Medium sand | 15-30% |
| Coarse sand | 2-5% |

**Fine fabric**

PPL: 7.5YR 2.5/3 (very dark brown)
OIL: 5YR 5/6 to 4/6, yellowish red.
Speckled. Low to moderate birefringence.

**Coarse organic**

Rare charcoal fragments up to 1mm. Fragments of red fibrous material with cracked black material within, up to 1mm.

**Fine organic**

V. rare diatoms. V. rare phytoliths. Cluster of cells in varying states of preservation, each c. 30μm in diameter. 9 cells in the cluster and another nearby.

**Groundmass:** Dominantly close porphyric. Chitonic in areas of loose discontinuous material.

**Pedofeatures**

5-15% of the mineral grains have discontinuous yellow, white or orange coatings, c. 2-5μm thick.
2-5% porous excrement. The fine fabric may be wholly excremental (v. dense).

FABRIC 3

This occurs in the lower left corner of the slide.
Fine fabric 20-30%, Mineral 20-35%, Porosity 30-40%

Area of denser fine fabric, redder than Fabric 1. Fine fabric makes up 20-30% of the slide in this area. Mineralogy is similar but with increased amounts of silt:

| | |
|---|---|
| Silt | 2-5% |
| V. fine sand | 5-10% |
| Fine sand | 5-10% |
| Medium sand | 10-20% |
| Coarse sand | 5-10% |

**Porosity** 30-40%, vughs and complex packing voids
**Fine Fabric:**
PPL 2.5YR 3/6 and 2.5/4 (dark red and dark reddish brown)
OIL 10YR 8/8 (yellow), 5YR 7/8 reddish yellow and (dominantly) 5YR 6/6 (reddish yellow)
Speckled. Moderate birefringence.
**Coarse organic:** 2-5% charcoal
**Fine organic:** V. rare phytoliths, v. rare, v. poorly preserved pollen
**Groundmass:** enaulic, with areas of porphyric
**Pedofeatures**
2-5% diffuse amorphous organo-mineral
10-20% porous and very porous excrement
10-20% dense and very dense excrement
2-5% glassy orange material (this particularly distinguishes the fabric from the other two).
10-20% of the mineral grains have yellow, white and orange coatings, 15µm (mostly <10µm)

**10096**
3 Fabrics: Context 2104, 2105 and areas of disturbance including earthworm channels

**2104**
**Microstructure:** Predominantly spongy, with areas of intergrain microaggregate/crumb structure.
**Porosity**
Variable: 25-40%. 5-10% channels, 25-35% vughs.
Coarse fraction

| | |
|---|---|
| Silt | 5-10% (c. 5%) |
| V. fine sand | 2-5% (c. 5%) |
| Fine sand | 10-15% |
| Medium sand | 15-25% |
| Coarse sand | 0.5-2% |

Quartz 10-20% rounded to angular, mostly sub-rounded and sub-angular.
Lithic clasts 15-25% dominantly rounded and sub-rounded
Other, including hornblende and feldspars <2%
Shell: v. rare—only one fragment. Becomes more common (0.5-2%) in the disturbed area of the context, on the right side of the slide.
Bone: v. rare.
**Fine fabric**
PPL: 7.5YR 5/4 (brown). 5YR ¾ dark reddish brown (in what appears to be an earthworm channel). 7.5YR ¾ (dark brown)
OIL: 7.5YR 7/6 reddish yellow, 5YR 6/6 reddish yellow.
Speckled. Moderate birefringence.
**Coarse organic**
0.5-2% charcoal, including fragments with mineral grains. Fragments are up to 800 µm but are predominantly <400 µm. There is one 1400µm blackened fragment (under OIL), red and black under PPL, with many cracks.
**Fine organic:**
v. rare phytoliths, 5-10% rubified clay-sized flecks in the fine fabric.
**Groundmass:** porphyric
**Pedofeatures**
Yellow and white coatings <10 µm on % of the mineral grains.
Fabric is total excremental: 5-10% porous and very porous and 20-30% dense and very dense excrement.
5-10% glassy red material in the fine fabric
<5% diffuse amorphous organo-mineral

**10096, Context 2105**
**Microstructure**: intergrain microaggregate, but grains are partly coated with fine fabric.
**Porosity**: 40-50%, simple and complex packing voids
Coarse fraction

| | |
|---|---|
| Silt | 0.5-2% |
| V. fine sand | 0.5-2% |
| Fine sand | 10-20% |
| Medium sand | 25-35% |
| Coarse sand | 5-10% |

Quartz 10-20% rounded to angular
Lithic clasts 15-25%
Other, including hornblende and feldspars 0.5-2%. Biotite? Brown rod-shaped crystals with pleochrism.
Bone: v. rare
Shell: none apparent, although it's in the adjacent, intermixed Fabric 3.
**Fine fabric**
PPL: 5YR 3/4 (dark reddish brown) to 7.5YR 3.4 (dark brown)
OIL: 7.5YR 6/6 (reddish yellow) and 7.5YR 8/6 (also reddish yellow)
Speckled. Low birefringence.
**Coarse organic**
c. 2% charcoal (0.5-2%) including fragments with mineral material. Dark red material with mineral grains may also be organic.
**Fine organic**: v. rare phytoliths, v. rare possible pollen. Rare rubified clay-sized flecks. V. rare single cells—6 in one cluster, unconnected, each c. 75μm in diameter.
**Groundmass**: predominantly chitonic, with small aggregates making it also partly enaulic.
**Pedofeatures**
V. rare diffuse organo-mineral material
Most of the mineral grains (>50%) are coated in fine fabric. Some of this material is yellow/white in XPL, forming yellow and white coatings up to c. 25μm.
5-10% porous and v. porous excrement
5-10% dense excrement

**10096 Fabric 3**
The left side of the slide is very disturbed. Fabric 3 is derived from 2105 but also has large channels (c. 4mm wide) filled by dense complete material. This material also occurs in areas of fabric which are not clearly channels in the area of disturbance.
**Microstructure:** Complex; areas of dense fine fabric have a crack structure, with a predominant intergrain microaggregate structure.
**Porosity**: 50-60% overall. V. dominant complex packing voids. Coarse fraction is similar to 2105.

| | |
|---|---|
| Silt | 0.5-2% |
| V. fine sand | 2-5% |
| Fine sand | 5-10% |
| Medium sand | 10-20% |
| Coarse sand | 0.5-2% |

**Fine fabric**
PPL 2.5YR 2.5/3 (dark reddish brown)
OIL 2.5YR 5/6 (red)
Speckled. Low birefringence.
**Coarse organic**
2-5% charcoal, including fragments with mineral grains
0.5-2% shell, but concentrated in clusters, especially at the base of the slide.
Rare bone, some poorly preserved, some well preserved. Sharp edged frags when viewed at higher magnifications seem to be decaying at the edges.
0.5-2% reddened fibrous material—bright red in PPL, brown in OIL
V. rare parenchymatic tissues.
**Fine organic**
V. rare phytoliths
V. rare single cells, pos. pollen
2-5% rubified clay-size flecks
**Groundmass**: Porphyric in areas of dense fabric. Chitonic where fine fabric is sparse.

**Pedofeatures**
Discontinuous yellow and white coatings up to 25 μm thick on 2-5% of the mineral grains
Shell decaying slightly at the edges but looks fairly well preserved.
5-15% porous and v. porous excrement
15-25% dense and v. dense excrement
0.5-2% diffuse amorphous organo-mineral material; v. rare nodules

**10097**
**Context 2104**
**Microstructure**: spongy
**Porosity**: 40-50%. V. dominant vughs. V. few channels and cracks.
**Coarse component**: 30-40%

| | |
|---|---|
| Silt | 2-5% |
| V. fine sand | 2-5% |
| Fine sand | 10-20% |
| Medium sand | 10-20% |
| Coarse sand | 2-5% |

10-20% of the slide is quartz
10-20% lithic clasts
<2% shell
Other, including feldspars (microcline, plagioclase)
V. rare bone
V. rare rubified mineral grains
Lithic clasts are dominantly rounded and subrounded. Quartz is rounded to angular.
**Fine fabric**: 20-30%
PPL: 2.5YR 2.5/3, dark reddish brown.
OIL: 5YR 5/6 yellowish red
Speckled. Moderate birefringence.
Coarse organic
<2% charcoal, including charred material with mineral grains.
V. rare plant organs and parenchymatic tissues
Fine organic
V. rare phytoliths
**Groundmass**: close porphyric
**Pedofeatures**
5-15 % porous mammilated excrement
30-50% dense mammilated excrement
V. rare nodules of organo-mineral material with diffuse edges.
<2% diffuse amorphous organo-mineral material

**10098**
**Microstructure**: c. 95% of the slide is intergrain microaggregate. 2-5% areas of denser fabric with a subangular blocky structure
**Porosity**: 35-50%
V. dominant complex packing voids. Areas of denser fabric make up 2-5% of the slide—these areas have planar voids separating subangular blocky aggregates. c. 5% channels.
**Coarse Fraction**: 50-60%
10-20% of the slide quartz and compound quartz
10-20% lithic clasts
5-15% shell
V. rare bone
<2% other, including hornblende, feldspars (microcline, plagioclase)
V. rare rubified mineral grains
Quartz is rounded to angular: lithic clasts are rounded and subrounded

| | |
|---|---|
| Silt | <2% |
| V. fine sand | 2-5% |
| Fine sand | 5-10% |
| Medium sand | 15-30% |
| Coarse sand | 2-5% |

**Fine fabric**

PPL 2.5YR 3/6 dark red
OIL 7.5YR 4/4 brown
Low birefringence. Speckled
**Coarse organic**
V. rare parenchymatic tissues
2 fragments of fibrous red material with 5-10% mica. Glassy yellow material in voids and in material itself. Also a similar fibrous red fragment but without mica (contains 1 grain of sandstone, i.e. 0.5-2% mineral). Fibrous red frags make up 0.5-2% of the slide. Some look to be completely made up of red pellets. Rare charcoal, including fragments with mineral grains.
**Fine organic**
Small area of bright orange fine fabric (OIL); possible ash? Also one very distinct bright orange area with mineral grains, which looks identical to CG4 burnt turf reference slide, especially the 800°C slide (although there are some bright frags in the 400°C slide. This fragment looks blackish brown under PPL.
V. rare diatoms and phytoliths.
**Groundmass:** enaulic
**Pedofeatures**
Excremental: 5-15% porous and very porous. 5-10% dense and v. dense. One large channel c. 1mm wide, containing v. porous mammilated excrement, loose continuous to loose discontinuous.
Very rare coatings on grains, <15μm, discontinuous.
Very rare earthworm/slug granules.
0.5-2% amorphous organo-mineral, mostly diffuse, some nodules.

**10099**
**Structure:** Intergrain microaggregate. <2% denser fabric with a subangular blocky structure.
**Porosity:** 40-50%
V. dominant complex packing voids; v. rare cracks (in areas of denser fabric). Rare channels.
**Coarse component:** 40-50%
Quartz 10-20% of the slide. Lithic clasts 10-20%. Shell (slightly weathered) 10-20%. V. rare bone, including possible fish bone?<2% other, including hornblende, feldspar. V rare earthworm/slug granules. Quartz is rounded to angular, but dominantly rounded and sub-rounded (this is unusual on this site). Lithic clasts are rounded to angular, dominantly rounded and subrounded. Very rare rubified mineral.

| | |
|---|---|
| Silt | 0.5-2% |
| V. fine sand | 2-5% |
| Fine sand | 5-10% |
| Medium sand | 25-35% |
| Coarse sand | 5-10% (this size fraction is mostly shell) |

**Fine fabric**
PPL: 5YR 3/4
OIL: 5YR 4/4 reddish brown.
Speckled. Low birefringence.
**Coarse organic**
V. rare charcoal
2-5% red fibrous material, dark red brown under OIL. Some are v. sharp edged and crazed with cracks.
V. rare parenchymatic tissues
**Fine organic**
v. rare pollen/spores, v. rare phytoliths
**Groundmass:** enaulic
**Pedofeatures:**
5-10% porous and v. porous mammilated excrement
5-10% dense and v. dense mammilated excrement
Fabric appears to be total excremental.
V. rare discontinuous coatings on grains, <15μm thick

**10100**
**Context 2101**
Notes: v. red fine fabric—like the kaleyard at Bragasetter—any other similarities? Lots of added peat (high LOI)? Lots of unburnt peat, as in the kaleyard.

