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Anthropic sediments on the Scottish North Atlantic seaboard: Nature, versatility and value of midden

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Statement of originality

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

Signature of candidate: **Date:**

Abstract

Traditionally archaeology has referred to the anthropic sediments accumulated around prehistoric settlements with the blanket term 'midden'. This is now recognised as an inadequate term to describe the complex formation processes and functions represented in these sediments. This thesis reviewed the body of evidence accumulated over the past century of research into Neolithic and Bronze Age settlements on the islands of the Scottish North Atlantic seaboard and extrapolated the many occurrences of 'midden'. Several contexts emerged for these sediments including interior floors, hearths, exterior occupational surfaces, dumped deposits, building construction materials and abandonment infill. In addition, 'midden' is described added to cultivated soils to form fertile anthrosols. The way in which prehistoric communities exploited this material for agriculture and construction has been described through geoarchaeological research which implied that to past communities 'midden' was a valuable resource. This led to the formation of a model based upon a human ecodynamics framework to hypothesise sediment formation pathways. Rescue excavation at the Links of Noltland, Westray provided an opportunity to conduct a holistic landscape and fine resolution based study of Neolithic and Bronze Age settlement to test this model. The research incorporated auger survey, archaeological and geoarchaeological excavation, thin section micromorphology and SEM EDX analyses. Sediments identified in literature review and recovered from the field site were described using this toolkit and set within a cultural and environmental context. Results demonstrate that anthropic materials were incorporated into all contexts examined. Discrete burning and maintenance activities were found to have taken place during the gradual accumulation of open-air anthropic sediments whilst incorporation of fuel residues and hearth waste into floors lead to the gradual formation of 'living floors' inside structures. An unexpected discovery was evidence of animal penning within late Neolithic/Early Bronze Age settlement and the in situ burning of stabling waste. Three types of land management strategy which relied upon the input of anthropic sediments were evidenced and the range and extent of anthropic inclusions in the landscape recorded. Spatial interpolation of auger survey data utilised a new sub-surface modelling technique being developed by the British Geological Survey to explore soil stratigraphic relationships in 3D. SEM EDX analysis supported micromorphological analysis providing chemical data for discrete inclusions and assisting in the identification of herbivore dun ash and the Orcadian funerary product 'cramp'. SEM EDX analysis was also applied to fine organo-mineral material for statistical testing of nutrient loadings across context groups. It was found that anthropic sediments were enriched in macro and intermediate plant nutrients Mg, P, K, S and Ca compared to geological controls, and the application of anthropic material to cultivated soils improved soil fertility for the three observed land management practices.

The versatility of anthropic sediments was explored through discussion of context groups based upon the results of this research and the potential significance of this material to prehistoric communities is explored.

For my mother, Lynda Anne McKenna who has always encouraged and believed in me and Ian Colquhoun who in his lifetime was an inspiration to community archaeology

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Links of Noltland 2010 excavation team (photo credit, Graeme Wilson EASE).

Conventions and abbreviations

Radiocarbon dating

Within the review chapter of this thesis conventions regarding radiocarbon dating reports are presented as the original author published the results. The general notations ‘BC’ and ‘AD’ for millennia refer to the Western or Gregorian calendar designations of ‘Before Christ’ and ‘Anno Domini’. The year 0 BC is equivalent to 1950 before present and present is considered 1st of January 1950 AD. Radiocarbon dating results presented for the field site at the Links of Noltland are reported as follows:

<date range> cal BC = Calibrated radiocarbon date reported to 2 sigma

<^{14}C year> ± <range> BP = un-calibrated radiocarbon date

Others

OSL = Optically Stimulated Luminescence dating

[9024] = denotes archaeological context number relates to the site record or data structure report

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Thesis introduction: Life on an Island, the Scottish North Atlantic seaboard in Prehistory

The North Atlantic seaboard of the British Isles seems a far reach from the fertile and temperate agrarian landscapes of the early centres of civilization acknowledged by archaeology in the Middle East, North Africa, South America and the Indus Valley (Downes 2005, Greene & Moore 2010). However, during the fourth millennium BC, people chose to settle and farm these wind-swept archipelagos. Their innovative subsistence strategies adopted within a hostile environment lead to the formation of unique landscapes composed of extensive stone architecture and modified soils (anthrosols) and sediments (anthropic sediments). Anthrosols and anthropic sediments formed during prehistory are subject to the same diagenic changes as natural soils and so are often altered over time and subsequent land use, but occasionally they are found preserved in situ buried beneath wind-blown marine shell sands deposited by prehistoric North Atlantic storms. Studies of these rare survivals have revealed an archive of cultural and environmental material assisting in the characterisation of land management practices and changes over time (Simpson et al 2006, Guttmann et al 2006, Simpson et al 1998). This has allowed consideration of sustainable agricultural practice in the face of environmental extremes (Guttmann-Bond, 2010) – now one of the greatest challenges of the 21st century - but the social dynamics and practical activities involved in anthropic sediment manufacture and use are still poorly understood. Traditionally, archaeologists have used the blanket term ‘midden’ (Simpson et al 2006) to describe anthropic sediments but this is an inadequate delineation, anthropic sediments and their applications are diverse and must be recognised as such in order to understand them. *This thesis employs geoarchaeological methods to explore the versatility of anthropic sediments and how their value changed as communities dealt with increased storminess during the Late Neolithic and Early Bronze Age.*

Chapter One

Chapter 1 Anthropic sediments on the Scottish North Atlantic seaboard: nature, versatility and value of midden.

1.1 Introduction

The following chapter will introduce the study area and review the current knowledge of form and function of prehistoric 'middens' in the Orkney, Shetland and Outer Hebridean archipelagoes, concluding that although the importance of this material is well respected by archaeologists and much is understood about its use in arable soils, no attempt has yet been made to explain its spatial organization with regards to both domestic and arable management.

Midden is described in the Concise Oxford Dictionary of Archaeology as *"Any heap of rubbish or occupation debris adjacent to a dwelling or other site"* (Darvill 2008) but archaeologists working in the Scottish North Atlantic region have long been using the term to explain materials which fulfil a diverse range of functions (e.g. Clarke & Sharples 1985, Ritchie 1983) and occur in various colours and textures with differences also noted in their coarse components (e.g. Childe 1931). Recent geoarchaeological investigation has helped to explain some of these differences, finding the term 'anthropic sediment' (Simpson et al 2006) a more appropriate appellation. In soil science 'sediment' refers to the 'transported and deposited particles or aggregates derived from soils, rocks, or biological materials' (Brady & Weil 2008: 946) and geoarchaeology has built upon this to describe the deposition of materials by humans (Courty et al 1989, Simpson et al 2006). In the following review of literature the term 'midden' is used if the original author or site report referred to anthropic sediments as such.

Organic material and domestic waste were actively and routinely exploited by prehistoric communities as a fertiliser and land surface stabiliser (Guttmann et al 2008, Simpson et al 2006, Guttmann et al 2006, Simpson et al 1998) and were important materials for building and construction (Simpson et al 2006, Ritchie 1985).

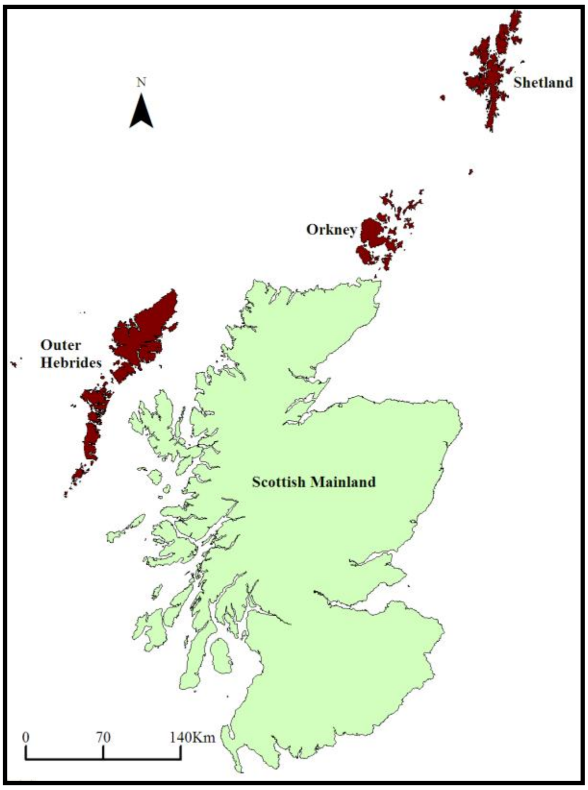


Figure 1.1: Archipelagos which make up the British North Atlantic seaboard

In later prehistory and up until the pre-modern era, sediments of this type were managed in both the study area and wider North Atlantic context to create carefully prepared domestic floor surfaces (Milek & Roberts 2013, Milek 2012, McKenna & Wilson 2011, McKenna & Simpson 2009, Simpson et al 1999a). In cases where field systems have been observed, floors from domestic and byre settings are shown to have been raked out and used as agricultural manures (Simpson & Guttmann 2002, Davidson & Carter 1998, Fenton 1997, Davidson & Simpson 1994). As yet no parallel investigation into Neolithic and Bronze Age floors has been attempted and no study has been able to elucidate whether midden was purposefully generated for specific functions around the site or whether the detritus of occupation was opportunistically exploited in whichever way seemed appropriate at the time.

1.2 Broad framework for research

The landscape of the Scottish North Atlantic seaboard has been forged through epochs of mountain building, tectonic movement and volcanic activity. In Northern Britain, the resultant diversity of rock type and subsequent erosion processes produced rugged coastlines and islands of igneous gabbro, metamorphic gneiss and ancient sandstones which have served as parent materials for nutrient rich soil development.

Although much of mainland Britain was once densely vegetated by mature forests, similar succession within the outer island landscapes was repelled by the weather systems of the North Atlantic Ocean which scour bare rock in less sheltered places – what woodland existed was mainly birch and hazel scrub by about 3500BC (Farrell 2009, Butler 1999, Edwards & Whittington 1998, Edwards & Whittington 1997, Fossitt 1996, Davidson & Jones 1985).

Sea level changes and a fluctuating climate during the Holocene era have had a profound effect upon these islands, depositing thousands of tons of marine shell sand to form white beaches (Ritchie & Whittington, 1994) and submerging great swathes of dry land (Dawson & Smith 1997).

Despite this, human occupation of these islands began in the Mesolithic period (10,000-3600BC), following glacial retreat at the end of the last ice age (c. 10,000 years BC) and has continued through to the modern day. Good transport networks and technological innovation allows for a comfortable standard of living in what are the farthest fringes of civilization in the British Isles today but the earliest settled prehistoric (Neolithic, 3600-2000 BC) communities also had their ways of dealing with the worst of the Atlantic weather and provisioning themselves with the basic human requirements of food and fuel.

Neolithic, Bronze (2000-700 BC) and Iron Age (700BC-500 AD) communities used peat, turf, seaweed and animal dung in their domestic hearths (Church et al 2007) throughout the Shetland, Orkney and the Outer Hebridean islands (figure 1.1). The emerging body of evidence seems to suggest that materials were carefully chosen for specific tasks and wood, by then a scarce resource despite the availability of drift and scrub wood (Armit 1996, Branigan & Foster

1995, Davidson & Sharples 1985), may have been set aside for another purpose (Mills et al 2004). Fuel residues such as ash and char were incorporated with other household wastes to form middens which communities then redistributed onto fields to enhance fertility or flattened out and cultivated in situ (Guttmann et al 2006). This system of land management developed gradually from the Neolithic through to Norse colonization (c.800AD) and was still a key aspect of manuring into the pre-modern era throughout the Scottish Islands (Guttmann 2005, Fenton 1997, Macleod 1994).

In the Orkney Islands, midden was also mixed with clay and used within wall core for construction (Simpson et al 2006) and in places to stabilize land surfaces subject to wind erosion (Simpson et al 2006, McKenna & Simpson 2011).