25-35% mineral, porosity 50-60%, fine fabric 10-25%
**Microstructure:** complex: 1) intergrain microaggregate and 2) subangular blocky
**Porosity:** 50-60%, including 30-40% complex packing voids, 10-20% channels, <2% planar voids
Coarse fraction

| | |
|---|---|
| Silt | 2-5% |
| V. fine sand | 2-5% |
| Fine sand | 2-5% |
| Medium sand | 10-20% |
| Coarse sand | 2-5% |

Quartz 5-15%, rounded to angular
Lithic clasts 10-20%
Other 2-5%, including hornblende, feldspars
Bone v. rare. Small frags <500μm. Bone is in varying degrees of preservation—mostly good.
Shell 5-15% only slight decay around the edges
**Fine fabric**
PPL: 2.5YR 3/6 (dark red) to 5YR 4/6 (yellowish red)
OIL: 5YR 5/6 (yellowish red)
Speckled. Low birefringence.
**Coarse organic**
2-5% fibrous red material. Some frags have v. rare mineral grains (silt size quartz and micas). Some are cracked. Several frags contain spherical looking clusters of brown cells (fungal spores?). One contains a diatom.
0.5-2% charcoal
2-5% parenchymatic tissues
One plant organ fragment
Rectangular red frags, c. 150-170μm, in a loose cluster, possibly organic. Not like the usual red nodules. 10R 5/8 and 4/8 (red).
**Fine organic**
V. rare single cells, c. 160Um, brown wall end empty contents or frags of yellow or brown cell contents. These also occur in the fibrous red frags.
V. rare phytoliths
V. rare pollen in fibrous red frags
A diatom was found in a fibrous red frag
**Groundmass:** dominantly porphyric, bordering on and with areas of enaulic. Fine fabric is sparse, making up only 10-25% of the slide.
**Pedofeatures**
2-5% organo-mineral, dominantly irregular nodules with clear or diffuse edges
5-10% of the grains have very discontinuous yellow or white coatings up to c. 25μm thick
10-15% of the slide is porous and v. porous excrement
10-15% dense and v. dense excrement

**10101**
Mineral 30-40%, fine fabric 20-30%, porosity 40-50%
**Microstructure:** very complex. Spongy, with channels and chambers and sub-angular blocky areas
**Porosity:** 40-50%, including 10-20% chambers, 5-10% channels, 2-5% cracks, 5-10% vughs, 10-20% complex packing voids.
**Coarse fraction**

| | |
|---|---|
| Silt | 0.5-2% |
| V. fine sand | 2-5% |
| Fine sand | 5-10% |
| Medium sand | 10-20% |
| Coarse sand | 5-10% |

Quartz 15-25%, rounded to angular, mostly sub-angular
Lithic clasts (possibly rhyolite) 15-25%, rounded to sub-angular
Other, inc. feldspars, hornblende, amphibole <2%
Bone v. rare, small fragments <400μm. Very rare frags of pos. bone which look dissolved rather than decayed—mammilate edges, yellow and red, isotropic, speckled.
Shell 5-15% (c. 10%).
V. rare earthworm/slug granules
V. rare (a single 4mm frag) half-burnt coal

**Fine fabric**
PPL: 5YR 4/6 (yellowish red), 2.5YR 3/6 (dark red)
OIL: 5YR 4/4 reddish brown
Speckled. Low birefringence.
**Coarse organic**
Rare charcoal—some only partially burnt and still red around the voids.
Rare red and glassy yellow fibrous or pellet textured material, sometimes forming cracked nodules, some with mineral material. These can be diffuse, or can be nodular.
5-10% parenchymatic tissues and organ residues—root cross sections and longitudinal sections in channels
V. rare cell clusters, with hundreds of cells c. 10μm in diameter. These resemble fungal spores but they are bigger and aren't contained within a cell wall.
**Fine organic**
Single cell 160μm, thick red wall and red contents, decaying
V. rare fungal spores (these also occur in the red fibrous material)
V. rare single cells c. 80μm, yellow walled, no contents in some, some with pale yellow contents. These occur individually or in unattached clusters.
V. rare phytoliths.
V. rare rubified clay-sized particles.
Looked for diatoms but couldn't find any.
**Groundmass**: enaulic, with areas of porphyric
**Pedofeatures**
V. rare thin yellow and white coatings on grains and on shell (<25μm thick). Shell shows signs of decalcification—degraded around the edges
2-5% amorphous organo-mineral material, brown in OIL, red and glassy yellow in PPL. Forms coatings on rare mineral grains.
Channels and passage features. Several channels are filled by dense continuous fine fabric, slightly redder brown than the surrounding fine fabric.
5-10% of the fine fabric is porous and very porous excrement (mammilated aggregates). 15-20% is dense excrement with mammilated edges.

**10103**
**Microstructure**: spongy, with c. 20% channels. Complex packing voids in areas of intergrain microaggregate (<5%)
**Porosity**: 40-50%. Dominant vughs, frequent channels.
**Coarse fraction**: 20-30%.
Quartz: 10-20% of the slide, rounded to angular. Lithic clasts 10-15%, rounded to subrounded. Rare feldspars (microcline, plagioclase). Rare mica, v. rare hornblende. V. rare shell, v. rare bone, v. rare rubified material.

| | |
|---|---|
| Silt | 2-5% |
| V. fine sand | 2-5% |
| Fine sand | 5-10% |
| Medium sand | 10-20% |
| Coarse sand | 5-10% |

**Fine fabric**
PPL: 2.5YR 3/4 to 2.5/4 dark reddish brown.
OIL: 2.5YR 6/8 light red (to bright orange)
Low to medium birefringence. Speckled.
**Coarse organic**
2-5% charcoal and tarry fragments. V. rare fibrous material (more like red pellets strung together) (iron replacement?)
V. rare plant tissues
**Fine organic**
Areas of the fine fabric look ash-like under OIL. Fine fabric probably gets its colour from burnt turf/peat.
V. rare pollen and phytoliths.
**Groundmass**: porphyric (both open and close)
**Pedofeatures**
Excremental: Fabric is total excremental. Dominant fabric is porous. Loose continuous porous and v. porous excrement fills two of the major channels.

Textural: V. rare, thin (<10μm) coatings on grains (XPL: yellow and white). One red coating, also visible in PPL, c. 15μm thick. Slight darkening around the edges of one channel—almost a sort of silt hypocoating.
Depletion: none apparent.
Amorphous and cryptocrystalline: 0.5-2% amorphous organo-mineral, diffuse, with some sharp edged nodules.

**10106**
**Microstructure:** complex. Spongy and intergrain micro-aggregate.
**Porosity:** 50-60% vughs, complex packing voids, channels.
Coarse fraction

| | |
|---|---|
| Silt | 2-5% |
| v. fine sand | 2-5% |
| fine sand | 2-5% |
| medium sand | 10-20% |
| coarse sand | 5-10% |

Quartz and compound quartz grains: 10-20%. Rounded to angular
Lithic clasts: 10-20%. Rounded to sub-angular, mostly rounded
Feldspars: <2%
Bone: 0.5-2%. Well preserved and poorly preserved fragments.
Shell: occurs in the upper right quarter of the slide. Shell makes up 2-5% of the slide in this area but does not occur in the lower half of the slide, or on the left side. Shell is slightly decayed.
Other: hornblende (v. rare), micas 2-5%
**Fine fabric**
PPL: 5YR 3/4 dark reddish brown
OIL: 2.5YR 6/8 light red
Low birefringence. Speckled.
**Coarse organic**
2-5% charred material.
V. rare parenchymatic tissue- just one fragment in a channel.
**Fine organic**
V. rare phytoliths—but slightly more than in most of the other slides.
**Groundmass:** close porphyric
**Pedofeatures:**
5-10% diffuse amorphous organo-mineral in the lower half of the slide. 0.5-2% in the upper part of the slide. Accumulations of red material permeate the charred material as well as the fine fabric. This grades into yellow glassy material. Red material makes up 2-5% of the slide. Iron accumulations also forming on bone. The dominant fabric is porous excrement; dense and very dense excrement make up c. 2-5% of the slide.
V. rare earthworm/slug granules.
V. rare reddish orange coatings on grains, up to 25 μm thick.
V. thin yellow and white coatings <10μm on v. rare grains.
Red coating on (?)sandstone, visible only in PPL, lower left corner. One side of this stone is red (burnt?) under OIL.

**10109**
**Microstructure:** spongy
**Porosity:** 30-40%. 5-10% channels, v. dominant vughs.
Coarse fraction

| | |
|---|---|
| Silt | 2-5% |
| v. fine sand | 5-10% |
| fine sand | 5-10% |
| medium sand | 10-20% |
| coarse sand | 2-5% |

Quartz 15-25%. Rounded to angular, mostly sub-rounded and sub-angular.
Lithic clasts: 15-25%, rounded and sub-rounded.
Other: <2%, inc. feldspars, hornblende.
Shell: none.
Bone: v. rare. Both well preserved frags with fairly sharp edges and decaying frags.

**Fine fabric**
PPL: 5YR 4/6 to 4/4 yellowish red to reddish brown
OIL: 10YR 7/6 (yellow), 7.5YR 5/4 (brown) and bright orange.
Speckled. Moderate birefringence.
**Coarse organic**
10-15% charred material (large fragments contain mineral grains) (The large frags look identical to the large blackened frags in the Corrigal peat ash)
**Fine organic**
V. rare phytoliths, v. rare diatoms. Single cells with orange walls and partially filled with pale yellow material (3 in a cluster in the lower left corner)
**Groundmass**: close porphyric
**Pedofeatures**
Amorphous organo-mineral 2-5%, inc. diffuse-edged nodules
V. rare, v. thin (<5μm) discontinuous yellow coatings on mineral grains. Only occurs on a few grains.
Fabric is rounded and mammilated on the edges and may be v. dense excremental.
Area of paler brown fabric with frequent glassy orange material. One v. well preserved diatom in this material.

**10110**
**Contexts 1731** (lower: orange brown) and **1730** (upper: red)
**1730**
Mineral 20-30%, porosity 30-40%, fine fabric 30-40%
**Microstructure**: spongy
**Porosity**: 30-40%, including 2-5% channels and c. 30% vughs
**Coarse fraction**

| | |
|---|---|
| Silt | 2-5% |
| V. fine sand | 2-5% |
| Fine sand | 2-5% |
| Medium sand | 10-20% |
| Coarse sand | 2-5% |

Quartz 10-15% of the slide
Lithic clasts 10-15%
Other, including feldspars and hornblende <2%
Bone: very rare
Shell: none
**Fine fabric**
PPL: black and 7.5YR 3/4 (dark brown), 5YR 4/6 yellowish red
OIL: 2.5YR 6/8 (light red), 10R 5.8 (red) and bright orange.
Speckled. Low birefringence
**Coarse organic**
5-15% charred material, inc. charred fibrous fabric with mineral grains and partially burnt material.
C. 20-30% of the slide is blackened material under PPL, red around the voids.
**Fine organic**
V. rare single cells (yellow walled and c. 80 μm across. Some have yellow contents) in an unattached cluster, set in speckled yellow fabric the colour of bone.
V. rare diatoms.
**Groundmass**: porphyric
**Pedofeatures**
V. rare, v. thin clay coatings <5μm
Rare amorphous organo-mineral
1 bright red nodule (PPL) with bright red, highly birefringent flecks (XPL). Irregular shape, fairly sharp edges

**Context 1731** (lower)
Mineral 20-35%, fine fabric 20-30%, porosity 50-60%
**Microstructure**: spongy/intergrain microaggregate
**Porosity** 50-60%, including 20-35% vughs and 15-25% complex packing voids
**Coarse fraction**

| | |
|---|---|
| Silt | 2-5% |

V. fine sand 2-5%
Medium sand 10-20%
Coarse sand 5-10%
Quartz: 10-20%
Lithic: clasts 15-25%
Other: <5%, including lithic clasts, feldspars, v. rare hornblende
Bone: v. rare
Shell: none
**Fine fabric**
OIL: 5YR (reddish brown), 5YR 5/6 (yellowish red), 2-5% bright orange rubified fabric and minerals
PPL: Predominantly black, with 7.5YR 4/6 (strong brown) and 7.5YR 3/4 (dark brown), 5YR 3/4 (dark reddish brown). Speckled. Low birefringence.
**Coarse organic**
10-20% reflective black charred material (OIL). Under PPL much of this material is red around the voids.
One large (c. 4.8mm) charcoal fragment; regular pattern of parallel cells
**Fine organic**
V. rare diatoms, V. rare pos. pollen, 0.5-2% rubified material
**Groundmass**: enaulic/porphyric
**Pedofeatures**
2-5% amorphous organo-mineral
V. rare, v. thin (<5µm) yellow and white coatings on grains (<5% of the grains)

**10111** Context 1730 (red)
**Fabric 1**
**Microstructure**: spongy.
**Porosity**: 20-30%. 20-25% of the slide is vughs, <5% channels, <2% cracks
Coarse fraction
Silt <2%
V. fine sand <2%
Fine sand 2-5%
Medium sand 5-10%
Coarse sand 2-5%
Quartz and compound quartz: 2-5% of the slide. Sub-rounded to angular.
Lithic clasts: 5-10%. Rounded and sub-rounded.
Other, inc. hornblende and feldspar
Shell: v. rare—only saw one
Bone: 0.5-2%
**Fine fabric**
PPL: black
OIL: bright orange—around 10R 6/8 (light red) and 5/8 (red), but more orange.
V. low birefringence. Fabric is entirely, apart from channel infill, composed of bright orange (OIL) material.
**Coarse organic**
2-5% reflective (OIL) black material (i.e. charred material)
**Fine organic**
v. rare diatoms, v. rare pollen
**Groundmass**: Mostly open porphyric. Close porphyric in areas, and in the channel infill (Fabric 3).
**Pedofeatures**
Discontinuous yellow coatings up to 15µm thick on v. rare grains.
No obvious excremental fabric, apart from the large (2mm wide) channel with a distinct brown, unburnt fill (Fabric 3).

**Fabric 2**
Small area of fabric with 5-10% phytoliths.
PPL: 7.5YR 5/6-4/6 (strong brown)
OIL: 2.5Y 6/4 (light yellowish brown)

**Fabric 3**

Channel infill. Much more concentrated mineral fraction, making up 30-40% of the slide (same composition as Fabric 1: quartz, lithic clasts, feldspars). Fine fabric is dark brown in PPL (7.5YR ¾) and reddish brown (5YR 5/4) under OIL- v. distinct from the bright orange material of the dominant fabric. 2-5% charcoal and 2-5% bright orange flecks and small areas. Infilling is dense incomplete.

**Fabric 4**

Second channel infill, below Fabric 3. Material looks like v. decayed bone but under XPL the material can be seen to contain around 5-10% micas—also c. 2% quartz and lithic clasts. Also includes hornblende. Rare pollen (0.5-2%). Fine fabric is v. flat looking, not really speckled. Yellow (10YR 7/6, PPL) and dark reddish brown (5YR 3/4) under OIL.

**10111** Context 1729 (brown)
**Microstructure:** spongy
**Porosity:** 30-40%
5-10% channels
25-30% vughs and complex packing voids
Coarse fraction

| | |
|---|---|
| Silt | 2-5% |
| V. fine sand | 2-5% |
| Fine sand | 2-5% |
| Medium sand | 15-25% |
| Coarse sand | 5-10% |

10-20% quartz and compound quartz. Rounded to angular, dominantly sub-angular and sub-rounded.
10-20% lithic clasts, rounded and sub-rounded.
<2% other, including feldspars and hornblende
V. rare bone. No shell.
**Fine fabric**
PPL: black and brown to strong brown (7.5YR 4.4 to 4/6)
OIL: 5YR 6/6 reddish yellow—much paler than Context 1730. 5-15% is the bright orange of 1730.
Note: the material which is black under PPL is bright orange under OIL, apart from the charcoal.
Speckled. Low birefringence.
**Coarse organic**
5-15% charred material (reflective black under OIL)
black material (bright orange under OIL) with surviving cells—both cell walls and contents are preserved (v. rare).
**Fine organic**
v. rare pollen, phytoliths, diatoms
**Groundmass:** close porphyric
**Pedofeatures**
V. rare white and yellow coatings on mineral grains, <10μm thick, discontinuous.
Rare amorphous organo-mineral material (diffuse)
Fabric isn't clearly excremental.

**10112**
**Context 1729** (midden)
Mineral 20-40% (c. 30%), porosity 50-60%, fine fabric 20-30%
**Microstructure:** spongy
**Porosity:** c. 50%, including 5-10% channels, 5-10% vughs, 30-40% complex packing voids
**Coarse mineral**

| | |
|---|---|
| Silt | 2-5% |
| V. fine sand | 2-5% |
| Fine sand | 5-10% |
| Medium sand | 10-20% |
| Coarse sand | 5-10% |

Quartz: 15-25%, rounded to angular, dominantly sub-angular
Lithic clasts: 5-10%
Other, including feldspars, hornblende 2-5%
Bone: v. rare
Shell: none

**Fine fabric**
PPL: 7.5YR 4/4 (brown), 7.5YR 5/4 (brown)
OIL: 7.5YR 6/4 to 6/6 (light brown to reddish yellow); 5YR 7/6 (reddish yellow)
Speckled. Low to medium birefringence.
**Coarse organic**
15-25% charred black (OIL) material, mostly containing mineral material. Rare fragments are made up of cells (wood)
**Fine organic**
V. rare pollen, diatoms, phytoliths. V. rare fungal spores. Some clusters of diatoms. V. rare single cells with yellow walls, up to c. 200μm
**Groundmass:** porphyric
**Pedofeatures:**
Rare discontinuous yellow, white and orange coatings on 10-20% of the mineral grains, mostly <25μm but noted up to 40 μm.
Fabric is mammilated in places and may be excremental but is not obviously so.
2-5% glassy yellow and red material (PPL), brown under OIL (amorphous organo-mineral material). V. rarely this coats mineral grains (bright orange coatings in OIL).

**10113**
**Context 1728** (midden)
Notes: 1 dominant fabric with variations; the fabric is a mix of charred peat and brown excremental soil. There is a layer (clearly a different context) of bright red fabric (OIL), red-brown under PPL, along the top of the slide. Passage feature down the right side of the slide, infilled with bright orange material in OIL (i.e. infilled with the same fabric as the overlying context).
Mineral 30-40%, porosity 30-40%, fine fabric 30-40%
**Microstructure:** spongy
**Porosity:** 30-40%, including 5-10% channels, c. 20% vughs, c. 10% complex packing voids.
**Coarse mineral**

| | |
|---|---|
| Silt | 5-10% |
| V. fine sand | 5-10% |
| Fine sand | 10-20% |
| Medium sand | 10-20% |
| Coarse sand | 5-10% |

Quartz: 15-25%, rounded to angular, mostly sub-rounded and sub-angular
Lithic clasts: 5-10%
Other: <2%, inc. feldspars, hornblende
Bone: v. rare
Shell: none
**Fine fabric**
OIL: 5YR 6/4 (light reddish brown), 10YR 8/8 and 7/6 (yellow)
PPL: 5YR 4/4 (reddish brown)
Speckled. Low birefringence.
**Coarse organic**
5-10% charred material (black in PPL and OIL); larger frags usually have mineral grains.
V. rare fibrous red material
V. rare charred plant organs—root sections?
Rare charred reddish frags with rod-shaped and circular cells (wood?)
**Fine organic**
V. rare single cells, c. 80 μm, yellow/orange walls and yellow contents. These occur in clusters.
V. rare pollen, phytoliths, diatoms (quite a few diatoms but still <0.5%)
Area of single brown cells (6-8μm each in dia); cluster is 700μm across.
**Groundmass:** close porphyric
**Pedofeatures**
Rare yellow, white and 2nd/3rd order material forming discontinuous coatings up to 40 μm thick.
2-5% amorphous organic and organo-mineral material, brown or red-brown under OIL, red or red-brown under PPL.
Excremental: Passage feature 1200-1600μm wide, with dense complete infill, 2.5YR 3/4 (dark reddish brown) in PPL and bright orange in OIL.
<2% of the slide is v. porous excrement
c. 30% (i.e. the remainder of the fine fabric) is porous to dense excrement.

**10114**
**Microstructure:** spongy
**Porosity:** 25-35%. 95% or more are vughs, with occasional (2-5%) channels.
**Coarse Component**
c. 40%
Quartz, compound quartz, lithic clasts. Grains are rounded to angular. Very rare bone.

| | |
|---|---|
| Silt | 2-5% |
| V. fine sand | 5-10% |
| Fine sand | 5-10% |
| Medium sand | 10-20% |
| Coarse sand | 5-10% |

**Fine fabric**
PPL: 5YR 4/4 to 4/6 (reddish brown to yellowish red) and 5YR ¾ (dark reddish brown)
OIL: 10R 6/8 light red. Bright red and orange.
Low birefringence. Speckled.
**Coarse organic**
10-20% charcoal and charred material
**Fine organic**
v. rare diatoms, v. rare phytoliths, v. rare pollen
**Groundmass:** close porphyric
**Pedofeatures**
Rare thin yellow coatings up to c. 25 μm thick on mineral grains

# APPENDIX 3: Phosphates, Loss on ignition and pH

1) Bragasetter (mgP per 1g soil)