Midden, or "anthropic sediments" created as a result of human (anthropic) occupation, began to play a part in shaping the landscapes of the Scottish North Atlantic seaboard during the Neolithic period. It allowed greater crop yields by enhancing the fertility of cultivated soil and was an important part of construction and maintenance. The ability of these island communities to manipulate anthropic sediments has allowed continuity of occupation within a changing, often hostile, environment for millennia. Because of this, the investigation of these sediments has the potential to inform present and future resilience strategies (Guttmann 2010).

Undisturbed anthropic sediments in the archaeological contexts found in the Northern and Western isles often yield evidence of their composition, allowing consideration of the origins of components, the manner of their creation and their redistribution across settlement sites – giving insight into the level of management involved and any changes in this over time. The challenge faced with this type of investigation is the poor survival of extensive archaeological anthropic sediments within any one site which can offer a full range of evidence whilst controlling for differences in parent materials, geomorphology and post depositional processes. However, the recent discovery of an extensive multi-phase settlement with associated anthropic sediments and field systems dating from the Neolithic and Early Bronze Age at the Links of Noltland, Orkney provides an opportunity to explore the ways in which sediments were created and managed.

The research which is presented in this thesis builds upon this key theme, seeking to provide a narrative for continuity and change in land management practices set within their archaeological and palaeo-environmental contexts which will contribute to understanding of cultural responses to environmental changes in the Neolithic and Bronze Age Scottish North Atlantic seaboard.

1.3 The development of 'midden' in the Northern and Western Isles

The earliest evidence for human activity in the Northern or Hebridean Isles corresponds with the late glacial retreat at the end of the Pleistocene epoch. The earliest hunter-gatherer (Mesolithic) activity sites have been radiocarbon dated to the seventh millennium BC (Edwards & Mithen 1995, Hardy & Wickham-Jones 2000, Woodward et al *forthcoming*). Ephemeral building remains have been identified at Links House (Lee & Woodward 2008) on Stronsay in the Orkney Islands (figure 1.3) but otherwise these communities seem to have left very little trace upon the landscape. Evidence often rests upon the survival of 'shell-middens' which comprise diverse assemblages of sea-shell, stone/bone tools, crustaceans, sea-bird and mammal bones and other organic food-debris (Pickard & Bonsall 2009, Mainland et al 2005, Pirie et al 2006, Melton 2004) but sometimes a black sticky substance representing organic matter is all that remains (Saville & Wickham Jones 2012). The term 'midden' is applied in Hebridean and Northern Isles archaeology to all of these deposits despite differences in internal structure, components and location (cave, coast etc) (ibid.). This is not limited to Mesolithic sites as 'midden' is described at sites throughout the study area from the Mesolithic through to the Iron Age and even into the Medieval period (Simpson et al 2005).

Recent research has however begun to disentangle these complex sediments and demonstrate the importance of understanding their diverse nature and cultural significance (Thomas 1999, Jones 2005, Simpson et al 2006). As communities began to settle in one place (the Neolithic period in the study area spans c.3600 -2000BC) they considered midden to be a suitable building material (Simpson et al 2006, Clarke & Sharples 1985, Ritchie 1983, Childe & Grant 1938) and recognised its potential as an agricultural fertilizer (Guttmann et al 2006, Simpson et al 1998).

Evidence from Northton, Harris in the Outer Hebrides indicates that Neolithic communities exploited the cultivation potential of organic Mesolithic middens even as they continued to generate their own materials (Gutmann 2005, Guttmann 2006, Gregory & Simpson 2006). This blurs archaeological boundaries between Mesolithic and Neolithic 'midden' but attests to a prehistoric understanding of the benefits of midden to soil fertility.

Midden and cultivated ground from Neolithic and Bronze Age sites are well preserved in the Orkney Isles (Clarke & Sharples, 1985, Simpson et al 1998, Guttmann 2005, Simpson et al 2006, Guttmann et al 2006, Cluett 2007, Guttmann et al 2008, McKenna & Simpson 2011) and later artificially deepened top soils dating from the Norse Period (AD 800 - AD 1468) are also well documented (Simpson 1993). Research in the Western Isles is also beginning to reveal areas of preserved anthrosols and anthropic sediments spanning the Neolithic to Medieval period (Shepherd & Tuckwell, 1975, Gilbertson et al 1999, Barber 2003, Milek 2005, Guttmann 2006, McKenna 2008, McKenna & Simpson 2009, McKenna & Wilson 2011, Hamlet & Simpson 2013).

In Shetland recent soils work has indicated that occupational debris may have been influential in the selection of sites for stone buildings.

Typically the pattern in both the Northern and Western Isles is for midden to be composed of hearth and kitchen waste including burned and unburned bone, charcoal, ash (including peat ash), artefacts such as broken pottery and organic residues. Midden was used as building foundations in Orkney (Childe 1931, Childe & Grant 1938, Ritchie 1983, Clarke & Sharples 1985, Ritchie 1985, Simpson et al 2006) and in construction across the study area (Whittle et al 1986, Simpson et al 2006, Cluett 2007). Similar deposits are also found as floor layers and ground surface accumulations in and around settlements. Resource exploitation after this model has been identified at the Links of Noltland, Knap of Howar, Tofts Ness, Scord of Brouster, Jarlshof and Old Scatness in the Northern Isles – and possibly Northton, Cladh Hallan, Dun Vulan and Eilean Domhuill in the Western Isles - sites which range from the Neolithic to Iron Age in date.

1.4 Midden in context I: The Neolithic

The Neolithic is an archaeologically defined cultural period which is characterised by a shift to more sedentary settlement, the invention of ceramics and uptake of farming (Nobel 2006, Thomas 1999, Whittle 1996). The societal changes inherent to these new ways of life included new ways of cooking and feasting (Thomas 1999) but also came with new ideas about spirituality and the creation of ritual landscapes (ibid.). In the Outer Hebridean, Orkney and Shetland archipelagoes, this relatively rapid transition (compared to the rest of Britain and Europe, Nobel 2006) enters the archaeological record during the early to mid-fourth millennium BC (Gillmore & Melton 2011, Mills et al 2004, Ritchie 1985). In the beginning there is some evidence that timber was used in construction in all three archipelagoes (Carey 2012, Mills et al 2004, Whittle et al 1986 – cited in Sheridan & Brophy 2012, Hedges, 1986) but the record in Shetland is largely untapped (Sheridan & Brophy 2012) and so little is known about the early Neolithic. The architecture of the period is typified by stone building in Orkney and Shetland (Card 2005, Ritchie 1985, Calder 1956) and parts of the Outer Hebrides (Armit 1996).

This is mirrored in large communal funerary and megalithic monuments (Card 2005, Pollard 2002) which include chambered cairns and stone circles (figure 1.2) although regional differences are striking and there are no stone circles in Shetland (Fojut 1999).

Associated palaeo-landscapes have been rarely excavated, with the focus usually falling on archaeological structures. More recently however, soil and sediment studies are beginning to demonstrate a more subtle Neolithic cultural record in the wider landscape which largely

Figure 1.2: Left, Ring of Brodgar stone circle, Orkney. Right, Maes Howe chambered cairn, Orkney.

relies on the presence of domestic waste (Mills et al 2013, Turner 2013, Cluett 2007, Guttmann et al 2006, Simpson et al 2006). Neolithic cereal cultivation is evidenced in all three island groups by the presence of carbonised wheat and barley grains found in anthropic sediments (Sheridan & Brophy 2012, Cluett 2007, Simpson D.D.A et al 2006, Armit 1986, Whittle et al 1986, Clarke & Sharples 1985). Mixed agriculture and fishing was practiced in the Neolithic period in Orkney (Farrell 2009, Clarke & Sharples 1985) and fish and cattle bones found in Neolithic midden at Barvas, Isle of Lewis (figure 1.9) (Cook 1999) support this model in the Outer Hebrides too. The main cereal crop grown was barley. This enters the palaeoecological record in association with evidence of woodland clearance in some areas (Farrell 2009). Cultural distinctions often rest upon the morphology and decoration of ceramic artefacts. Beginning with geographically homogenous 'carinated bowls' (Nobel 2006), regional styles developed in the middle Neolithic period (Sheridan & Brophy 2012, Nobel 2006) with distinctive 'Unstan-wear' in Orkney and 'Hebridean–wear' in the Western Isles. Less is known about the Shetland tradition, but the sherds collected so far are 'plain' style with parallels to early Hebridean pottery (Sheridan & Brophy 2012) and Tofts Ness in Orkney (Dockrill et al 2007). Unstan and Hebridean traditions were replaced towards the later Neolithic by 'Grooved-ware' pottery which originated in Orkney (Sheridan & Brophy 2012). Shetland remained outside of this ceramically defined cultural indicator (ibid.) continuing with plain style into the Bronze Age. Preservation and excavation are the two main barriers to understanding regional variations and there is a strong research bias towards Orcadian sites (Clarke & Sharples 1985). This has however allowed comparison at a finer resolution in Orkney and architectural distinctions which include the use of midden have been recorded. These will be explored in the following section and a model based upon the current knowledge given as a summary at the end. This model is not easily extrapolated to the Hebridean and Shetland contexts, and so these will be considered separately before a discussion of Midden use in the Neolithic period is attempted.

1.4.1 *Orkney*

1.4.1.1 *Knap of Howar: foundations, wall cores and extensive spreads*

The earliest known permanent settlement in Orkney has been dated to the fourth millennium BC (Ritchie 1983) and is found at the Knap of Howar on Papa Westray (figure 1.3). The settlement consists of two stone houses built to a high standard using local flagstones (Ritchie 1985). The initial phase of activity at this site is represented by a layer of midden 0.4m thick onto which the first house was built. Midden forms a substantial constituent of the settlement. It was used as the core material for double skinned dry stone walls and was flattened out to a uniform thickness of 0.35m over an area of around 500m^2 adjacent to the house. This was composed of artefacts, shells, sheep, cattle, bird and fish bones, organic debris and a few burned hulled barley grains (ibid.). Two levels were distinguished within this sediment but no difference in components was noted by the excavators (ibid.). The first house to be constructed was rectilinear with rounded corners and the aforementioned double skinned walls, 1.5m thick. The building was entered via a short paved and linteled passageway into a 10m by 5m room divided by upright flags and containing stone benches, an aumbry and a central hearth. The second house was built immediately adjacent to the first and was joined by a short passage. Also rectilinear in plan it measured 7.5m by 3m, was divided into three and contained several cupboards or shelves and a square central hearth (ibid.). The settlement was interpreted as a self-supporting farmstead and placed into the ‘Unstan-ware culture’ based upon associated pottery. Although Knap of Howar is the earliest known Neolithic settlement in the study area, the younger radiocarbon dates from this site show that its occupation was contemporaneous with settlement at Skara Brae, on Mainland Orkney.