| Area | Total P | Inorganic P | Organic P | Ptot/Pinorg. | %LOI | pH |
|---|---|---|---|---|---|---|
| K1.15 | 2.255 | 1.403 | 0.852 | 1.61 | 14.42 | 5.9 |
| K2.15 | 3.128 | 2.458 | 0.67 | 1.27 | 9.56 | 5.4 |
| K3.15 | 2.594 | 1.011 | 1.583 | 2.57 | 17.56 | 5.0 |
| K4.15 | 2.122 | 1.43 | 0.692 | 1.48 | 12.92 | 7.0 |
| K4.30 | 2.007 | 1.599 | 0.408 | 1.26 | 14.67 | 6.2 |
| K4.45 | 1.526 | 0.868 | 0.658 | 1.76 | 24.40 | 5.8 |
| K4.60 | 0.312 | 0.188 | 0.124 | 1.66 | 6.25 | 5.6 |
| K1.30B | 1.325 | 1.044 | 0.281 | 1.27 | 11.97 | 6.2 |
| K1.45 | 0.339 | 0.245 | 0.094 | 1.38 | 2.38 | 6.5 |
| R1.15 | 1.584 | 1.259 | 0.325 | 1.26 | 9.93 | 5.9 |
| R2.15 | 3.459 | 2.695 | 0.764 | 1.28 | 10.17 | 6.2 |
| R3.15 | 0.417 | 0.315 | 0.102 | 1.32 | 8.91 | 5.5 |
| R4.15 | 0.661 | 0 | 0.661 | 0 | 12.65 | 5.7 |
| R1.30 | 1.306 | 0.879 | 0.427 | 1.49 | 8.88 | 6.3 |
| R1.30A | 1.367 | 0.81 | 0.557 | 1.69 | 9.01 | 6.1 |
| R1.30B | 1.4 | 0.804 | 0.596 | 1.74 | 9.19 | 6.3 |
| R2.30 | 6.478 | 3.081 | 3.397 | 2.1 | 8.00 | 6.9 |
| R4.30 | 0.271 | 0.104 | 0.167 | 2.61 | 5.16 | 5.5 |
| R2.45 | 3.521 | 2.687 | 0.834 | 1.31 | 6.83 | 6.4 |
| R2.60 | 1.085 | 0.847 | 0.238 | 1.28 | 1.90 | 6.9 |
| R1.45 | 0.386 | 0.167 | 0.219 | 2.31 | 3.23 | 6.0 |
| R1.45A | 0.867 | 0.337 | 0.53 | 2.57 | 5.46 | 5.9 |
| G1.15 | 0.215 | 0.058 | 0.157 | 3.71 | 1.88 | 7.0 |
| G2.15 | 0.34 | 0 | 0.34 | 0 | 8.54 | 5.3 |
| G3.15 | 1.077 | 0.12 | 0.957 | 8.98 | 20.08 | 4.6 |
| G4.15 | 0.464 | 0 | 0.464 | 0 | 19.91 | 4.8 |
| G1.30 | 0.193 | 0.009 | 0.184 | 21.44 | 2.24 | 8.1 |
| P1.15 | 1.363 | 1.036 | 0.327 | 1.32 | 16.25 | 5.2 |
| P2.15 | 1.003 | 0.354 | 0.649 | 2.83 | 11.38 | 6.2 |
| P3.15 | 1.052 | 0.185 | 0.867 | 5.69 | 11.72 | 5.4 |
| P4.15 | 0.452 | 0.039 | 0.413 | 11.59 | 7.55 | 5.5 |
| Control1 | 0.284 | 0 | 0.284 | 0 | 21.04 | 4.7 |
| Control2 | 0.781 | 0.069 | 0.712 | 11.32 | 29.04 | 4.7 |
| Control3 | 0.337 | 0.015 | 0.322 | 22.47 | 36.75 | 4.4 |
| Control4 | 0.619 | 0.079 | 0.54 | 7.84 | 40.49 | 5.0 |
| Control5 | 0.461 | 0.05 | 0.411 | 9.22 | 26.33 | 5.0 |
| Control6 | 0.552 | 0.054 | 0.498 | 10.22 | 29.13 | 4.6 |
| Control7 | 0.476 | 0.231 | 0.245 | 2.06 | 58.38 | 4.6 |
| Byre floor | 7.54 | 7.28 | 0.26 | 1.04 | 43.40 | |
| Byre drain | 11.721 | 10.456 | 1.265 | 1.12 | 18.08 | |
| K1.15A | | | | | | 6.5 |
| K1.15B | | | | | | 6.0 |
| K1.30 | | | | | | 6.3 |
| K1.30A | | | | | | 6.2 |
| K2.30 | | | | | | 5.8 |
| K3.30 | | | | | | 5.0 |
| K1.45A | | | | | | 6.5 |
| K1.45B | | | | | | 6.4 |
| R1.15A | | | | | | 5.8 |
| R1.15B | | | | | | 6.0 |
| R1.45B | | | | | | 6.1 |
| G1.15A | | | | | | 7.2 |

| Area | Total P | Inorganic P | Organic P | Ptot/Pinorg. | %LOI | pH |
|---|---|---|---|---|---|---|
| G1.15B | | | | | | 6.5 |
| G1.30A | | | | | | 7.9 |
| G1.30B | | | | | | 8.4 |
| P1.15A | | | | | | 4.9 |
| P1.15B | | | | | | 5.0 |

2) *Scatness (mgP per 1g soil)*

| Site | Sample | Total P | Inorganic P | Organic P | Ptot/Pinorg. | %LOI | pH |
|---|---|---|---|---|---|---|---|
| Scatness | 10102 | 4.022 | 4.022 | 0 | 1 | 4.29 | 7.4 |
| Scatness | 10105 | 8.634 | 7.122 | 1.512 | 1.212 | 4.52 | 7.9 |
| Scatness | 10108 | 10.715 | 9.675 | 1.04 | 1.107 | 4.11 | 8.1 |
| Scatness | 10115 | 3.304 | 2.982 | 0.322 | 1.108 | 3.97 | 8 |
| Scatness | 10116 | 2.789 | 2.274 | 0.515 | 1.226 | 4.37 | 8.2 |
| Scatness | 10117 | 3.406 | 3.285 | 0.121 | 1.037 | 2.85 | 8.3 |
| Scatness | 10118 | 3.594 | 3.23 | 0.364 | 1.113 | 7.87 | 8 |
| Scatness | 10119 | 2.624 | 2.469 | 0.155 | 1.063 | 3.56 | 8.3 |
| Scatness | 10120 | 2.734 | 2.547 | 0.187 | 1.073 | 0.91 | 8.2 |
| Scatness | 10121 | 6.912 | 6.317 | 0.595 | 1.094 | 2.96 | 8 |
| Scatness | 10122 | 8.02 | 8.02 | 0 | 1 | 3.79 | 8 |
| Scatness | 10123 | 3.065 | 1.811 | 1.254 | 1.692 | 1.01 | 8.1 |
| Scatness | 10124 | 7.965 | 7.694 | 0.271 | 1.035 | 2.86 | 7.2 |
| Scatness | 10125 | 7.309 | 5.812 | 1.497 | 1.258 | 2.34 | 7.6 |
| Scatness | 10126 | 5.597 | 5.421 | 0.176 | 1.032 | 2.55 | 7.7 |
| Scatness | 10127 | 2.151 | 2.151 | 0 | 1 | 1.82 | 7.9 |
| Scatness | 10128 | 4.408 | 4.104 | 0.304 | 1.074 | 4.08 | 8.3 |
| Scatness | 10129 | 2.706 | 1.355 | 1.351 | 1.997 | 3.96 | 8.4 |
| Scatness | 10130 | 1.732 | 0.869 | 0.863 | 1.993 | 6.21 | 7.8 |
| Scatness | 10131 | 1.025 | 0.497 | 0.528 | 2.062 | 5.38 | 8 |
| Scat Ness | Control | 0.207 | 0.123 | 0.084 | 1.683 | 14.56 | 6.1 |
| Toab | turf | 0.248 | 0.144 | 0.104 | 1.722 | 10.44 | 6.4 |
| Toab | subsoil | 0.145 | 0.113 | 0.032 | 1.283 | ------ | 6.4 |
| Hestingott | | 0.516 | 0.516 | 0 | 1 | 5.05 | 5.3 |

3) Tofts Ness (mgP per 0.05g soil)

| Sample | Total | Inorganic | Organic | P ratio | %LOI | pH |
|---|---|---|---|---|---|---|
| 200 | 1.646 | 0.326 | 1.32 | 5.05 | 3.50 | 7.7 |
| 201 | 1.358 | 0.226 | 1.132 | 6.01 | 4.93 | 8.1 |
| 202 | 0.733 | 0.238 | 0.495 | 3.08 | 4.01 | 8.2 |
| 203 | 0.247 | 0 | 0.254 | 0.00 | 0.67 | 8.1 |
| 204 | 1.306 | 0.174 | 1.132 | 7.51 | 4.49 | 8.2 |
| 205 | 0.409 | 0.05 | 0.359 | 8.18 | 2.42 | 8.3 |
| 206 | 1.944 | 0.012 | 1.932 | 162.00 | 5.08 | 8.1 |
| 207 | 1.78 | 0 | 1.826 | 0.00 | 2.44 | 8.2 |
| 208 | 0.848 | 0.017 | 0.831 | 49.88 | 1.74 | 7.8 |
| 209 | 0.51 | 0.038 | 0.472 | 13.42 | 4.10 | 8.1 |
| 210 | 1.996 | 0.124 | 1.872 | 16.10 | 4.75 | 8.1 |
| 211 | 3.923 | 0.464 | 3.459 | 8.45 | 4.94 | 8.1 |
| 212 | 1.825 | 0.107 | 1.718 | 17.06 | 4.55 | 8.2 |
| 213 | 1.753 | 0 | 1.825 | 0.00 | 3.99 | 8.2 |
| 214 | 0.482 | 0 | 0.505 | 0.00 | 2.60 | 8.3 |
| 215 | 0.787 | 0.087 | 0.7 | 9.05 | 6.28 | 7.8 |
| 216 | 1.365 | 0.053 | 1.312 | 25.75 | 4.37 | 8.1 |
| 217 | 4.288 | 0.415 | 3.873 | 10.33 | 4.26 | 7.8 |
| 218 | 2.965 | 0.21 | 2.755 | 14.12 | 4.47 | 7.6 |
| 219 | 4.12 | 0.088 | 4.032 | 46.82 | 5.13 | 7.7 |
| 220 | 5.142 | 0.523 | 4.619 | 9.83 | 5.33 | 7.6 |
| 221 | 2.466 | 0.115 | 2.351 | 21.44 | 3.48 | 7.6 |
| 222 | 2.857 | 0.474 | 2.383 | 6.03 | 5.43 | 7.8 |
| 223 | 4.956 | 0.384 | 4.572 | 12.91 | 6.19 | 7.6 |
| 224 | 4.985 | 0.203 | 4.782 | 24.56 | 5.51 | 7.7 |
| 225 | 4.863 | 0.236 | 4.627 | 20.61 | 4.68 | 7.6 |
| 226 | 3.139 | 0.248 | 2.891 | 12.66 | 3.95 | 7.6 |
| 227 | 2.671 | 0 | 2.897 | 0.00 | 3.77 | 7.6 |
| 228 | 0.049 | 0.016 | 0.033 | 3.06 | 1.28 | 8.4 |
| 229 | 1.175 | 0.398 | 0.777 | 2.95 | 4.14 | 8.2 |
| 230 | 0.685 | 0.18 | 0.505 | 3.81 | 11.60 | 8.2 |
| 231 | 0.752 | 0.251 | 0.501 | 3.00 | 13.50 | 8.2 |
| 232 | 0.752 | 0.639 | 0.113 | 1.18 | 10.15 | 8.7 |
| 233 | 0.355 | 0.192 | 0.163 | 1.85 | 23.55 | 8.2 |
| 234 | 0.171 | 0.133 | 0.038 | 1.29 | 18.18 | 7.6 |
| 235 | 0.084 | 0.067 | 0.017 | 1.25 | 18.46 | 7.6 |
| 236 | 0.184 | 0.163 | 0.021 | 1.13 | 38.02 | 7.6 |
| 237 | 1.268 | 0.316 | 0.952 | 4.01 | 5.92 | 7.9 |
| 238 | 0.803 | 0.197 | 0.606 | 4.08 | 20.63 | 8.2 |
| 239 | 0.632 | 0.346 | 0.286 | 1.83 | 17.21 | 8.1 |
| 240 | 0.06 | 0.026 | 0.034 | 2.31 | 19.25 | 8.2 |
| 241 | 0.363 | 0.094 | 0.269 | 3.86 | 21.29 | 8.1 |
| 242 | 0.747 | 0.068 | 0.679 | 10.99 | 13.80 | 8.0 |
| 243 | 0.461 | 0.047 | 0.414 | 9.81 | 5.24 | 7.4 |
| 244 | 0.192 | 0.094 | 0.098 | 2.04 | 32.91 | 8.0 |
| 245 | 0 | 0 | 0.004 | 0.00 | 16.47 | 8.1 |
| 246 | 0.388 | 0.096 | 0.292 | 4.04 | 15.58 | 8.0 |
| 247 | 0.677 | 0.379 | 0.298 | 1.79 | 10.54 | 7.37.6 |
| 248 | 0.497 | 0.326 | 0.171 | 1.52 | 7.42 | 8.07.3 |

| Sample | Total | Inorganic | Organic | P ratio | %LOI | pH |
|---|---|---|---|---|---|---|
| 249 | 0.828 | 0.239 | 0.589 | 3.46 | 4.65 | 8.0 |
| 250 | 0.458 | 0 | 0.567 | 0.00 | 13.54 | 8.5 |
| 251 | 1.321 | 0.471 | 0.85 | 2.80 | 10.64 | 8.4 |
| beach | 0 | 0 | 0 | 0.00 | | |
| seaweed | 0.404 | 0.355 | 0.049 | 1.14 | | |
| 204a | 1.442 | 0.282 | 1.16 | 5.11 | | |
| 204b | 1.268 | 0.172 | 1.096 | 7.37 | | |
| 204c | 1.369 | 0.174 | 1.195 | 7.87 | | |