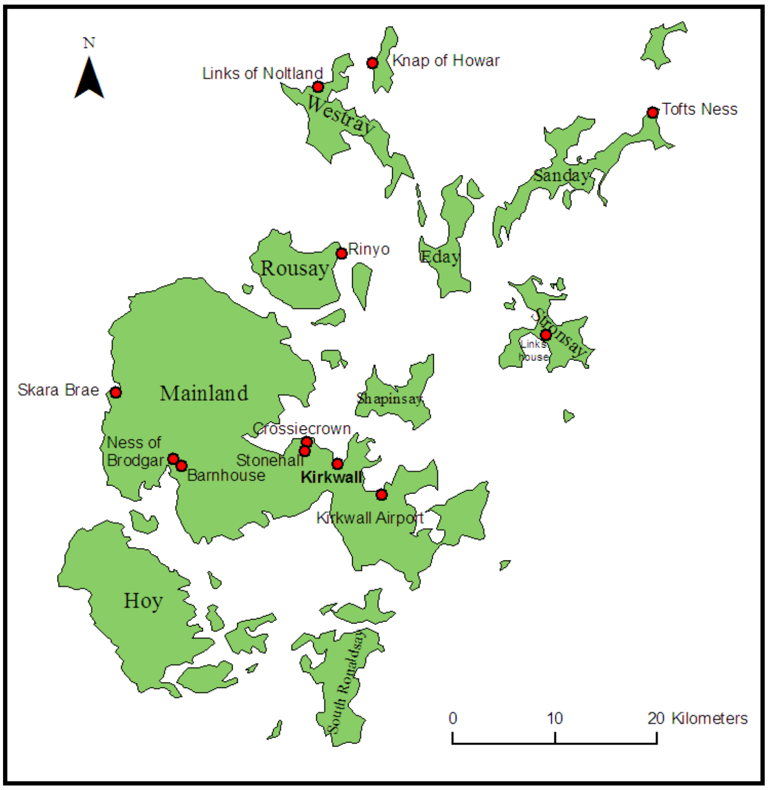


Figure 1.3: Orkney places mentioned in text

1.4.1.2 *Skara Brae: Foundations, wall cores, floors and dung heaps*

Skara Brae is much larger than Knap of Howar. Described as a ‘village’ (Childe 1931, Clarke 1976) it is thought to be the best surviving prehistoric settlement in northern Europe (Clarke & Sharples 1985) and is managed as part of the ‘Heart of Neolithic Orkney’ World Heritage Site (Downes et al 2005). Occupied from the third millennium BC, the settlement consists of ten or more houses (figure 1.4) built in two phases, beginning around 3360BC and continuing through the second phase around 2900BC until their abandonment around 2500BC (Simpson et al 2006). Like Knap of Howar the structures were built upon a foundation of midden which was also used as wall core in double skinned dry stone construction (ibid.).

The earlier phase of building consisted of at least three approximately square houses but these were incorporated into the second settlement which was built into so much midden as to be semi-subterranean. This is interpreted as a deliberate act and not a by-product of settlement waste (Clarke & Sharples 1985). The later houses followed the same, off-square plan as the earlier structures, with rounded corners and small cells built into the walls (ibid.).

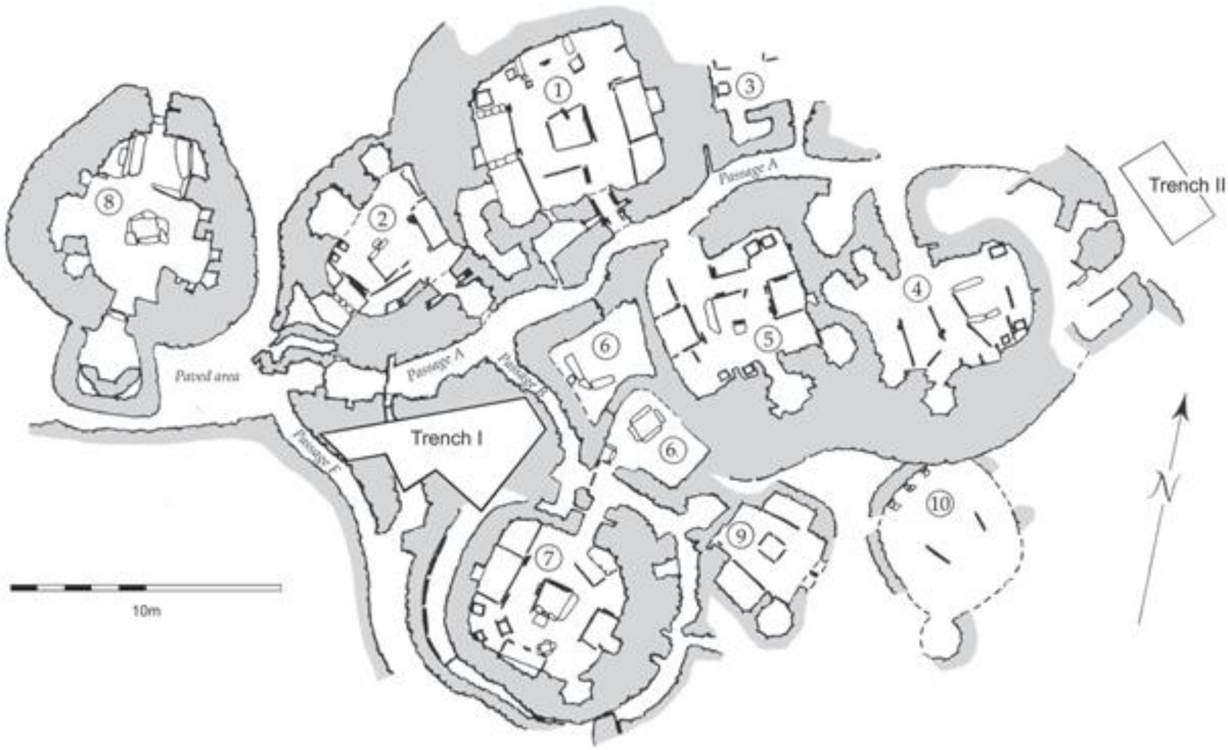


Figure 1.4: The Skara site, showing structures (fig.2, Simpson et al 2006, adapted from Clarke's 1972-73 excavations)

In divergence from the Knap of Howar architecture, the Skara Brae houses are not conjoined by small passageways but each has its own entrance passage which opens onto a long central passageway (figure 1.4). A separate structure (structure 8) was built away from the main settlement, not into deep midden but rather onto 'blue clay' which was described as occupational surface, virgin soil or building materials and foundations (Childe 1929 & 1930).

Stone-built furnishings at Skara Brae have allowed consideration of the interior arrangements of the home (Clarke & Sharples 1985). Benches, beds, sunken tanks, cupboards and dressers are typical as is a central square hearth.

An attempt to characterise the midden at Skara Brae was made during early excavations. Archaeologist Gordon Childe noted black, brown, red, ashy and 'ordinary' midden types. The 'black midden' contained wood, plant roots and mosses as well as animal bones, limpet shells and artefacts (Childe 1930). It was found associated only with the initial phase of occupation and was between 30 and 91cm thick (table 1.1). The 'brown midden' was found in both earlier and later phases of occupation. Usually artefact-sterile but rich in bone fragments the brown midden was mainly used as building foundations. Red and ashy middens are similar in form, containing no artefacts, bones, shells or stratigraphy and mainly found within structure interiors associated with hearths (Childe 1930). The ordinary midden accumulated throughout settlement at Skara Brae and it was used as a construction material for ground levelling prior to building, mixed with rubble upon the abandonment of phase one (houses 9 and 10) and formed 'stamped' floors (Childe 1930). Ordinary midden contained artefacts such as pins, beads, pot sherds and tools and was found stratified with thin layers of sand where it occurred out-with structures. The 'ordinary midden' has also been described as an occupational deposit and was thought to have accumulated above the level of the structures as the inhabitants cooked and lived at the surface (Childe 1930).

Detailed investigation of anthropic sediments from Trenches 1 and 2 excavated in 1972 & 1973 (figure 1.4) demonstrated that midden associated with the earlier phases of settlement is dominated by fuel residues and house hold waste (Simpson et al 2006). This was used as building material and so seems to concur with the 'brown midden' type described by Childe.

Table 1: Anthropic sediments at Skara Brae identified by Childe (1930)

Phases	Context	Type	Thickness (cm)
4	**Under passageway A floor**	**Red midden**	**66**
4, 3, 2 & 1	**Wall foundation, structure 5** **East of structure 4, several layers overlying blue clay associated with a drain** **Beneath clay floor in structure 6** **Against walls in between structures 1 & 2** **Several layers separated by sand overlying clay in between structures 1 & 2** **Overlying sand and black/brown midden south of structure 8**	**Ordinary midden**	**10- 92**
3	**Under red midden, separated by sand layer** **Structure 5, north of hearth** **Structure 1, north of hearth**	**Ash midden**	**15 -175**
4, 2 & 1	**Under black midden in passageway A** **Between structures 2 & 8, several layers separated by sand and blue clay** **Beneath structure 10 floor** **East of structure 4 associated with a drain, beneath ordinary midden, black midden and blue clay. On top of sand and clay.** **Beneath paving slabs south of structure 8, two layers separated by sand, over lying black midden.** **Beneath black midden under paving south of structure 8** **Underlying black midden south of structure 8**	**Brown midden**	**15-99**
1	**Under drain in passageway A** **East of structure 4 associated with a drain, beneath ordinary midden and blue clay; overlying brown midden** **Under sand and ordinary midden south of structure 8, overlying brown midden**	**Black midden**	**30-91**

The sediments related to later occupation appeared to be concerned with the stabilization of windblown sand intrusion, utilising a wide range of domestic waste to consolidate this (*ibid.*). Domestic waste was also found to be incorporated with clay to create constructional material for walls in the later phase of settlement (ibid.). Midden analysed at the edge of the settlement in trench 2, contained a greater amount of organic material with domestic waste components similar to those in trench 1 with the crucial addition of herbivore dung.

The midden found in trench 2 and to the east of structure 4 at the eastern edge of the settlement indicate this area was a refuse dump (Childe 1930, Simpson et al 2006). All midden sediments were found to peter out to the north and south of the settlement site (1930). To date no anthropic modification of soils/sediments has been identified beyond the immediate settlement area.

Using ceramic evidence Skara Brae has been culturally contextualized as a ‘Grooved-ware’ settlement. This together with differences in architecture and material goods places it into a tribal group distinct from the Unstan-ware culture at Knap of Howar (Ritchie 1985). The midden at Knap of Howar has not yet been studied in detail but the evidence reviewed here suggests that alongside stone, sediments containing large amounts of domestic waste were an important component for building foundation and construction at both Grooved-ware and Unstan-ware type settlements.

1.4.1.3 *Rinyo: Foundations, wall cores and floors*

This is emphasized at a second Grooved-ware site in Orkney called ‘Rinyo’ (Simpson et al 2006). Here midden was used to level out the ground surface into foundation terraces for stone buildings (Childe & Grant 1938). Rinyo, on the Island called Rousay (Figure 1.5) was occupied over two phases, roughly contemporary with Skara Brae. No absolute dating has been achieved but the artefact typological analysis links the early phases of both Rinyo and Skara Brae. The building construction at Rinyo is architecturally similar to Skara Brae, consisting of individual off-square rooms constructed of stone flags forming double skinned dry stone walls with a midden core (Ritchie 1985). The midden at Rinyo has not been studied in detail and no attempt at characterisation has been made. However Childe & Grant describe foundational terraces, stamped floors and deep (91cm) midden beneath chamber C

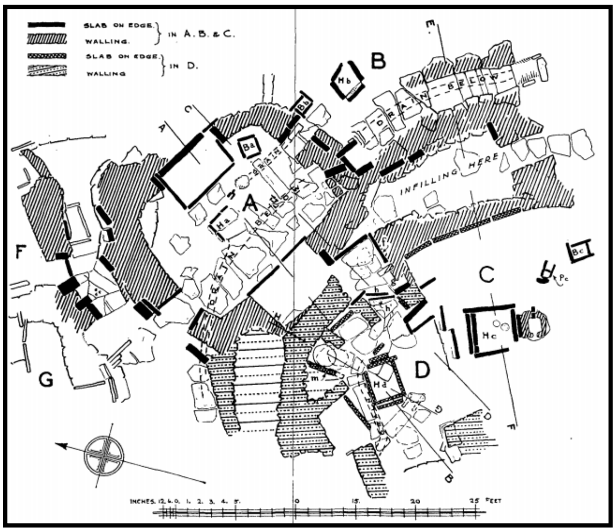


Figure 1.5: Plan of structures excavated at Rinyo, Rousay, Orkney. From Childe & Grant (1938).