## APPENDIX 4: Soil Magnetism

A4.1: Bragasetter magnetic data

| Area | depth | mass | xfd | SARM | sirm | sarm/mass | sarm/sirm |
|---|---|---|---|---|---|---|---|
| kale 1 | 15 | 1.05 | 9.6 | 0.86 | 9.56 | 0.82 | 0.09 |
| kale 2 | 15 | 0.55 | 9.78 | 0.57 | 5.7 | 1.04 | 0.1 |
| kale 3 | 15 | 0.46 | 8.7 | 0.46 | 4.6 | 1 | 0.1 |
| kale 4 | 15 | 1.26 | 9.8 | 1 | 12.5 | 0.79 | 0.08 |
| kale 4 | 30 | 1.3 | 9.78 | 1.16 | 14.5 | 0.89 | 0.08 |
| kale 4 | 45 | 0.86 | 9.71 | 0.75 | 8.33 | 0.87 | 0.09 |
| kale 4 | 60 | 0.06 | 8.54 | 0.03 | 0.43 | 0.5 | 0.07 |
| rig 1 | 15 | 0.74 | 11 | 0.64 | 7.11 | 0.86 | 0.09 |
| rig 2 | 15 | 1.26 | 9.6 | 1.22 | 13.6 | 0.97 | 0.09 |
| rig 3 | 15 | 0.09 | 7.56 | 0.06 | 0.86 | 0.67 | 0.07 |
| rig 4 | 15 | 0.13 | 8.36 | 0.09 | 1.5 | 0.69 | 0.06 |
| rig 1 | 30 | 0.78 | 10.3 | 0.61 | 7.63 | 0.78 | 0.08 |
| rig 2 | 30 | 1.27 | 8.68 | 1.35 | 13.5 | 1.06 | 0.1 |
| rig 4 | 30 | 0.08 | 6.31 | 0.04 | 1 | 0.5 | 0.04 |
| rig 1 | 45 | 0.12 | 9.54 | 0.08 | 0.89 | 0.67 | 0.09 |
| rig 2 | 45 | 1.34 | 8.24 | 1.19 | 11.9 | 0.89 | 0.1 |
| rig 2 | 60 | 0.18 | 8.2 | 0.16 | 1.45 | 0.89 | 0.11 |
| planti 1 | 15 | 0.33 | 6.99 | 0.29 | 5.8 | 0.88 | 0.05 |
| planti 2 | 15 | 0.43 | 9.39 | 0.36 | 4.5 | 0.84 | 0.08 |
| planti 3 | 15 | 0.32 | 9.09 | 0.23 | 3.29 | 0.72 | 0.07 |
| planti 4 | 15 | 0.32 | 5.77 | 0.17 | 4.25 | 0.53 | 0.04 |
| graze 1 | 15 | 1.1 | 4.94 | 0.39 | 13 | 0.36 | 0.03 |
| graze 2 | 15 | 0.34 | 5.63 | 0.13 | 4.33 | 0.38 | 0.03 |
| graze 3 | 15 | 0.03 | 3.39 | 0.01 | 0.25 | 0.33 | 0.04 |
| graze 4 | 15 | 0.25 | 8.01 | 0.09 | 1.13 | 0.36 | 0.08 |
| control 1 | 15 | 0.05 | 0 | 0.02 | 0.67 | 0.4 | 0.03 |
| control 3 | 15 | 0.16 | 6.9 | 0.05 | 1.25 | 0.31 | 0.04 |

A4.2 Tofts Ness magnetic data

| Sample | weight | mass | lf | hf | ARM99 | Demag40 | IRM60mt | IRMit | lf/mass | mass sus | *xfd* | SARM | sarm/sirm | sarm/sus |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 200 | 4.2 | 18.22 | 308 | 281 | 2619.5 | 396.2 | 182.3 | 216.3 | 16.9045 | 1.69045 | 8.766234 | 1.437706 | 0.006647 | 0.850487 |
| 201 | 4.2 | 17.5 | 412 | 377 | 2220.4 | 204.6 | 186 | 221.3 | 23.54286 | 2.354286 | 8.495146 | 1.2688 | 0.005733 | 0.538932 |
| 202 | 4.15 | 17.25 | 191 | 173 | 1299.3 | 131.9 | 89.1 | 104.9 | 11.07246 | 1.107246 | 9.424084 | 0.753217 | 0.00718 | 0.680262 |
| 203 | 4.2 | 21.17 | 10 | 10 | 52.8 | 19.2 | 3.6 | 16.2 | 0.472367 | 0.047237 | 0 | 0.024941 | 0.00154 | 0.528 |
| 204 | 4.15 | 17.97 | 428 | 393 | 2313.6 | 235.3 | 203.9 | 244.8 | 23.81747 | 2.381747 | 8.17757 | 1.287479 | 0.005259 | 0.540561 |
| 205 | 4.22 | 18.14 | 160 | 149 | 668.2 | 64 | 77 | 96.2 | 8.820287 | 0.882029 | 6.875 | 0.368357 | 0.003829 | 0.417625 |
| 206 | 4.16 | 16.69 | 1114 | 1046 | 2269.4 | 358.8 | 462.8 | 622.1 | 66.74655 | 6.674655 | 6.104129 | 1.359736 | 0.002186 | 0.203716 |
| 207 | 4.16 | 17.88 | 1447 | 1352 | 4166.7 | 447.2 | 789 | 1025.3 | 80.92841 | 8.092841 | 6.565308 | 2.330369 | 0.002273 | 0.287954 |
| 208 | 4.15 | 19.64 | 28 | 26 | 206.1 | 32.2 | 12.9 | 22.7 | 1.425662 | 0.142566 | 7.142857 | 0.104939 | 0.004623 | 0.736071 |
| 209 | 4.23 | 18.52 | 783 | 730 | 1944.7 | 344.5 | 297.1 | 412.2 | 42.27862 | 4.227862 | 6.768838 | 1.050054 | 0.002547 | 0.248365 |
| 210 | 4.23 | 16.65 | 1588 | 1495 | 3853.7 | 393.2 | 851.8 | 1130.3 | 95.37538 | 9.537538 | 5.856423 | 2.314535 | 0.002048 | 0.242676 |
| 211 | 4.29 | 16.59 | 2435 | 2296 | 5334 | 418.3 | 1290 | 1665 | 146.7752 | 14.67752 | 5.708419 | 3.21519 | 0.001931 | 0.219055 |
| 212 | 4.25 | 17.67 | 1282 | 1203 | 3170.8 | 371.1 | 600.4 | 757 | 72.55235 | 7.255235 | 6.162246 | 1.794454 | 0.00237 | 0.247332 |
| 213 | 4.28 | 17.9 | 852 | 793 | 3309.3 | 353.9 | 418.6 | 532.7 | 47.59777 | 4.759777 | 6.924883 | 1.848771 | 0.003471 | 0.388415 |
| 214 | 4.18 | 17.9 | 189 | 176 | 802.6 | 82.8 | 90.2 | 116.5 | 10.55866 | 1.055866 | 6.878307 | 0.44838 | 0.003849 | 0.424656 |
| 215 | 4.22 | 16.95 | 410 | 379 | 1813.8 | 324.5 | 169.5 | 217.2 | 24.18879 | 2.418879 | 7.560976 | 1.070088 | 0.004927 | 0.44239 |
| 216 | 4.35 | 17.62 | 1079 | 1009 | 2846.3 | 362.7 | 451 | 620.9 | 61.23723 | 6.123723 | 6.487488 | 1.61538 | 0.002602 | 0.263791 |
| 217 | 4.26 | 17.42 | 507 | 468 | 3342 | 319.3 | 297.3 | 353.6 | 29.10448 | 2.910448 | 7.692308 | 1.918485 | 0.005426 | 0.659172 |
| 218 | 4.24 | 16.91 | 1784 | 1652 | 7133.5 | 849.3 | 929 | 1121.1 | 105.4997 | 10.54997 | 7.399103 | 4.21851 | 0.003763 | 0.39986 |
| 219 | 4.25 | 16.07 | 1312 | 1216 | 5797.6 | 464.7 | 660.5 | 778.9 | 81.64281 | 8.164281 | 7.317073 | 3.607716 | 0.004632 | 0.44189 |
| 220 | 4.33 | 15.46 | 2382 | 2215 | 10211.7 | 688.1 | 1457.9 | 1720 | 154.075 | 15.4075 | 7.010915 | 6.605239 | 0.00384 | 0.428703 |
| 221 | 4.23 | 17.2 | 1468 | 1357 | 6190.8 | 751.1 | 760.9 | 917.3 | 85.34884 | 8.534884 | 7.561308 | 3.599302 | 0.003924 | 0.421717 |
| 222 | 4.21 | 15.83 | 1439 | 1318 | 8246.7 | 710.8 | 676.8 | 813.3 | 90.90335 | 9.090335 | 8.408617 | 5.209539 | 0.006405 | 0.573085 |
| 223 | 4.17 | 15.55 | 1806 | 1674 | 7636.4 | 564.4 | 930.9 | 1108.9 | 116.1415 | 11.61415 | 7.30897 | 4.910868 | 0.004429 | 0.422835 |
| 224 | 4.2 | 16.07 | 1837 | 1707 | 7021.2 | 758.8 | 935.8 | 1101.3 | 114.3124 | 11.43124 | 7.076756 | 4.369135 | 0.003967 | 0.38221 |
| 225 | 4.2 | 15.2 | 1880 | 1753 | 8217.6 | 527.4 | 1218 | 1464.3 | 123.6842 | 12.36842 | 6.755319 | 5.406316 | 0.003692 | 0.437106 |
| 226 | 4.15 | 16.72 | 1307 | 1211 | 6191.7 | 616.4 | 683 | 833.1 | 78.16986 | 7.816986 | 7.345065 | 3.70317 | 0.004445 | 0.473734 |
| 227 | 4.2 | 16.15 | 1562 | 1460 | 6798.7 | 867.9 | 988.6 | 1234.6 | 96.71827 | 9.671827 | 6.53009 | 4.209721 | 0.00341 | 0.435256 |
| 228 | 4.15 | 19.13 | 5 | 5 | 47.1 | 3.2 | 2.4 | 3.1 | 0.26137 | 0.026137 | 0 | 0.024621 | 0.007942 | 0.942 |
| 229 | 4.22 | 17.09 | 673 | 615 | 4420.3 | 383.6 | 310.7 | 365.9 | 39.37975 | 3.937975 | 8.618128 | 2.586483 | 0.007069 | 0.656805 |

| Sample | weight | mass | lf | hf | ARM99 | Demag40 | IRM60mt | IRMit | lf/mass | mass sus | *xfd* | SARM | sarm/sirm | sarm/sus |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 230 | 4.16 | 16.94 | 165 | 152 | 906.7 | 129.4 | 86.1 | 100.3 | 9.74026 | 0.974026 | 7.878788 | 0.535242 | 0.005336 | 0.549515 |
| 231 | 4.16 | 16.95 | 247 | 224 | 1408.7 | 136 | 109.8 | 128.8 | 14.57227 | 1.457227 | 9.311741 | 0.831091 | 0.006453 | 0.570324 |
| 232 | 4.15 | 18.66 | 1.5 | 1.4 | 9.6 | 3.5 | 0.4 | 0.8 | 0.080386 | 0.008039 | 6.666667 | 0.005145 | 0.006431 | 0.64 |
| 233 | 4.23 | 16.53 | 15 | 14 | 74.3 | 19 | 11.4 | 16.2 | 0.907441 | 0.090744 | 6.666667 | 0.044949 | 0.002775 | 0.495333 |
| 234 | 4.23 | 17.55 | 5.9 | 5.7 | 107.7 | 47.6 | 9.4 | 24.3 | 0.336182 | 0.033618 | 3.389831 | 0.061368 | 0.002525 | 1.825424 |
| 235 | 4.29 | 17.58 | 3.7 | 3.5 | 88.2 | 33.3 | 7 | 16.4 | 0.210466 | 0.021047 | 5.405405 | 0.050171 | 0.003059 | 2.383784 |
| 236 | 4.25 | 14.67 | 1.7 | 1.7 | 21.2 | 12.5 | 3.2 | 10 | 0.115883 | 0.011588 | 0 | 0.014451 | 0.001445 | 1.247059 |
| 237 | 4.28 | 16.5 | 400 | 366 | 3172 | 312.8 | 226 | 263.8 | 24.24242 | 2.424242 | 8.5 | 1.922424 | 0.007287 | 0.793 |
| 238 | 4.18 | 17.02 | 268 | 244 | 1847.8 | 202.1 | 133 | 158.5 | 15.74618 | 1.574618 | 8.955224 | 1.085664 | 0.00685 | 0.689478 |
| 239 | 4.22 | 16.14 | 90 | 83 | 432.6 | 68.9 | 43.4 | 52.6 | 5.576208 | 0.557621 | 7.777778 | 0.26803 | 0.005096 | 0.480667 |
| 240 | 4.35 | 18.55 | 0.5 | 0.5 | 10.7 | 2.8 | 0.5 | 1.1 | 0.026954 | 0.002695 | 0 | 0.005768 | 0.005244 | 2.14 |
| 241 | 4.26 | 17.71 | 87 | 80 | 482.4 | 69.7 | 39.6 | 51.4 | 4.912479 | 0.491248 | 8.045977 | 0.272388 | 0.005299 | 0.554483 |
| 242 | 4.24 | 16.54 | 300 | 274 | 1219.8 | 154.7 | 114.6 | 131.2 | 18.13785 | 1.813785 | 8.666667 | 0.737485 | 0.005621 | 0.4066 |
| 243 | 4.25 | 16.73 | 58 | 56 | 291.1 | 89.8 | 50.7 | 71.1 | 3.466826 | 0.346683 | 3.448276 | 0.173999 | 0.002447 | 0.501897 |
| 244 | 4.33 | 15.18 | 0.5 | 0.4 | 7 | 3 | 0.5 | 1.5 | 0.032938 | 0.003294 | 20 | 0.004611 | 0.003074 | 1.4 |
| 245 | 4.23 | 16.07 | 0.6 | 0.5 | 12.8 | 4 | 0.9 | 2 | 0.037337 | 0.003734 | 16.66667 | 0.007965 | 0.003983 | 2.133333 |
| 246 | 4.21 | 16.9 | 5.5 | 5.1 | 53.9 | 21.3 | 4.1 | 8.8 | 0.325444 | 0.032544 | 7.272727 | 0.031893 | 0.003624 | 0.98 |
| 247 | 4.17 | 15.07 | 18 | 17 | 125.3 | 32.5 | 11.4 | 19.1 | 1.194426 | 0.119443 | 5.555556 | 0.083145 | 0.004353 | 0.696111 |
| 248 | 4.2 | 16.47 | 8 | 8 | 135.4 | 65.3 | 9.1 | 19.8 | 0.485732 | 0.048573 | 0 | 0.08221 | 0.004152 | 1.6925 |
| 249 | 4.2 | 17.3 | 162 | 148 | 1649.8 | 185.5 | 111 | 132.9 | 9.364162 | 0.936416 | 8.641975 | 0.953642 | 0.007176 | 1.018395 |
| 250 | 4.15 | 17.94 | 115 | 104 | 880.3 | 89.6 | 61.3 | 71.2 | 6.410256 | 0.641026 | 9.565217 | 0.490691 | 0.006892 | 0.765478 |
| 251 | 4.2 | 16.54 | 192 | 177 | 897.6 | 151.1 | 97.1 | 116.6 | 11.60822 | 1.160822 | 7.8125 | 0.542684 | 0.004654 | 0.4675 |
| 252 | 4.15 | 15.38 | 613 | 561 | 3535.5 | 362 | 281.6 | 338.6 | 39.85696 | 3.985696 | 8.482871 | 2.298765 | 0.006789 | 0.576754 |
| 253 | 4.22 | 16.72 | 1041 | 969 | 3132.6 | 422.7 | 395.1 | 530.3 | 62.26077 | 6.226077 | 6.916427 | 1.873565 | 0.003533 | 0.300922 |
| 254 | 4.16 | 15.13 | 680 | 628 | 4604.5 | 622.8 | 399.5 | 474.5 | 44.94382 | 4.494382 | 7.647059 | 3.043291 | 0.006414 | 0.677132 |
| 255 | 4.16 | 15.75 | 2083 | 1927 | 9489.6 | 883.2 | 1089.5 | 1299.2 | 132.254 | 13.2254 | 7.489198 | 6.025143 | 0.004638 | 0.455574 |
| 256 | 4.15 | 16.33 | 1738 | 1609 | 7273.6 | 717.6 | 925.1 | 1112.2 | 106.4299 | 10.64299 | 7.422325 | 4.454133 | 0.004005 | 0.418504 |
| 257 | 4.23 | 16.39 | 1724 | 1596 | 6883 | 893.7 | 918.4 | 1100.1 | 105.1861 | 10.51861 | 7.424594 | 4.199512 | 0.003817 | 0.399246 |
| 258 | 4.23 | 16.52 | 1734 | 1605 | 7429 | 708 | 921.1 | 1105.3 | 104.9637 | 10.49637 | 7.439446 | 4.496973 | 0.004069 | 0.428431 |
| 259 | 4.29 | 16.86 | 1788 | 1655 | 7451.7 | 700.8 | 942 | 1131.8 | 106.0498 | 10.60498 | 7.438479 | 4.419751 | 0.003905 | 0.416762 |

## APPENDIX 5: Particle size distribution (μm)

### Bragasetter

| Area | Mean | Median | Skewness | Kurtosis |
|---|---|---|---|---|
| K1.15 | 146.8 | 102 | 5.5 | 36.8 |
| | 118 | 94.29 | 1.82 | 5.78 |
| K1.15A | 133 | 95.51 | 4.49 | 37.1 |
| | 125.7 | 88.48 | 4.77 | 40.2 |
| K2.15 | 129.8 | 103.4 | 1.84 | 5.42 |
| | 122.7 | 95.02 | 2.05 | 6.34 |
| | 117.6 | 89.79 | 2.04 | 6.07 |
| K3.15 | 150.7 | 127.1 | 2.72 | 15.9 |
| | 140.1 | 116.7 | 2.54 | 13.3 |
| | 133.7 | 110.8 | 2.51 | 13.7 |
| K4.15 | 139.2 | 107.3 | 2.12 | 8.59 |
| | 125.6 | 94.85 | 1.84 | 5 |
| | 121 | 89.07 | 1.99 | 5.94 |
| K1.30A | 153 | 118.2 | 2.48 | 12 |
| | 143 | 108.6 | 1.87 | 5.75 |
| | 137.8 | 102.2 | 2.09 | 7.18 |
| K1.30B | 156 | 117.4 | 1.68 | 4.03 |
| | 145.5 | 103.9 | 1.7 | 3.47 |
| K2.30 | 155.5 | 82.4 | 1.96 | 5.57 |
| | 109.4 | 76.79 | 2.03 | 6.01 |
| | 109.8 | 74.64 | 2.02 | 5.53 |
| K3.30 | 79.76 | 64.57 | 1.37 | 2.12 |
| | 78.14 | 63.43 | 1.37 | 2.18 |
| K4.30 | 160.7 | 118.3 | 1.31 | 1.58 |
| | 156.5 | 114.1 | 1.3 | 1.54 |
| | 154.5 | 111.5 | 1.34 | 1.72 |
| K4.45 | 172.1 | 140.8 | 1.94 | 8.29 |
| | 156.7 | 127.6 | 1.22 | 1.81 |
| | 146.9 | 116.8 | 1.45 | 3.01 |
| K4.60 | 75.8 | 46.16 | 2.52 | 9.86 |
| | 71.79 | 44.42 | 1.79 | 3.42 |
| | 74.63 | 43.98 | 2.59 | 10.2 |
| K1.45 | 99.9 | 52.31 | 2.03 | 5.08 |
| K1.45A | 78.32 | 53.85 | 1.37 | 1.65 |
| | 76.82 | 51.65 | 1.4 | 1.69 |
| | 75.48 | 49.97 | 1.41 | 1.68 |
| K1.45B | 120.4 | 80.51 | 1.89 | 4.66 |
| | 118.5 | 79.34 | 1.8 | 4.06 |
| | 120.3 | 79.56 | 1.84 | 4.19 |
| R1.15 | 115 | 85.71 | 1.85 | 5.12 |
| | 106.5 | 76.04 | 2.18 | 7.13 |
| | 103.5 | 71.18 | 2.34 | 7.97 |
| R1.15A | 123.9 | 91.7 | 2.13 | 6.88 |
| | 116.5 | 82.66 | 2.22 | 6.98 |
| | 111.5 | 77.13 | 2.15 | 6.19 |
| R1.15B | 132.6 | 97.47 | 1.75 | 4.07 |
| | 128 | 88.51 | 2.59 | 11.6 |

| Area | Mean | Median | Skewness | Kurtosis |
|---|---|---|---|---|
| | 120.3 | 82.25 | 2.05 | 5.55 |
| R2.15 | 142 | 97.63 | 1.73 | 3.35 |
| | 136.6 | 89.51 | 1.87 | 3.9 |
| | 133.5 | 84.42 | 1.91 | 4.02 |
| R3.15 | 108.7 | 71.32 | 2.23 | 8.02 |
| | 101.5 | 64.89 | 2.03 | 5.55 |
| | 97.78 | 60.75 | 2.22 | 7.04 |
| R4.15 | 139.4 | 109.3 | 5.42 | 48.6 |
| | 122.3 | 98.03 | 2.48 | 13.7 |
| | 120.9 | 92.83 | 4.51 | 39.9 |
| R1.30 | 108.5 | 83.7 | 1.72 | 4.58 |
| | 99.46 | 74.6 | 2.24 | 8.77 |
| | 95.1 | 69.85 | 1.93 | 5.73 |
| R1.30A | 110 | 78.41 | 2.94 | 16 |
| | 102.4 | 71.79 | 2.27 | 7.78 |
| | 100.8 | 68.49 | 2.26 | 7.42 |
| R1.30B | 148.1 | 102.8 | 5.05 | 36.1 |
| | 132.6 | 90.23 | 5.15 | 41 |
| | 118.7 | 83.64 | 1.99 | 5.31 |
| R2.30 | 191.6 | 153.6 | 1.65 | 3.98 |
| | 177.2 | 137.1 | 1.91 | 5.68 |
| | 171.3 | 128.9 | 1.72 | 3.64 |
| R4.30 | 133 | 101.8 | 1.49 | 3.04 |
| | 133.2 | 100.9 | 1.58 | 3.54 |
| | 135.6 | 101.3 | 1.66 | 3.83 |
| R1.45 | 153.4 | 120.8 | 1.38 | 2.28 |
| | 149.8 | 115.8 | 1.39 | 2.19 |
| | 146.1 | 112.2 | 1.43 | 2.4 |
| R1.45A | 145.5 | 104.8 | 4.42 | 33.1 |
| | 131 | 93.76 | 2.62 | 12.5 |
| | 126.2 | 88.37 | 2.66 | 13.2 |
| R1.45B | 121.8 | 88.75 | 5.41 | 50.2 |
| | 118.5 | 85.76 | 4.53 | 40.8 |
| | 112.2 | 83.03 | 1.82 | 5.19 |
| R2.45 | 184.6 | 147.1 | 1.64 | 3.87 |
| | 171.3 | 131.2 | 1.85 | 4.96 |
| | 167 | 124.1 | 1.8 | 4.15 |
| R2.60 | 139.3 | 106.6 | 1.54 | 3.16 |
| | 134.5 | 98.2 | 2.57 | 12.3 |
| | 129.7 | 93.24 | 2.68 | 13 |
| G1.15 | 349.7 | 399.2 | -0.0744 | -1.2 |
| | 349.4 | 399.3 | -88 | -1.2 |
| | 354.2 | 405.8 | -0.105 | -1.18 |
| G1.15A | 356.8 | 405.1 | -0.138 | -1.16 |
| | 362.8 | 410 | -0.126 | -1.11 |
| | 357.6 | 406.2 | -0.131 | -1.15 |
| G1.15B | 327.6 | 346.3 | 0.168 | -1.12 |
| | 324.8 | 342 | 0.188 | -1.1 |
| | 326.6 | 345.3 | 0.175 | -1.12 |
| G2.15 | 210.4 | 153.6 | 1.08 | 0.53 |
| | 206 | 141.9 | 1.09 | 0.438 |
| G3.15 | 218.5 | 191.4 | 0.9 | 0.611 |