(figure 1.5) containing pottery sherds and flints (1938) indicating at least three distinct types of sediment. The internal layout of these structures is similar to Skara Brae, containing square hearths, stone beds, tanks and possible dressers. Also in keeping with Skara Brae design, Rinyo exhibits a stone-built drainage system (Childe & Grant 1938). The drains at Skara Brae were associated with 'black midden' but those at Rinyo alternately contained a bright green clayey sediment and pottery and stone tools.

1.4.1.4 *Tofts Ness: Foundations, Infill, wall cores, dumps and gardens*

At Tofts Ness, Sanday (see figure 1.3), multiple phases of occupation were recognised commencing in the later Neolithic period and spanning into the Bronze Age and onto the Iron Age. The preservation of earlier buildings is very poor due to stone robbing (Dockrill et al 2007) but the earliest phase recorded demonstrates that ash and midden like material formed the foundation for construction of dwellings (Dockrill et al 2007). Tofts Ness has benefitted from extensive research into anthropogenically modified or created soils and sediments (Dockrill et al 2007, Guttmann et al 2006, Simpson et al 1998, Simpson 1985) and so, alongside work done at Skara Brae, forms the current bench mark for analytical study. Tofts Ness comprises seven large mounds and 300 smaller ones (Guttmann et al 2006). Mound 11 (figure 1.6), dated to the Neolithic period (Ambers 2007) was composed of limpet shells, animal bone, artefacts, fuel residues including ash and burned soil, charred plant and possibly seaweed in a red ashy matrix (Dockrill et al 2007), classified as midden (ibid.). This midden is stratified with layers probably representing 'tipping' of ashy or organic materials in parallel with midden at Skara Brae. Solid bands of limpet shell may indicate seasonal exploitation (ibid.). Fuel residues have been shown

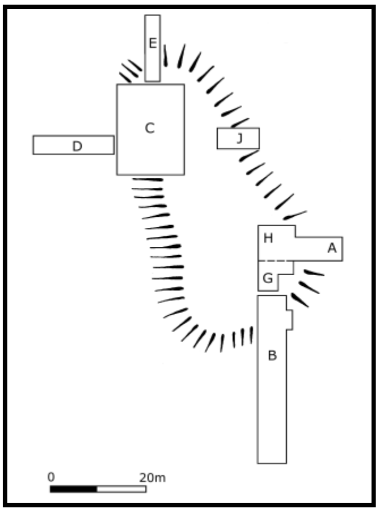


Figure 1.6: Mound 11 at Tofts Ness showing the locations of excavations ferom 1984 to 1999 (from Dockrill & Bond 2006)

to be an important component of midden material (Simpson et al 2006) and the sediments at Tofts Ness demonstrated that iron rich turf was a likely source, although ethnographic evidence suggests that burning turves was the final event in a complex use history (Dockrill et al 2007) which involved building construction and animal bedding as well as mixing with other materials (Fenton 1997).

Where the outer walls of structural remains were preserved they were recorded as having several concentric, or 'onion skin' walls, packed with earth (Dockrill et al 2007), in divergence from the other Neolithic settlements discussed above. The earliest Neolithic building recorded (structure 1) was poorly preserved and sub-circular with a central square hearth and obliterated stone furnishings (ibid.). An occupational surface was recognised around the hearth containing fine lenses of ashy material (ibid.). Midden and ash tips associated with this phase were recorded in association with a drain (Dockrill et al 2007). A later rebuilding phase occurred in the later Neolithic directly over the first. The floor of this structure was paved with flagstones set into a yellow clay material mixed with ash (Dockrill et al 2007). Upon its abandonment, midden containing animal bone (including an articulated bull skeleton), limpet shells and fuel residues was tipped into structure 1 forming a stratified sequence (Dockrill et al 2007). The Neolithic settlement at Tofts Ness fits into neither Unstan-ware nor Grooved-ware categories. Instead, cultural links with Shetland are evidenced (Dockrill et al 2007). The Neolithic midden at Tofts Ness has been studied in detail and much like the Skara Brae deposits, has been shown to contain a large fuel residue component including peat ash, charred peat/turf fragments and woody charcoal (Guttmann et al 2006). Turf and peat were cut from an iron rich source and burned as fuel (Simpson et al 1998, Dockrill et al 2007). Organic material was also noted as a strong component and, although this was well decomposed, laboratory analyses confirmed the presence of either pig or human faeces (Simpson et al 1998). Midden at the edges of the mound extends over an area roughly $20m^2$

(Dockrill & Bond 2006) and was flattened out and cultivated using an ard during the Neolithic period (Guttmann et al 2006).

1.4.1.5 *Links of Noltland: Foundations, wall cores, floors and extensive spreads*

Perhaps the most extensive midden deposits recorded in Orkney occur at the Links of Noltland, Westray (figure 1.3) where spreads occur over an area at least 1100m². This settlement site is more dispersed than Knap of Howar, Skara Brae or Rinyo but exhibits many architectural similarities. Set in a landscape almost 2.5km², stone built structures have been recorded and placed culturally into the 'Grooved-ware' settlement category and dated to the Late Neolithic and Early Bronze Age (Moore & Wilson 2009a). Both Neolithic and Bronze Age structures were built in the double-skinned style with midden wall core (Moore & Wilson 2009a & b). The 'Grobust' structure (figure 1.7) was built into wind-blown sand deposits lined with midden (Clarke & Sharples 1985). This building contains two rooms linked by a passageway. The smallest of these is rectangular with small rounded cells in the east and west walls. Large slabs were placed either side of the entrance to the structure, stuck to the walls with yellow clay (ibid.). The inner room is lobate in plan. Upon abandonment the entrances to both rooms were carefully blocked up and the interiors were filled with structured midden and large stone slabs (ibid.). Articulated animal and fish skeletons were incorporated into the structured midden, including a complete eagle (Clarke & Sharples 1985). Current excavation of midden covering Area 5 is also producing articulated skeletons along with carefully arranged 'compositions' of bone and shell (Moore & Wilson 2011a).

A number of structures in Area 5 are as yet un-resolved but initial assessment does indicate square hearths and at least two structures exhibit compartmentalization/recesses (Moore & Wilson 2009a). One building (structure 9) contained midden wall core with the addition of at least 30 intact cattle skulls and a second (structure 10) had at least three concentric wall faces with a core of clay. The buildings in Area 5 appear to have been deliberately filled with midden containing organic material, stone tools and 'special' artefacts such as an anthromorphic figurine and the 'compositions' already mentioned above.

A large amount of midden material was discovered, set apart from Area 5 associated with structure 7 (figure 7. This was reported to cover an area of at least 1100m² and has been shown to contain at least two anthropic sediment horizons separated by wind-blown sand which may have been cultivated (Moore & Wilson 2009a, Clarke & Sharples 1985). Ard marks

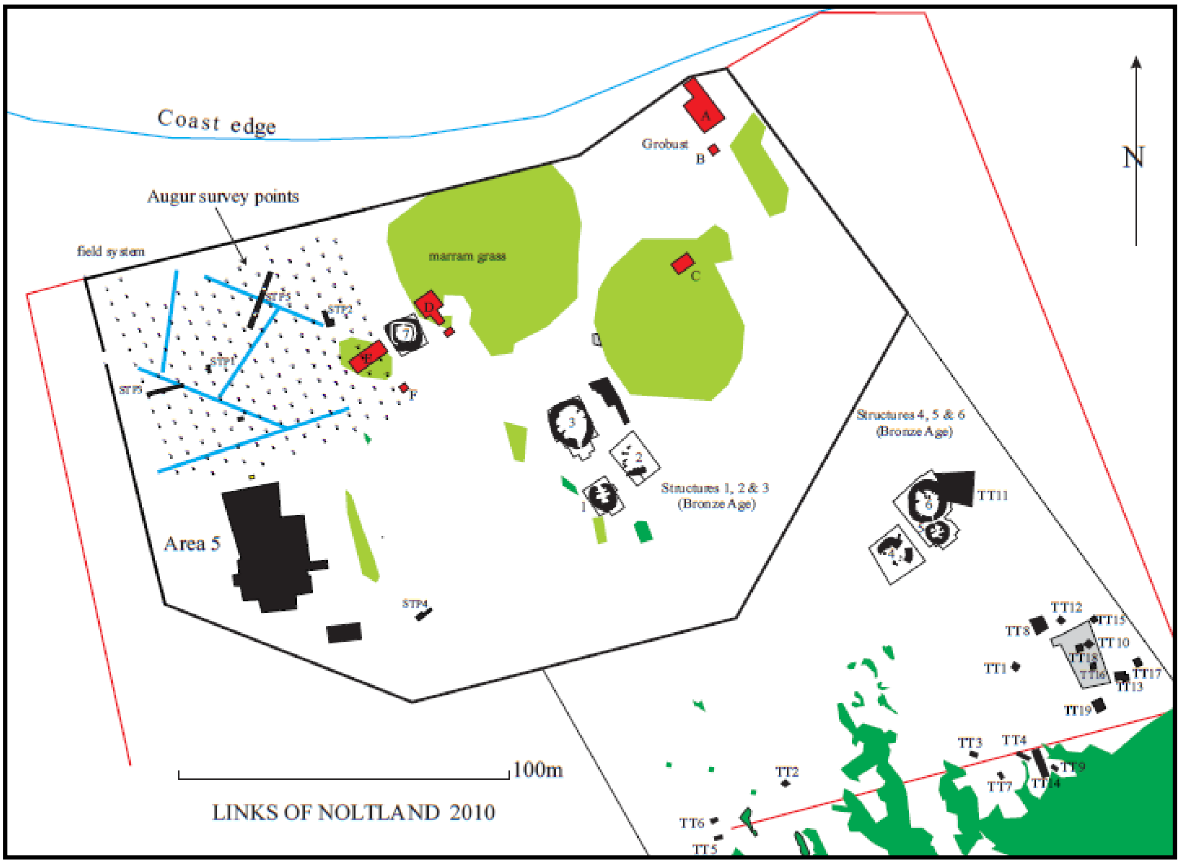


Figure 1.7: Links of Noltland, Westray, Orkney. Locations of archaeological remains. The heavy black line designates the area taken into care by Historic Scotland (Moore & Wilson 2011a).

and boundary ditches were identified within these horizons (Clarke & Sharples 1985). Structure 7 has not yet been fully excavated but so far seems comparable with Skara Brae and contains a dresser. The building was infilled with organic soils containing struck flint, pottery and other materials (Moore & Wilson 2009a).

1.4.2 *Neolithic midden in Orkney: a model*

Despite diverse cultural, architectural and location preferences, a pattern for the use of midden is beginning to emerge in Orkney in the Neolithic period:

Communities procured or produced large amounts of midden to build foundations before occupying stone-built houses and generating more midden material. This did not however occur at Barnhouse where lacustrine silt and turf was used in construction rather than midden (French 2005 cited in Cluett 2007). How these initial midden deposits were generated, and by whom are as yet poorly understood.

Midden varies in composition, but can contain marine-shells, bone, fuel residues of peat, turf and wood, animal manure, pottery and tools as well as articulated skeletons and deliberately placed artefacts perhaps indicating rules for spatial distribution of specific components. Previous research has described these components individually or collectively under the term 'midden'.

'Midden material' was also incorporated into occupational surfaces and used to infill structures upon abandonment (also noted at Ness of Brodgar, Card & Cluett 2005).

Midden was dumped near the settlement and left untouched or sometimes flattened out in-situ and cultivated. It was also a preferred material for use in construction and building repairs, either in a raw state or mixed with clay.

Although the deposition of midden is assumed to have had some meaning in Orkney (Carey 2012) and is understood to vary in composition across and within individual sites, to date no opportunity has arisen to investigate the composition of a range of sediments in detail across a well preserved archaeological settlement and associated land surfaces.