| Area | Mean | Median | Skewness | Kurtosis |
|---|---|---|---|---|
| | 207.2 | 180.1 | 0.952 | 0.809 |
| | 202.4 | 175.4 | 0.941 | 0.732 |
| G4.15 | 79.6 | 54.75 | 2.73 | 12.7 |
| | 72.73 | 51.62 | 1.8 | 3.6 |
| | 70.31 | 49.67 | 1.87 | 3.97 |
| G1.30 | 346.7 | 266.7 | 2.12 | 5.79 |
| | 352 | 277.1 | 2.07 | 5.46 |
| | 360.6 | 281.4 | 2.05 | 5.04 |
| G1.30A | 159.6 | 100.2 | 1.51 | 1.98 |
| | 158.3 | 98.29 | 1.53 | 2.12 |
| | 160 | 98.25 | 1.5 | 1.94 |
| G1.30B | 224.5 | 144.6 | 0.917 | -0.198 |
| | 223.6 | 143.2 | 0.894 | -0.278 |
| | 223.9 | 143.6 | 0.859 | -0.381 |
| P1.15 | 96.97 | 74.38 | 1.27 | 1.45 |
| | 90.81 | 70.13 | 1.28 | 1.48 |
| | 87.88 | 67.64 | 1.33 | 1.73 |
| P1.15A | 193.9 | 164.2 | 1.44 | 3.69 |
| | 188.8 | 158.9 | 1.24 | 1.94 |
| | 186 | 154.6 | 1.49 | 4.01 |
| P1.15B | 128 | 99.83 | 3.38 | 23.7 |
| | 127.2 | 95.57 | 5.15 | 46 |
| P2.15 | 129.4 | 92.11 | 1.71 | 3.9 |
| | 119.2 | 82.4 | 1.83 | 4.26 |
| | 114.1 | 77.25 | 1.95 | 4.91 |
| P3.15 | 129.2 | 95.53 | 2.24 | 11.6 |
| | 116.6 | 83.09 | 2.97 | 16.3 |
| | 109.1 | 76.72 | 2.12 | 6.53 |
| P4.15 | 149 | 105.9 | 1.46 | 2.28 |
| | 140.7 | 96.42 | 1.49 | 2.33 |
| | 136.1 | 90.67 | 1.54 | 2.51 |
| Control1 | 210.6 | 151.5 | 2.69 | 11.3 |
| | 201.4 | 145.8 | 2.55 | 10.5 |
| | 203.3 | 140.9 | 3.27 | 15.7 |
| Control2 | 249.4 | 214.2 | 0.887 | 0.447 |
| | 237.4 | 201.9 | 0.931 | 0.565 |
| | 233.5 | 196.8 | 0.988 | 0.782 |
| Control3 | 86.49 | 55.07 | 2.27 | 7.85 |
| | 75.6 | 45.67 | 2.76 | 11.2 |
| Control4 | 211.9 | 163.2 | 2.55 | 13.3 |
| | 204.3 | 152.7 | 2.83 | 15.5 |
| | 202.7 | 146.4 | 3.37 | 19.1 |
| Control5 | 116.6 | 74.4 | 2.87 | 12.5 |
| | 111.4 | 68.03 | 2.64 | 10.4 |
| | 108.1 | 64.05 | 2.36 | 6.7 |
| Control6 | 129.8 | 95.89 | 1.81 | 4.86 |
| | 121.5 | 85.95 | 2.12 | 6.33 |
| | 113.4 | 78.55 | 2.23 | 6.95 |
| Control7 | 104.4 | 73.07 | 3.26 | 18.8 |
| | 96.74 | 64.76 | 3.27 | 16.7 |
| | 90.4 | 59.2 | 3.64 | 21.3 |
| Byre floor | 174.5 | 131.6 | 1.15 | 1.02 |

| Area | Mean | Median | Skewness | Kurtosis |
|---|---|---|---|---|
| | 164.8 | 119.6 | 1.22 | 1.25 |
| | 155.1 | 111 | 1.25 | 1.35 |
| Byre drain | 143.8 | 97.92 | 1.29 | 1.44 |

**Tofts Ness**

| Sample | Mean | Median | Skewness | Kurtosis |
|---|---|---|---|---|
| 200 | 102.1 | 67.6 | 1.75 | 4.47 |
| | 90.49 | 58.99 | 2.03 | 6.13 |
| 201 | 52.61 | 22.81 | 2.27 | 5.13 |
| | 52.54 | 22.7 | 2.28 | 5.22 |
| 202 | 153.7 | 97.57 | 0.0863 | -0.275 |
| | 151.6 | 93.76 | 0.888 | -0.23 |
| | 152.2 | 93.92 | 0.86 | -0.335 |
| 203 | 102.9 | 79.41 | 0.969 | 0.475 |
| | 99.36 | 76.26 | 1.04 | 0.791 |
| | 97.73 | 74.96 | 1.06 | 0.907 |
| 204 | 126.8 | 62.52 | 1.75 | 3.6 |
| | 124.1 | 60.51 | 1.64 | 2.78 |
| | 121.6 | 59 | 1.53 | 2.03 |
| 205 | 235.2 | 228.6 | 0.772 | 0.472 |
| | 234.3 | 227.1 | 0.747 | 0.353 |
| 206 | 120.6 | 74.06 | 2.23 | 8.25 |
| | 104.7 | 62.7 | 2.42 | 9.24 |
| | 95.35 | 56.58 | 2.41 | 9.14 |
| 207 | 81.89 | 36.07 | 3.01 | 14 |
| | 74.26 | 32.79 | 3.51 | 19.2 |
| | 67.9 | 30.98 | 2.41 | 7.09 |
| 208 | 88.95 | 58.64 | 1.08 | 0.495 |
| | 85.61 | 56.38 | 1.16 | 0.82 |
| | 83.96 | 54.79 | 1.28 | 1.48 |
| 209 | 58.26 | 24.66 | 1.93 | 3.7 |
| | 56.38 | 23.9 | 2 | 4.21 |
| | 56.46 | 23.53 | 2.13 | 5.15 |
| 210 | 67.33 | 43.03 | 1.82 | 3.76 |
| | 64.27 | 41.02 | 1.99 | 4.94 |
| | 62.6 | 39.52 | 2.22 | 6.72 |
| 211 | 122.9 | 74.27 | 1.47 | 2.44 |
| | 108.7 | 65.47 | 1.52 | 2.66 |
| | 102 | 60.35 | 1.76 | 4.01 |
| 212 | 105.7 | 48.21 | 1.4 | 1.37 |
| | 97.96 | 43.67 | 1.59 | 2.17 |
| | 94.24 | 40.71 | 1.71 | 2.64 |
| 213 | 100.5 | 42.91 | 1.68 | 2.58 |
| | 94.55 | 40.18 | 1.83 | 3.33 |
| | 92.25 | 38.76 | 1.89 | 3.53 |
| 214 | 246.4 | 256.5 | 0.278 | -0.716 |
| | 247.4 | 257.8 | 0.276 | -0.691 |
| | 244.9 | 255.9 | 0.248 | -0.771 |
| 215 | 234 | 233.7 | 0.464 | -0.757 |
| | 244.8 | 235.6 | 1.88 | 8.21 |
| | 252.3 | 241.1 | 2.07 | 9.04 |
| 216 | 86.01 | 33.67 | 2.13 | 5.26 |
| | 82.29 | 32.05 | 2.13 | 5.14 |
| | 81.24 | 31.56 | 2.1 | 4.86 |
| 217 | 77.32 | 38.34 | 1.37 | 1.28 |
| | 74.41 | 36.53 | 1.46 | 1.69 |
| | 72.63 | 35.33 | 1.5 | 1.87 |

| Sample | Mean | Median | Skewness | Kurtosis |
|---|---|---|---|---|
| 218 | 132.4 | 74.48 | 1.08 | 0.222 |
| | 101.5 | 53.65 | 1.32 | 1.04 |
| | 89.97 | 46.14 | 1.55 | 2.05 |
| 219 | 104.6 | 69.62 | 1.38 | 1.92 |
| | 96.72 | 62.2 | 1.56 | 2.65 |
| | 91.34 | 57.13 | 1.65 | 2.97 |
| 220 | 86.01 | 33.67 | 2.13 | 5.26 |
| | 82.29 | 32.05 | 2.13 | 5.14 |
| | 81.24 | 31.56 | 2.1 | 4.86 |
| 221 | 48.86 | 18.52 | 2.97 | 11.6 |
| | 41.64 | 17.33 | 1.93 | 3.51 |
| | 40.78 | 17 | 1.92 | 3.46 |
| 222 | 111 | 58.62 | 1.32 | 0.974 |
| | 103.2 | 54.19 | 1.38 | 1.21 |
| | 99.02 | 51.66 | 1.42 | 1.36 |
| 223 | 66.06 | 23.45 | 1.92 | 3.5 |
| | 61.38 | 22.33 | 2.06 | 4.53 |
| | 58.34 | 21.59 | 2.15 | 5.19 |
| 224 | 63.45 | 22.92 | 2.05 | 4.74 |
| | 60.08 | 21.98 | 2.26 | 6.28 |
| | 58.6 | 21.46 | 2.45 | 7.66 |
| 225 | 55.25 | 17.32 | 2.26 | 4.97 |
| | 51.4 | 16.72 | 2.38 | 5.83 |
| | 49.88 | 16.44 | 2.48 | 6.55 |
| 226 | 75.51 | 50.57 | 1.27 | 1.27 |
| | 69.7 | 46.3 | 1.37 | 1.72 |
| | 66.32 | 43.38 | 1.61 | 3.32 |
| 227 | 43.76 | 12.43 | 7.41 | 71 |
| | 36.25 | 12.01 | 3.86 | 21.2 |
| | 35.42 | 11.84 | 3.63 | 17.7 |
| 228 | 418.9 | 404.3 | 0.592 | 1.77 |
| | 419.3 | 404.6 | 0.665 | 2.01 |
| | 418.3 | 404.1 | 0.651 | 2.01 |
| 229 | 144.3 | 84.1 | 1.15 | 0.749 |
| | 142.5 | 81.04 | 1.16 | 0.637 |
| | 141 | 79.6 | 1.12 | 0.46 |
| 230 | 153.1 | 109.7 | 1.16 | 0.949 |
| | 146.1 | 102.2 | 1.17 | 0.89 |
| | 142.3 | 97.55 | 1.22 | 1.02 |
| 231 | 121.8 | 86.27 | 1.13 | 0.676 |
| | 115.4 | 81.43 | 1.17 | 0.747 |
| | 110.5 | 77.31 | 1.23 | 0.958 |
| 232 | 288.8 | 288.1 | 0.148 | 0.119 |
| | 281.4 | 282.4 | 0.159 | 0.104 |
| | 277.5 | 279.5 | 0.17 | 0.083 |
| 233 | 202.3 | 195.6 | 0.45 | -0.405 |
| | 173.5 | 161.8 | 0.478 | -0.6 |
| | 157.7 | 139.1 | 0.566 | -0.568 |
| 234 | 209.3 | 187.1 | 2.83 | 17.9 |
| | 178.4 | 158.6 | 0.703 | 0.0661 |
| | 166 | 141.4 | 0.742 | 0.025 |
| 235 | 316.5 | 303.2 | 1.23 | 4.06 |