Analysis of midden material at Tofts Ness with emphasis on arable land management practices (Guttmann 2001, Guttmann et al 2006) demonstrated in situ cultivation of midden generated by the Neolithic settlement containing shell, bone, wood charcoal and burned peat/turf fragments and enhanced levels of organic phosphate. Whether this material differed from occupational floors, infill, wall core or foundation material is unknown. The question of how long midden would have taken to accumulate and become suitable for cultivation also remains. Settlement sites may have been deliberately chosen near accumulations of Mesolithic midden (Guttmann 2005) giving special significance to inherited resources. The cultivation of large amounts of midden has been suggested to support a hypothesis for a more sedentary lifestyle in Neolithic Orkney (Guttmann 2001).

Work at Skara Brae did examine foundations, wall core and dumped deposits (Simpson et al 2006) but occupational floors and infill were not considered and no amended cultivated soils are available at that site for a fuller comparison of domestic and agricultural midden use.

The challenge that variable midden deposits present to archaeologists is now being met head on, both at excavation (see Moore & Wilson 2011a for an example of detailed midden investigation) and in contemplation. The deliberate incorporation of desirable objects and carefully arranged assemblages has led to the proposal that midden held cultural and spiritual significance for Neolithic communities. This was perhaps brought about by their appreciation of insulating and fertile properties (Jones 2005, Garnham 2004, Thomas 1999).

The current model for Neolithic Midden in Orkney is fragmented but clearly demonstrates that midden was a valuable resource. The relationship between a community and the midden generated by their predecessors was intrinsic but whether or not a set of rules presided over the spatial deposition and reuse of individual components has not been investigated.

Possible parallels for the form of cultivation during the Neolithic described at Tofts Ness have been suggested between other Neolithic sites in the Orkney, Shetland and Western Isles (Guttmann et al 2006, Dockrill & Bond 2006) and have been confirmed at Scatness and

Jarlshof, Shetland (Dockrill & Bond 2006 – radiocarbon dates suggest early Bronze Age, Guttmann 2001) but the function of midden in building, agricultural and domestic settings is not a composite model which can be comfortably extrapolated across the study area.

1.4.3 *The Outer Hebrides*

Much of the landscape of the Outer Hebrides is characterised by blanket peat which began to develop c.1500bc (Gilbertson et al 1995). It is estimated that many Neolithic and Bronze Age domestic and agricultural sites lie undiscovered beneath this (Fojut et al 1994). Funerary monuments and stone circles, by contrast, are often found in areas of high ground raised above peat levels (figure 1.8) resulting in an under-representation of non-ritual sites in Hebridean archaeology.

Figure 1.8: Bharpa Langais chambered cairn, North Uist (top) and Cnoc fhillibhir bhig stone circle, Lewis (bottom)

Excavation in the Hebridean islands is not yet as comprehensively published as Orcadian data, many sites being chance peat cutting discoveries, nevertheless several sites have been recorded in detail and provide more than a glimpse into Neolithic settlement patterns and associated midden. In the Outer Hebrides, midden was not necessarily a prerequisite to the building of Neolithic structures but at least one later roundhouse at Barvas, Lewis (figure 1.9) used this method. The building itself does not survive but is recognised by a series of post settings indicating it was constructed using organic materials (MacLeod *pers comm.*). Neither the midden nor the house have been solidly dated. A settlement sequence of similar ephemeral composition was discovered at Bharpa Carinish, North Uist (figure 1.9), set back from the coastal edge. A series of stone hearths associated with post holes, pits and extensive ash spreads containing Unstan and Hebridean-ware (Crone 1989) were found here along with a possible wattle screen (Crone & Mills 1988). The ash spreads were radiocarbon dated to the mid Neolithic period (Crone 1989) but their function is unknown.

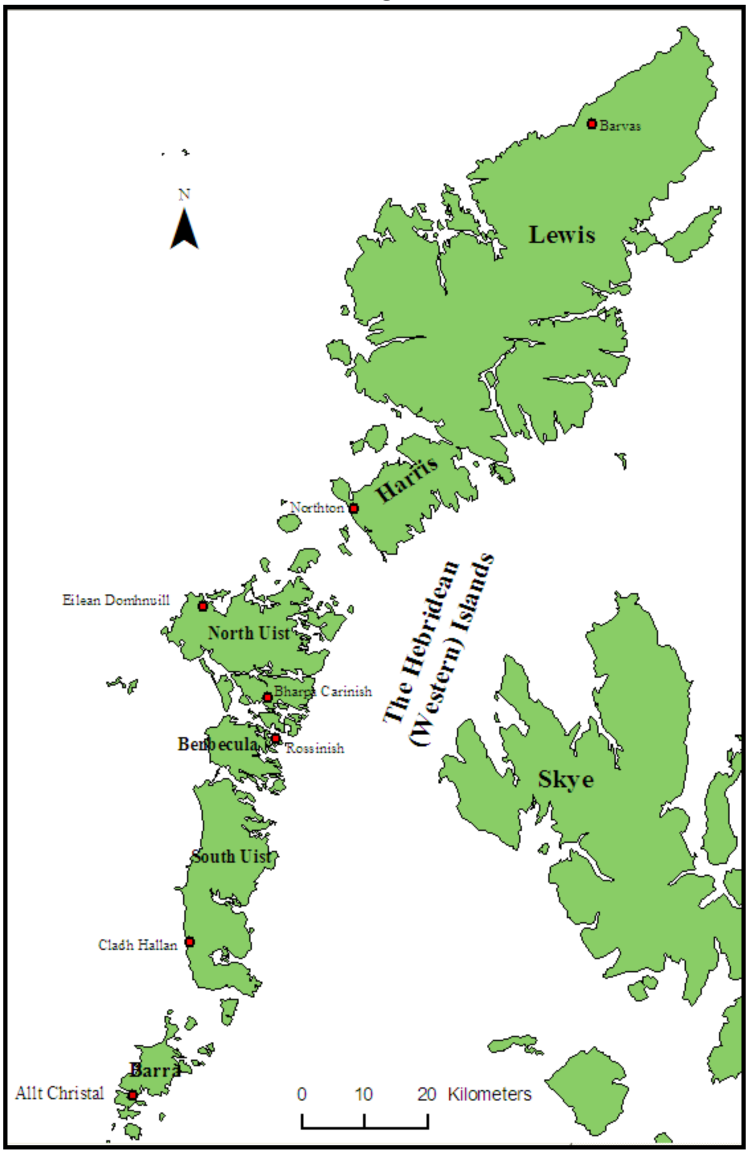


Figure 1.9: Shetland places mentioned in text.

The lack of substantial structure in the Hebrides suggests that many dwellings were slight, perhaps built using organic materials such as timber or turf. Stone alignments at Allt Chrisal (figure 1.9) for example might indicate that buildings were frequently remodelled (Armit 1996).

1.4.3.1 *Allt Chrisal: Floors*

Though settlement at Allt Chrisal was a little less ephemeral, hearths and post holes echo the pattern at Bharpa Carinish and may represent seasonal use. However several stone 'huts' of Neolithic date are dotted around a low valley (Foster et al 1995) and palaeo-environmental evidence indicates that barley cultivation was carried out near-by (Gilbertson et al 1995). At least one structure was built onto boulder foundations designed to level sloping ground (Foster 1995) and a thin layer of ash and charcoal rich soil accumulated upon this foundation platform. A second Neolithic structure was a stone round house with several annexes and boulder foundations (ibid.). The more ephemeral structures were thought to represent activity areas whilst the round house was the centre of domestic occupation (ibid.). The mid-late Neolithic phases were characterised by Plain, Unstan, Incised and Impressed-ware pottery (ibid.). No contemporary midden dump was recorded, however thin trampled or mixed 'layers' of accumulated material containing ash, charcoal, burned soil, pottery and stone tools are described (Foster 1985). Bone and shell were not preserved due to soil acidity (ibid.).

1.4.3.2 *Eilean Domhuill: Floors, dumps, dung heaps… and a 'tell'*

A settlement on an artificial islet called Eilean Domhuill, North Uist (figure 1.10) has been securely dated to the Neolithic (Mills et al 2004). Settlement here would not have been possible if occupational debris had not raised the level of the islet above the fluctuating water levels of Loch Olabhat (Armit 1996). The earliest occupation layers are presently submerged and are yet to be excavated, but at least 11 phases have been identified so far (ibid.).

Figure 1.10: Eilean Domhuill crannog, North Uist, Outer Hebrides.

The islet was reached by a causeway (figure 1. 10) which initially was built using timber but latterly replaced by stone following a period of water inundation (Armit 1996): the earliest buildings may have been turf built but were demolished when a series of oval or rectangular single stone buildings were erected. Their walls were stone faced with a rubble and earth core and the interiors are characterised by a central round or square hearth and timber partitions and fittings (Armit 1996). Floor layers were exceptionally well preserved under water and these contained straw, peat, bracken, ferns, twigs and other comminuted vegetation (Dixon 1989) indicating that a kind of thresh was laid. A wattle-work hurdle was found preserved underwater associated with these floors (Dixon 1989, Armit 1996) and hearth material, related to a later phase, was deposited over them (Dixon 1989). Midden like material was also found preserved containing pottery, animal bone, winkle shells, hazelnuts and coprolites as well as a length of straw rope (ibid.). Despite the remarkable opportunity this site provides to study Early Neolithic floors and middens, no further excavation has been undertaken. Occupation at Eilean Domhuill continued for almost a thousand years (Mills et al 2004) resulting in an almost 'tell like' appearance as midden and successive building operations debris accumulated (ibid.). Some buildings had turf superstructures built upon stone foundations (ibid.). Following water inundation, two adjoining rectilinear houses were constructed of stone with a possible timber frame work. These have been compared to Knap of Howar, Orkney (Armit 1996) and were constructed over a thick deposit of kitchen midden containing Unstan and Hebridean-ware pottery and stone balls (Armit 1988, Beveridge 1911). Dried dung was stored around the settlement area and this has been interpreted as a potential fuel store (Mills et al 2004). Unpublished data hints that peat was another principle fuel source (Mills et al 2004). Wood does not seem to have been exploited much as a fuel source despite evidence for birch and alder in the pollen record but it seems as though specific wood species were selected for either use as fuel or other specific purposes (ibid.). Turf may have been recycled as a fuel upon dismantlement of turf built structures but it was not routinely stripped for fuel.

That the surrounding landscape at Eilean Domhuill was cultivated by the Neolithic community is evidenced in the pollen record, but whether any buried soils exist is unknown. Information is available on land management practices but this is limited to the identification of erosion of surrounding soil into the loch which commenced around the same time as occupation (Mills et al 2004).

1.4.3.3 *Northton*

Large amounts of midden material were recognised at Northton, (figure 1.9) buried beneath coastal dune sands in a stratified sequence dating from the Mesolithic to the Iron Age (Gregory & Simpson 2006). The Mesolithic layers contained marine shell, charred peat, charcoal, bone and possibly herbivore dung in the later horizons. The Mesolithic midden seems likely to have been cultivated along with the natural boulder clay by Neolithic occupants (Guttmann 2006).

The Neolithic occupation layer contained Unstan and Hebridean-ware pottery, animal bone, charred grain, hazelnut shells and flakes of flint and quartz (Murphy et al 2001, Simpson, D.D.A 2006) and a length of well-built dry-stone wall suggests that at least one structure may have been built into this material (Simpson, D.D.A. et al 2006). The presence of a crown antler and a mace-head have been proposed as an indication of the midden holding a 'deeper conceptual and cosmological significance' with parallels drawn to the 'ritual use of refuse' at ceremonial sites in mainland Britain (Gregory & Simpson 2006).

Discrete midden deposits up to 1.5m deep have been recorded at other coastal locations across the Outer Hebridean archipelago, exposed by erosion. These accumulations may have begun as a Mesolithic phenomenon (Gregory et al 2005) but Neolithic pottery sherds found at a site on Barra (Branigan & Foster 2000) and Northton (Simpson D.D.A. 2006) suggest some continuity of use into the later period.

1.4.4 *Neolithic midden in the Outer Hebrides: a model*

Review of the most comprehensively excavated Neolithic settlement sites in the Outer Hebrides has demonstrated that midden material occurs both in association with settlement sites and as discrete deposits. Occupation activity is either slight and ephemeral leaving only the postholes and hearths with ashy deposits, or took place on artificial islets (Armit 1996).

1.4.4.1 *Islet based occupation*

Midden does not appear to have been chosen as a building material in either wall core or foundations but did accumulate around buildings on the islets, causing tell-like structures to develop (Mills et al 2004) and may have played an important role in keeping the ground level above the water-line at times. Hearths were cleaned out and the waste redeposited outside the dwelling but within the islet boundary. It is not known if midden was selected for use in cultivation and transported away from the islet settlements. The reasons for islet occupation in the Outer Hebrides are poorly understood but are unlikely to have been for defence purposes (Armit 1996), instead the view that a desire for control over nature which has been demonstrated in the wider European context (Whittle 1996, Hodder 1990) could have been a motivational factor (Armit 1996) is currently unchallenged.

1.4.4.2 *Non –Islet based occupation*

Evidence of settlement away from Islets is obscured by blanket-peat, erosion and later reuse. However ashy spreads have been reported at several excavated sites demonstrating that at least some aspects of domestic waste are preserved. Midden was not a pre-requisite to building and was not selected for use in construction but Mesolithic shell middens may have been recognised as suitable for cultivation. Some non-islet based settlement occurs in association with possible field walls but evidence for cultivation in such a context has not yet been sought.

1.4.4.3 *Summary*

The current body of evidence suggests that the deposition of waste in non-islet based settlements may reflect a landscape based way of life with ash and charcoal occurring around hearths and food debris collected in coastal middens. Within the islet settlements, waste was dumped outside the dwellings which may have been a deliberate ground-raising activity. The possible symbolic deposition of artefacts at Northon indicates that, like Orkney, midden may have been accredited with some special meaning. Much more research is necessary to elucidate these hypotheses and no attempt has yet been made to locate cultural material within Neolithic field systems and so the only evidence for the use of midden in cultivation comes from the in situ use of earlier midden at Northton.

1.4.5 *Shetland*

The earliest evidence for human presence recorded in Shetland is a shell midden at West Voe (figure 1.11). This comprises two midden horizons dating to the Mesolithic (4320-4030 BC, OSL) and early Neolithic (3750-3520 cal. BC) separated by a layer of sand and a length of stone wall. Midden containing diagnostic Neolithic artefacts abutted the stone wall and although the material in both layers was dominated by marine sourced food debris, the discovery of a cow tooth and pot sherds in the upper layer lent a crucial cultural dimension to radiocarbon and OSL dates. This implies that the West Voe Midden is the earliest known Neolithic site in Shetland (Gillmore & Melton 2011, Melton 2004, Melton et al 2004).

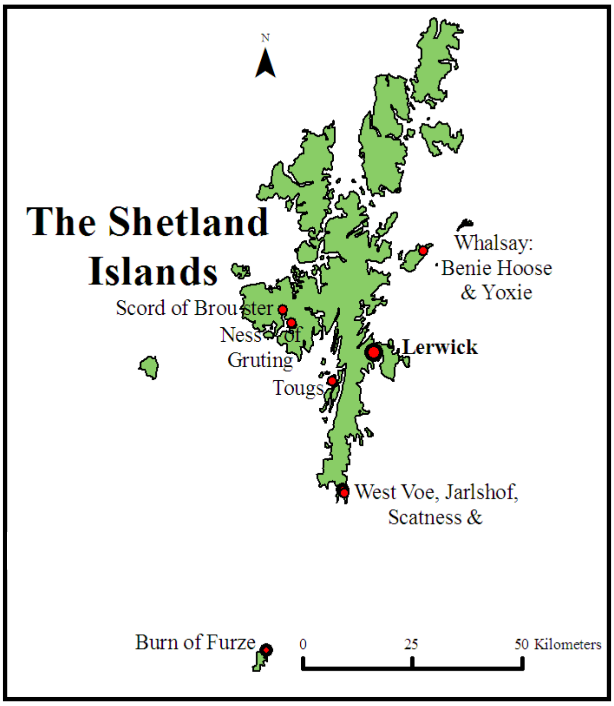


Figure 1.11: Shetland places mentioned in the text.

The continued use of Mesolithic coastal midden into the Neolithic allows a glimpse at the possible social connection to such sites in Shetland, despite storm inundation evidenced by the sand layer (Gillmore & Melton 2011). The West Voe middens indicate that the earliest 'Neolithic' settlement may have utilised stone as a construction material and that coastal middens were deemed suitable sites for continued activity. The wall has not been excavated sufficiently to allow insight into construction methods.

Like the Outer Hebrides, much of the Shetland landscape is peat-covered (50%, Robertson & Jowsey 1968 – cited in Barcham 1980). Peat commenced formation during the 6th millennium BC but gathered momentum during the Neolithic (Butler 1999) and many upland areas which were inhabited during the Neolithic and Bronze Ages were abandoned at the end of the Bronze Age. The complex reasons for abandonment might include environmental degradation or climatic deterioration, the debate, and data collection is ongoing. However, these landscapes have not subsequently been reclaimed for cultivation and as a result, it is possible that a wealth of archaeological structures survive beneath the present surface (Turner 201, Hunter 1996, Fojut 1993, Whittington 1979). Surveys between 1956 and 1980 by Calder (1956) and Winham (1980) have identified up to 200 prehistoric buildings preserved in this fashion (cited in Owen & Lowe 1999) but, as is the case with the Outer Hebrides, only a handful have produced any data relevant to this study.

1.4.5.1 *Scord of Brouster: pre-occupation surfaces, wall matrix, floors and fields*

Timber and stone houses at the Scord of Brouster (figure 1.11) have been identified as an early agricultural settlement. The earliest structures were wooden and were used whilst scrub clearance was carried out (Turner 1998). Two stone buildings (houses 1 and 2, figure 1.12) were radiocarbon dated to the Neolithic period (Whittle, 1986) and were contemporaneous with a surrounding field system (Turner 1998). Houses 1 and 2 were built upon 'occupation layers' which comprised dark brown to very dark greyish brown soils containing pot sherds, stone stools, burned bone, carbonised barley, charcoal and spreads of orange, yellow and red ash (Whittle 1986). The walls were built directly on top of these layers in 'dump' construction style. The interiors were faced with upright slabs and stones were heaped against their exterior, up to 4m thick. Cultural material including peat ash, pottery, stone tools and charcoal were incorporated into a very dark grey soil which formed the matrix of these stone dumps and may represent redeposited material from the earlier occupation layers (Whittle 1985).

Table 1.2: C14 Radiocarbon dating at Scord of Brouster (data retrieved from the Scottish Radiocarbon Database)

Lab Analysis ID	Material Dated	Uncalibrated date bc/ad	Calibrated date
Birm-966	Charcoal	2230 bc +/-100	3050 to 2450 cal BC
Birm-967	Charcoal	2230 bc +/-100	3050 to 2450 cal BC
CAR-242	Charcoal *(betula?)*	2270 bc +/-75	3020 to 2570 cal BC
CAR-243	Charcoal *(mixed)*	2145 bc +/-70	2880 to 2470 cal BC
CAR-244	Charcoal *(mixed)*	2510 bc +/-70	3350 to 2920 cal BC
CAR-245	Charcoal *(mixed)*	2395 bc +/-85	3350 to 2700 cal BC
CAR-246	Charcoal *(betula)*	2195 bc +/-70	2890 to 2490 cal BC
CAR-247	Charcoal *(mixed)*	2180 bc +/-80	2890 to 2490 cal BC
CAR-248	Charcoal	1715 bc +/-75	2300 to 1750 cal BC
CAR-249	Charcoal *(betula)*	2545 bc +/-75	3370 to 2920 cal BC
CAR-250	Charcoal *(betula)*	2505 bc +/-70	3350 to 2920 cal BC
CAR-251	Charcoal *(betula)*	2590 bc +/-65	3500 to 3020 cal BC
CAR-252	Charcoal	2440 bc +/-80	3340 to 2880 cal BC
CAR-253	Charcoal *(betula)*	3100 bc +/-85	3990 to 3650 cal BC
CAR-477	charred grain *(hordeum spp)*	1360 bc +/-60	1740 to 1440 cal BC
CAR-479	charred grain *(hordeum spp)*	1470 bc +/-70	1890 to 1520 cal BC
HAR-2413	Charcoal	2220 bc +/-80	2920 to 2490 cal BC

House 2 at Scord of Brouster was sub-circular with a kidney-shaped interior and house 1 was oval with a 'boat- shaped' interior. Both contained stone built recesses and were remodelled over time (ibid.). A stone bench was found in house 2 (ibid.) and a stone bed in house 1 (ibid.), the latter rested on a platform constructed using rubble, ash and a dark yellowish brown soil (ibid.). The floors were characterised by peat ash spreads originating from cobbled hearths, this was incorporated into a dark reddish brown to dark brown layer which contained charcoal flecks and concentrations. House 1 was the larger house and contained a gully running through its centre, this was stone lined in places and infilled with a dark sticky clay inter-lensed with peat ash (Whittle 1986). The floor layers petered out just outside the entrances to the structures.

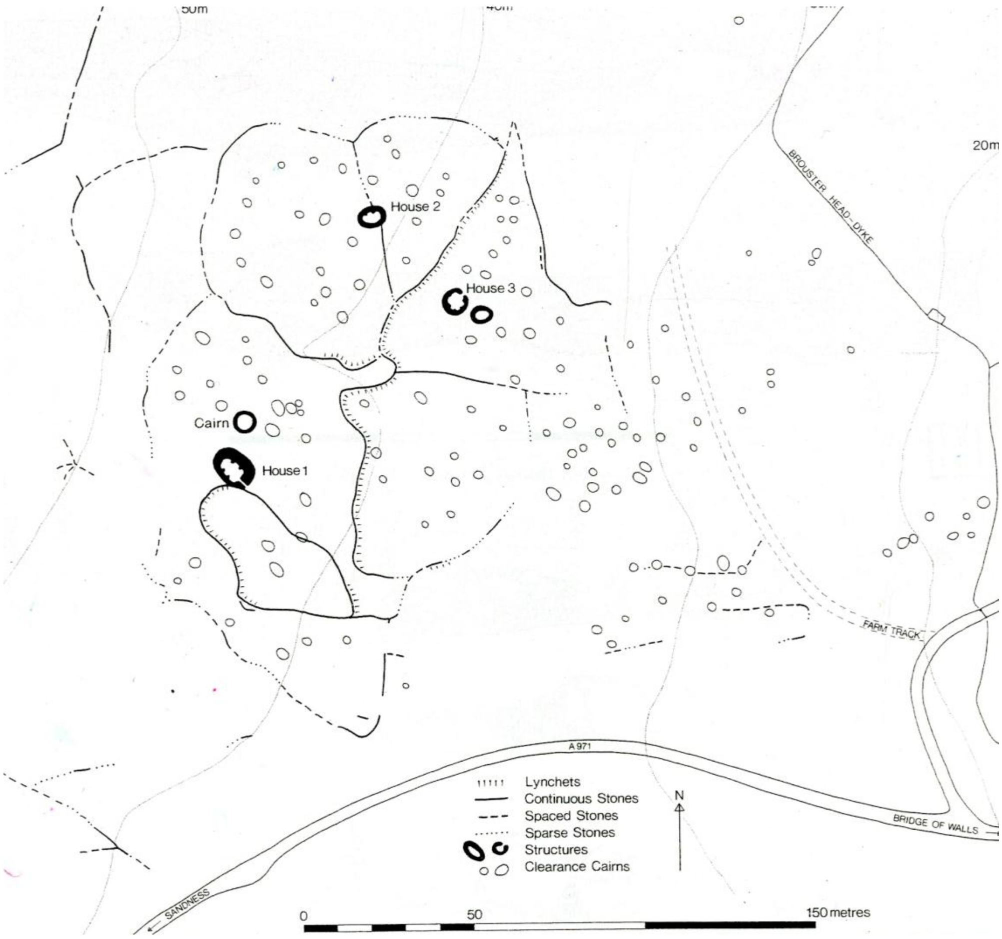


Figure 1.12: The main archaeological features at Scord of Brouster (reproduced from Whittle 1985)

Both houses were associated with field walls and a lynchet composed of dark, loose soil had formed against the exterior of house 1 (Whittle 1986), upon closer examination this was found to contain hearth ash, charcoal, charred peat fragments and woody plant material (Romans 1986: 128). The lynchet was interpreted as having been formed by ploughing and this is confirmed by extensive field walls and lynchets near-by buried beneath the peat (Whittle 1986). Further soils analysis at Scord of Brouster revealed that clearance of birch wood exposed a stony podzolic soil which was subsequently eroded by ploughing around the time that house 1 was occupied (Romans 1986). This appears to have been counteracted by the addition of domestic waste, though whether this was a deliberate approach to maintaining fertility is unknown (ibid.).