| Sample | Mean | Median | Skewness | Kurtosis |
|---|---|---|---|---|
| | 285.6 | 283.4 | 0.5 | 0.84 |
| | 277.3 | 272.9 | 1.67 | 8.73 |
| 236 | 258.8 | 258.2 | 0.422 | 0.27 |
| | 227.7 | 231.9 | 0.571 | 1.22 |
| | 204.2 | 211.3 | 0.726 | 2.58 |
| 237 | 181.1 | 149.2 | 0.79 | -0.0497 |
| | 159.3 | 123.1 | 0.903 | 0.2 |
| | 150.7 | 111.8 | 1.02 | 0.547 |
| 238 | 188.5 | 152.2 | 1.2 | 2.05 |
| | 161.7 | 113.9 | 1.63 | 4.32 |
| | 131.6 | 89.72 | 1.11 | 0.646 |
| 239 | 204.7 | 190 | 1.31 | 4.67 |
| | 186.3 | 168.4 | 1.41 | 4.89 |
| | 170.3 | 153.8 | 0.573 | -0.435 |
| 240 | 317.2 | 310.8 | 0.801 | 2.22 |
| | 295.3 | 298.7 | 0.263 | 0.145 |
| | 287.9 | 292.2 | 0.406 | 0.526 |
| 241 | 248.3 | 241.9 | 0.714 | 0.529 |
| | 219.6 | 202.9 | 1.1 | 2.4 |
| | 195.6 | 166.5 | 0.971 | 1.12 |
| 242 | 188 | 155.3 | 1.53 | 5.17 |
| | 169.9 | 129.9 | 1.73 | 6.33 |
| | 157.7 | 116.1 | 1.72 | 6.09 |
| 243 | 165.5 | 128.8 | 1.83 | 7.2 |
| | 156.4 | 121.1 | 1.65 | 5.41 |
| | 151 | 116.3 | 1.66 | 5.25 |
| 244 | 257.3 | 253.8 | 0.82 | 2.58 |
| | 235.1 | 234.1 | 0.845 | 2.16 |
| | 215.4 | 216.9 | 0.828 | 1.91 |
| 245 | 300.9 | 294.4 | 0.725 | 1.63 |
| | 289 | 286.8 | 0.541 | 0.82 |
| | 281.2 | 281.7 | 0.427 | 0.397 |
| 246 | 271.9 | 262 | 0.6 | 0.227 |
| | 254.7 | 243.6 | 0.725 | 0.591 |
| | 243.5 | 230.1 | 0.949 | 1.62 |
| 247 | 191.7 | 169.7 | 1.17 | 3.55 |
| | 177 | 154.6 | 0.69 | -0.178 |
| | 169.8 | 146.8 | 0.679 | -0.261 |
| 248 | 227.4 | 215.9 | 0.525 | -0.294 |
| | 216.2 | 204.5 | 0.521 | -0.342 |
| | 209.4 | 197.1 | 0.528 | -0.347 |
| 249 | 178.9 | 138.6 | 1.12 | 1.52 |
| | 158.6 | 118.7 | 1.45 | 3.73 |
| | 144.8 | 108 | 0.992 | 0.381 |
| 250 | 233.1 | 226.6 | 0.647 | 0.169 |
| | 225.8 | 216.4 | 0.787 | 0.755 |
| | 218.9 | 206.8 | 0.789 | 0.558 |
| 251 | 175.3 | 132.6 | 1.35 | 3.25 |
| | 174.3 | 127.8 | 1.47 | 2.8 |
| | 171.9 | 124.3 | 1.4 | 3.25 |
| dune sand | 600 | 566.1 | 0.726 | 1.7 |
| | 576.8 | 552.7 | 0.363 | 0.552 |

| Sample | Mean | Median | Skewness | Kurtosis |
|---|---|---|---|---|
| | 565.8 | 548 | 0.203 | 0.27 |
| beach | 729.4 | 727.2 | 0.247 | 0.0798 |
| | 700.1 | 711 | 0.165 | 0.0703 |
| | 688.2 | 692.8 | 0.326 | 0.214 |

**Scatness**

| Sample | Mean | Median | Skewness | Kurtosis |
|---|---|---|---|---|
| 10102 | 139.4 | 74.19 | 1.1 | 0.394 |
| | 138.7 | 72.83 | 1.1 | 0.387 |
| | 138.7 | 73.52 | 1.06 | 0.216 |
| 10105 | 114.4 | 31.67 | 2.1 | 5.92 |
| | 113 | 30.55 | 2.1 | 5.97 |
| | 113 | 30.43 | 2.04 | 5.49 |
| 10108 | 80.01 | 26.96 | 1.61 | 1.7 |
| | 80.62 | 26.6 | 1.6 | 1.66 |
| | 79.51 | 25.95 | 1.59 | 1.59 |
| 10115 | 73.44 | 17.62 | 3.56 | 19.2 |
| | 68.72 | 17.38 | 2.41 | 6.24 |
| | 68.99 | 17.36 | 2.39 | 6.14 |
| 10116 | 175.4 | 121.7 | 1.76 | 6.38 |
| | 166.9 | 119.6 | 0.597 | -0.782 |
| | 165.8 | 116.9 | 0.602 | -0.781 |
| 10117 | 68.86 | 19.53 | 2.68 | 9.09 |
| | 67.89 | 19.28 | 2.58 | 8.21 |
| | 67.36 | 19.05 | 2.53 | 7.7 |
| 10118 | 57.6 | 23.73 | 2.04 | 4.04 |
| | 57.13 | 23.5 | 2.09 | 4.34 |
| | 56.75 | 23.32 | 2.08 | 4.27 |
| 10119 | 129.3 | 51.33 | 1.28 | 1.17 |
| | 127 | 49.28 | 1.36 | 1.63 |
| | 128 | 50.09 | 1.26 | 1.02 |
| 10120 | 262.4 | 280.3 | 0.135 | -0.618 |
| | 262.8 | 281.2 | 0.126 | -0.616 |
| | 264.3 | 282.2 | 0.171 | -0.497 |
| 10121 | 165.7 | 113 | 1.36 | 3.67 |
| | 166.8 | 115.9 | 1.39 | 4.05 |
| | 162.9 | 113.9 | 0.824 | -0.0127 |
| 10122 | 103.5 | 59.93 | 1.59 | 3.04 |
| | 99.92 | 57.87 | 1.45 | 2.05 |
| | 100.2 | 57.03 | 1.56 | 2.72 |
| 10123 | 224.8 | 238.4 | 1 | 2.94 |
| | 226.7 | 240.4 | 0.871 | 2.05 |
| | 226.9 | 240.5 | 0.843 | 1.95 |
| 10124 | 195.4 | 179.8 | 1.17 | 2.19 |
| | 196.4 | 183.3 | 1.15 | 2.01 |
| | 198.4 | 183.8 | 1.3 | 2.68 |
| 10125 | 196.6 | 184.9 | 1.09 | 1.51 |
| | 202.4 | 191.5 | 1.18 | 1.84 |
| | 204.4 | 195.5 | 1.19 | 1.83 |
| 10126 | 143.9 | 55.63 | 1.72 | 3.83 |
| | 123.4 | 47.45 | 0.901 | -0.517 |
| | 125.9 | 48.18 | 0.867 | -0.597 |
| 10127 | 171.5 | 89.71 | 1.29 | 2.14 |
| | 172.7 | 92.77 | 1.36 | 2.47 |
| | 174.3 | 101.5 | 1.33 | 2.33 |
| 10128 | 140.4 | 45.3 | 1.63 | 3.46 |
| | 142.3 | 45.24 | 1.65 | 3.56 |

| Sample | Mean | Median | Skewness | Kurtosis |
|---|---|---|---|---|
| | 140.2 | 43.36 | 1.65 | 3.7 |
| 10129 | 232.1 | 249.4 | 0.776 | 1.49 |
| | 234.3 | 252.4 | 0.736 | 1.29 |
| | 236.3 | 253.9 | 0.741 | 1.29 |
| 10130 | 197.5 | 193.3 | 1.09 | 1.77 |
| | 204.2 | 200.2 | 1.25 | 2.36 |
| | 205.9 | 203.5 | 1.26 | 2.47 |
| 10131 | 233.9 | 244 | 0.79 | 0.749 |
| | 236.7 | 249.6 | 0.659 | 0.295 |
| | 238.9 | 250.9 | 0.825 | 0.947 |
| Scat Ness | 178.4 | 101.2 | 1.58 | 3.56 |
| | 182.1 | 105 | 1.67 | 4.04 |
| | 182.3 | 106 | 1.78 | 4.79 |
| Toab | 179.9 | 58.11 | 1.26 | 1.76 |
| | 179.8 | 57.3 | 1.21 | 1.47 |
| | 181.1 | 59.09 | 1.24 | 1.63 |
| Hestingott | 160 | 89.51 | 1.97 | 6.68 |
| | 159.9 | 91.72 | 1.85 | 5.99 |
| | 161.3 | 92.17 | 2.07 | 7.37 |

## Appendix 6: Phosphate colorimetry method

**1.2 % stock ammonium molybdate reagent :** Dissolve 6.0g ammonium molybdate and 0.150g antimony potassium tartrate in 300ml distilled water in a 500ml beaker. Carefully add, with mixing and cooling, 74ml concentrated sulphuric acid. When cool, transfer the solution to a 500ml volumetric flask and make to volume with distilled water.

Dilute the stock 1 volume to 8 volumes **(0.15%)** for the working reagent.

Both solutions should be stored in a cool and dark environment.

**Phosphorous standard :** Dry potassium dihydrogen orthophosphate in an oven at 105$^{o}$C for an hour and cool in a dessicator. Weigh 0.4393g dry $KH_2PO_4$ and dissolve in 500ml distilled water in a beaker. Add 1ml concentrated HCl from a pipette. Transfer the solution to a 1000ml volumetric flask and make to volume with distilled water. Add 1 drop of toluene.

This stock solution has 0.1 mg P/ml.

On the day of use, dilute the stock standard solution 50 times (0.002 mg P/ml) with 2.5% acetic acid.

**1.5% ascorbic acid :** NOTE : Prepare on the day of use.
Dissolve 1.5g in 60ml distilled water in a beaker. Transfer to a 100ml volumetric and make to volume with distilled water.

**Method :**
Pipette 0, 1, 2, 3 and 4ml of the dilute phosphorous standard solution (0,2,4,6,and 8 μg P) into five 100ml conical flasks and make up to 5ml with distilled water. Add to each, 20ml 0.15% ammonium molybdate reagent and 5 ml ascorbic acid solution. Swirl the flask to mix and allow the solutions to stand for 30 minutes to allow colour development. Transfer the solutions to a 40mm spectrophotometer cell and measure the absorbance at 880nm after zeroing the spectrophotometer on distilled water.

Prepare a calibration graph by plotting absorbance of standards against respective μP.

Pipette 5ml of sample or blank into a 100ml conical flask. Add 20 ml 0.15% ammonium molybdate reagent and 5ml ascorbic acid solution and swirl the flask to ensure complete mixing. Leave to stand for 30 minutes to allow colour development.

Measure the absorbance at 880nm after zeroing the spectrophotometer on distilled water.

Determine the concentration of the sample in μP from the calibration graph.

Calculate extractable phosphorous ($\mu g/l^{-1}$ P) by :

The 5ml aliquot contains $\chi$ $\mu$g P

1000ml water yields **200.$\chi$ $\mu g/l^{-1}$ P**