1.4.5.2 *Sumburgh runway:*

Evidence of Neolithic activity has been identified at the base of an occupational sequence extending into the Iron Age at North House, Sumburgh (figure 1.11) (Downes & Lamb: 2000). The earliest remains consist of ard-plough marks cutting into marine sand, covered by a 'thin layer of contaminated brown soil' (Downes & Lamb: 2000). Any contemporary settlement has not been uncovered, but a second phase of occupation evidenced by stake-holes and pits cut directly into the cultivated soil contained carbonised material including charcoal and a heather-rope fragment which have been radiocarbon dated to the late Neolithic or Early Bronze Age (table 1.3). This provides a useful *terminus ante-quem* for the erection of timber buildings over what must therefore have been earlier cultivation. The succeeding settlement at Sumburgh falls into the Bronze Age era of this study.

Table 1.3: Radiocarbon dating results from samples at North House, Sumburgh Airport. (Downes & Lamb 2000:10).

Context	Type of material	Uncalibrated radiocarbon age	Calibrated age range	Lab. ID
Shallow pit	Carbonized rope	3535±153bp	2290-1510BC	GU1015
Possible cooking pit or hearth	Charred wood	3629±53bp	2140-1790BC	GU1006

1.4.6 *Neolithic midden in Shetland: a model*

There are few settlement sites in Shetland which have been securely dated to the Neolithic period despite a strong research potential. The settlements which have been subject to investigation demonstrate that occupation was long lasting with buildings undergoing several phases of remodelling or rebuilding. The initial choice of settlement situation may have been based upon earlier social ties with specific sites. Midden material was an important indicator of past human occupation and Mesolithic shell midden sites continued to be a focus for activity in the Neolithic. The decision to construct stone buildings upon older occupational surfaces is evidenced at Scord of Brouster and this material was reworked into the walls of later buildings in a very different manner to that employed by contemporary communities in the Orkney and Outer Hebridean isles.

Fuel residues and other cultural materials were incorporated into cultivated soils at Scord of Brouster and Scatness. The description of 'contaminated brown soil' at Sumburgh runway may hint at a similar situation.

1.4.7 *Summary*

The Neolithic period in all three archipelagoes begins with an almost intangible transition from hunting and gathering life-styles to farming and more settled occupation. In keeping with the European model, the use of ceramics, growth of crops and domestication of animals is evidenced although this may have been adopted with cultural nuance. The trade of ideas and material culture is demonstrated in the similarities between ceramic styles but architectural wisdom manifests with well-defined regional differences. This may reflect regionally different lifestyle choices or necessities. There seems to be an early period characterised by timber buildings and a later period of stone construction across the study area. In the Outer Hebrides and Shetland it seems as though communities adopted certain aspects of the 'Neolithic Cultural Package' whilst choosing to maintain older traditions like using coastal midden sites and building slight, easily mobile shelters alongside these.

Despite their differences, activity sites across the Scottish North Atlantic seaboard all display evidence for the management or even veneration of anthropic sediments by the occupants.

The decision to occupy a particular place in the landscape may have been party influenced by the availability of this material.

Some communities in the Early Neolithic practiced a mobile way of life and built ephemeral houses and some, especially as the era unfolds, built stone structures.

Where information is available on the pre-stone settlement landscape, there is without exception evidence for these sediments. This ranges from thin occupation surfaces in Shetland and the Outer Hebrides to thick deposits in Orkney.

The use of midden material in construction is well documented in Orkney and a similar process seems to have taken place in Shetland. The wall core material in the Hebrides is described as 'earth' but the details of this haven't been published. Turf constructional material at Barnhouse, Orkney was found to contain a cultural component (Cluett 2007) and so it is possible that a similar situation may be found in the Hebrides.

Ash seems to have been spread from hearths around the floors of buildings. Whilst it is possible that ash spreads result from the final days or post-abandonment of the settlement, the incorporation through compact occupational layers might indicate spreading ash was considered an appropriate floor covering (Milek 2012).

Very little is known about the involvement of anthropic material in solidly dated Neolithic land management practices, evidence from the Orkney Isles and the Outer Hebrides suggests that dumped or accumulated organic material mixed with hearth residues and bone was cultivated whilst the same type of material is present in the Neolithic lynchet at Scourd of Brouster, Shetland.

This enigmatic situation might suggest that 'midden' had a defined 'recipe' during the Neolithic cultural area. However, given the current evidence, it is impossible to accept this as a resolved conclusion. Further work will be necessary to establish whether it is indeed fair to treat all occurences of ‘midden’ as the same and indeed what this constitutes. Although midden has been recorded in numerous different contexts, little attempt has been made to imagine what value prehistoric culture assigned to this material either perceived or actual. Actual value can be described in terms of nutrient availability for plant growth, usefulness as a building material and benefit to the community. However no attempt the define thse values has yet been undertaken.

1.5 Midden in context II: The Bronze Age

The transition into the Bronze Age is extremely gradual in the British Isles (Parker-Pearson 1993) with continuity of settlement noted in the Western, Shetland and Orkney Isles (Downes 2012, Nobel 2006, Armit 1996). In the North Atlantic Scottish Islands, a diagnostic cultural indicator of the period is the appearance of ‘beaker pottery’ in the archaeological record along with other novel technologies and fashions (ibid.). The beaker style pottery was introduced into the British Isles from the continent beginning around 2500BC along with metallurgy (Downes 2012). In Scotland this was met with a mixed response regionally (ibid.) with different communities choosing to adopt or adapt to new innovations at different times. Continuity of settlement is evident at Eilean Domhuill and Alt Chrisal in the Hebrides (Mills et al 2004, Armit 1996) but other Bronze Age sites were established on new land as well, especially in the latter part of the period (e.g.Cladh Hallan, Parker Pearson et al 1995). Orcadian settlements dating from the Neolithic period only rarely exhibit continuity of occupation into the Bronze Age (Dockrill et al 2007) but at least two exceptions have been identified at Tofts Ness and the Links of Noltland. Although evidence is in short supply, settlement in Shetland also seem to follow a similar pattern indicating a mixed cultural response to novel ideas and inventions across the study area. Some communities chose to continue occupation of the same sites whilst other sites were abandoned. One of the most obvious indicators that cultural change had indeed arrived in Orkney, Shetland and the Outer

Hebrides was a shift from communal burial in large funerary monuments to individual burials in cists (Nobel 2006). At the same time Neolithic megalithic monuments, midden and domestic structures were remodelled, this has been taken as an indication of a deliberate attempt to break away from the past (ibid.).

Domestic architecture did not change dramatically in either the Outer Hebrides or Orkney. Morphologically Orcadian houses became less rectangular and more rounded whilst Hebridean and Shetland structures shifted from oval to circular but the interiors continued to include similar features, especially in Orkney.

In Shetland and Orkney burned mounds began to enter the archaeological record during the Bronze Age. These are formed from midden-like material and contain heated, cracked stones interpreted as the residue of heating stones which then were placed into a water tank in order to boil water (Hedges 1986). Usually these mounds occur in association with small rectangular stone buildings containing a hearth and trough (ibid., Øvrevik 1985) but their exact purpose is subject to some debate (Øvrevik 1985, Turner 1998). In the Outer Hebridean Isles the few burnt mounds thus far identified date to the end of the Bronze Age but architectural parallels between a late Bronze Age/Early Iron-Age burnt mound at Ceann nan Clachan and Bronze Age settlement at Cladh Hallan indicate longevity of practice (Armit & Braby 2002). An internal analysis of burnt mounds indicate their composition to be of burnt stones and soil with various admixtures of charred peat, charcoal and ash (Carter in Armit & Braby 2002, Moore & Wilson 1999, Owen & Lowes 1999, Turner 1998, Hedges 1975). This material was allowed to accumulate into a mound with artefacts such as pottery and stone tools associated with it and allowed to remain in situ without any prehistoric cultivation or re-use noted.

Bronze Age settlements in Shetland and Orkney occur in association with field systems when preservation is favourable, which is especially the case in Shetland. Cultivated soils are evidenced by ard marks (Dockrill & Bond 2006, Simpson et al 1998), rig and furrow (Turner et al 2004) and micro-scale analysis of thin sections of soil (McKenna & Simpson 2011, Guttmann et al 2008, Guttmann et al 2006, Dockrill & Bond 2006, Turner et al 2004). The accumulated evidence demonstrates that large amounts of domestic waste were incorporated into agricultural soils during the Bronze Age.

1.5.1 *Orkney*

Few Neolithic Orcadian settlements continued into the Bronze Age (Dockrill et al 2007) and most of the archaeological evidence for the early Bronze Age comes from burials (Ritchie 1995). However, the cultural chronology interpreted during excavation at Crossiecrown, Mainland (figure 1.3) has been the subject of critical self-evaluation (Downes & Richards, 2000) which identified the challenges wrought by models of the 'Neolithic' and 'Bronze Age' in Orkney constructed by early, influential archaeologists. This high-lighted that the differences between Neolithic and Bronze Age settlements in Orkney are not clear-cut (ibid.).

1.5.1.1 *Crossiecrown: foundations, wall core and construction*

A paved area was created directly over natural soil at Crossiecrown (figure 1.11), over this, deep midden and rubble deposits containing early Neolithic pottery accumulated. Two almost identical structures dating to the Late Neolithic/Early Bronze Age were built into the midden (Card & Downes 2000). The entrances to these buildings face each other across an area of paving. The walls were built with a midden core within which a Bronze pin was discovered. The interiors contain stone furniture including recesses, beds, boxes and a small cell with a drain. The houses were occupied simultaneously and separately at different times and House 2 was filled with redeposited midden containing a sherd of Unstan ware (ibid.).

1.5.1.2 *Bronze Age Tofts Ness: deep midden, foundations and manuring*

During the Bronze Age agricultural endeavours were expanded at Tofts Ness, with a wider area brought into cultivation (Guttmann et al 2006). Domestic waste was an essential component of this expansion as it was used to create a deepened topsoil which allowed crops to be grown in a landscape which otherwise would not have accommodated this (Simpson et al 1998). Rigorous soils analyses have demonstrated that materials similar to the Neolithic midden were added to the extensive cultivation area during the Bronze Age, indicating economic similarities (Guttmann 2001). Human faeces have also been shown to have been incorporated into the Bronze Age cultivated soils (Simpson 1998).

A Bronze Age structure was erected by cutting into the stratified midden which continued to accumulate without stand-still from the Neolithic period (Dockrill 2007). The level of preservation of this building was such that only the flagged floor, post holes and the ghost of a cellular structure survive. Dating of bone and pottery in the stratified midden deposits showed that this building was in use during the later accumulation levels and a cultural change is represented by the appearance of incised pottery (Dockrill et al 2007).

That animal dung may have been used as a fuel source was suggested by soils analyses given the absence of sheep or cattle manure being applied as a fertiliser (Simpson et al 1998). Ethnographic evidence indicates that there was a complex relationship between different potential resources such as animal dung, seaweed and peat/turf and it is postulated that a similar model could be useful in understanding the deposition of materials at Tofts Ness (Dockrill et al 1994).

1.5.1.3 *Bronze Age Links of Noltland: manuring*

Two clusters of three buildings with associated yards, pathways and middens, dated to the Bronze Age, survive at the Links of Noltland (structures 1, 2 & 3 and 4, 5 & 6, figure 1.7). Each structure is oval in shape and is constructed with double skinned stone walls containing a midden core (Moore & Wilson 2009b). Both clusters are composed of two large domestic buildings with entrances facing each other and a smaller building, one of which contained a stone-lined tank. Each cluster is set within associated cultivation surfaces containing ard marks and possible hoof prints (Moore & Wilson 2012). The large buildings contain a central hearth and paved floors but one of the small buildings contains a clay floor. Structures 4,5 and 6 were surrounded by an area of shell-rich midden (Moore & Wilson 2009a) and middens surrounding both clusters contained stone and bone tools and objects, steatite vessel fragments, bone, shell and carbonised plant materials (Moore & Wilson 2009b).

Associated land surfaces were cultivated, with domestic waste and animal manures evidenced in the soils analysis, demonstrating a difference in land management practices between Tofts Ness and the Links of Noltland (McKenna & Simpson 2011).

1.5.2 *Bronze Age midden in Orkney: a model*

The use of domestic waste or 'midden' material in Bronze Age Orkney is poorly understood. This is largely due to the lack of excavation and subsequent publication which tackles the nuances of spatial distribution of this component. The additional challenge of reconciling cultural versus radiocarbon chronologies is difficult because many architectural and material traditions were carried through from the Neolithic.

Despite this the evidence available from the better known sites at Crossiecrown, Toftsness and Links of Noltland indicates that midden was an integral part of the settlement. At Crossiecrown and Toftsness midden accumulated in earlier phases of occupation was used as foundations but this does not seem to be the case at Links of Noltland. Double skinned walls with midden coring material have been recorded at these three settlements and also at the lesser known Bronze Age sites of Braes of Ha'Breck, Green, Howe, Knowes of Trotty, Stonehall and Wideford Hill (Carey 2012) but work is ongoing or unpublished. This continuation of practice from the Neolithic era is also evidenced by the architectural similarities between buildings of both periods. However, whether subtle changes in the type or distribution of anthropic sediments occurred has not been studied outside of the cultivation surfaces where indications that the 'ingredients' for material considered suitable for cultivation were slightly different during the Bronze Age as evidenced in soils from Tofts Ness and the Links of Noltland (Table 1.4).

Table 1.4: Anthropic material present in cultivated soils at Tofts Ness (Guttmann 2001) and the Links of Noltland (McKenna & Simpson 2011).

Site	Phase	Fuel residues	Ash	Seaweed	Bone	Burned Bone	Peat/turf	Charred peat/turf	Shells	Artefacts	Human/ animal manure
Tofts Ness	**Neolithic**	X	X	X	X	X		X	X	X	
	Bronze Age	X	X	X	X	X	X	X	X	?	X
Links of Noltland	**Early**				X		X		X		
	Later	X			X	X	X		X	X	X

Therefore, a model for the use of midden during the Bronze Age must be constructed using limited information. Anthropic sediments were sometimes cut to form foundations to buildings – as a continuation of earlier occupation and cultural material was mixed with human and animal manures to be incorporated into the fields. Anthropic sediments including artefacts and bones accumulated around the exterior of buildings and were used as wall-core.

1.5.3 *The Outer Hebrides*

Some of the best preserved beaker-period archaeology is found in the Outer-Hebrides (Parker-Pearson et al 2004) due to the favourable preservation alkaline marine shell sand machair landscapes present.

1.5.3.1 *Northton: floors, midden heap*

Overlying the Mesolithic/Neolithic midden at Northton were two or three beaker-period structures (Simpson D.D.A et al 2006) and associated midden deposits. The main structure excavated was oval-shaped and stone-built with a single skin wall revetted onto a sand bank and built into hollowed out sand. This building contained a central hearth and several peat-ash spreads. Within the stratified occupational floors were animal bones, antler, stone tools, ceramics and a fragment of bronze slag (ibid.). The midden which had accumulated outside was accumulated next to the structure, almost butting against the wall (ibid.) it was described as a brown sand containing peat ash, charcoal fragments, ceramics, stone and bone tools and lenses of sand, perhaps indicating aeolian inundation as it accumulated slowly or deliberate burial.

A slightly later midden contained similar components but was interspersed with 'dirty' sand., this was interpreted as having blown or eroded from another anthropic sediment near-by in the machair sand (Simpson, D.D.A. et al 2006). The extent of this midden was traced using auger survey and was found to occur also as an organic reddish brown layer containing more peaty turf or peat ash.

A consideration of these large amounts of midden material in association with the building was made by the excavator, the presence of a bone comb, human bone and a clay ball were interpreted as possible ritual deposits, expressing some form of social display (ibid.). The deposition of animal bone, craft produce and organic refuse is increasingly discussed using the framework of 'conspicuous consumption' alluding to the status of the household (Parker-Pearson et al 1996, Brück 2001 - both cited in Simpson D.D.A 2006). Midden accumulations directly outside the home therefore may be viewed as a 'positive social medium' (Simpson D.D.A 2006).

1.5.3.2 *Rosinish: cultivated surfaces*

A beaker-period settlement was excavated at a coastal site on Benbecula (figure 1.9) (Armit 1996). The details of the settlement excavation are as yet unpublished but the associated cultivated soils have been demonstrated to contain large amounts of midden material (Shepherd & Tuckwell 1976). Several phases of ard and spade cultivation were evidenced across an area 330m^2 buried beneath an old ground surface. Aeolian sand inundation occurred in between plough events and was incorporated into the underlying soil along with stone tools, ceramics, animal bone and carbonised cereal grains. These artefacts were interpreted as the spreading of midden material to consolidate sand-blow.

1.5.3.3 *Cladh Hallan: Floor deposits and infill*

A terrace (figure 1.13) of late Bronze Age round houses was built overlying an occupational surface at Cladh Hallan, South Uist (figure 1.9). Each house was dug into deep sand to create a semi-subterranean effect and the upcast material was incorporated into double skinned walls as core material (Parker-Pearson et al 2004).

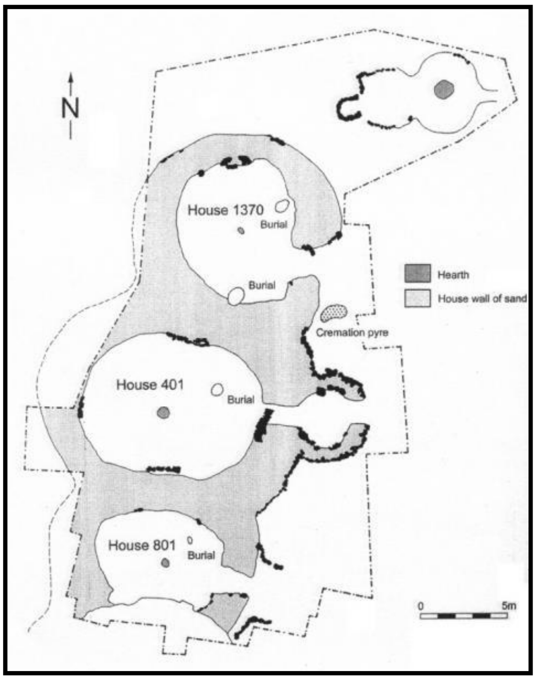


Figure 1.13: Plan of Cladh Hallan round houses. Reproduced from Parker-Pearson et al 2005, fig.3.

Different activities were proposed for different areas of the houses based upon the occupational floors excavated, for example cooking debris were found in the south-east quadrants and stone tools predominantly in the south-west (Parker-Pearson et al 2004). The floors are deeply stratified and accumulated over a 700 year period (ibid.), ash spreads surround a central hearth and different soil colours/textures were observed across the living space (ibid.). An interior platform was constructed using grassy turves in the northern half of the houses and human or animal burials are associated with the northeast, beneath the floors (Parker-Pearson et al 2005). The soils at the entrance of the south house were differentially eroded, this was interpreted as a result of controlling the movements of individuals in and out of the building using a line of stones (Parker-Pearson et al 2004).

The observation of controlled movement and activity within the houses is clearly reflected in the deposition of occupational debris at Cladh Hallan. Usually this type of spatial analysis is not employed on a settlement-wide scale and so this is a rare insight into possible resource control.

Cultivated field systems were associated with Bronze Age settlement (Parker-Pearson et al 2004).

Upon abandonment buildings filled up with windblown sand which contained artefacts and animal bone (Parker-Pearson et al 1995) perhaps indicating some midden material was incorporated. A building attached to the south house in the terrace contained large amounts of dog coprolites, indicating a conscious effort to concentrate this material in one place (Parker Pearson et al 2001).

1.5.4 *Bronze Age midden in the Outer Hebrides: a model*

As yet, there have been no comprehensive investigations published examining either Neolithic or Bronze Age midden exterior to dwellings in the Western Isles and so the spatial distribution and the social rules governing its generation, deposition and management are unclear. However, the records of midden preservation at datable sites presented in this short review demonstrate that potential does exist for this to be carried out.

The model which can be presented based upon this very limited and yet tantalizing data indicates that during the Bronze Age communities in the Outer Hebrides were involved with social control of movement and designated activity areas within the household. This lead to the discrete spatial accumulation of specific activity related debris in house interiors. There is as yet no complementary spatial analysis for exterior anthropic sediments, but a mild form of 'conspicuous consumption' may have been practiced as evidence suggests that midden was intentionally accumulated next to dwellings over long periods of time.

The constructional use of machair sands might indicate that selection of materials was dictated by environmental necessities (D.D.A. Simpson et al 2006). Upon abandonment, midden material was allowed to accumulate within structures.

The usefulness of midden material to consolidate loose sands for agriculture was appreciated but there is no obvious difference between the material collected in heaps or floor deposits and cultivated soils.

1.5.5 *Shetland*

Although the preservation of midden associated with houses in Orkney and the Outer Hebrides is excellent and extensive excavation in Orkney is facilitating some of the finest resolution research anywhere in the North Atlantic. Knowledge of midden investment in associated field systems is relatively scant, reflecting a lack of suitably preserved examples. This situation is certainly not the case in Shetland. The field systems of Shetland have recently been collated by Turner (2013) who demonstrated that a considerable volume of domestic waste was added to cultivated soils associated with Bronze Age settlement at the Burn of Furze and at Old Scatness representing significant investment of resource into arable activity (Turner et al 2004 cited in Turner 2013).

1.5.5.1 *Oval houses: Wall cores, floor and infill*

A stone building at Ness of Gruting, Mainland Shetland (figure 1.11), was recorded by Calder (1956). Although analysis of the cultural material (Henshall 1956) convinced the authors of a Late Neolithic origin, subsequent radiocarbon dating placed the construction in the Early Bronze Age (Barcham 1980) and it was noted that the ceramics may have had beaker influence (Henshall 1956). This emphasizes the gradual transition between 'Neolithic' and 'Bronze Age' in Shetland, and the dangers of reification in archaeology (Johnson 2004). Therefore it was difficult to determine the place of Ness of Gruting in this review.

The decision was taken to consider the site with the Bronze Age evidence in keeping with radiocarbon dates but the reliability of these has been called into question (Barcham 1980). Therefore the Ness of Gruting evidence is only hesitantly ascribed to the Bronze Age. The building itself was oval in plan (figure 1.14) and measured c.17m by 11.5m externally, it contained a central chamber with an apsidal-like recess at the rear (Calder 1956). The foundations of the building were not described in detail, but a scoop was dug into the natural top-soil to create a semi-subterranean chamber. The topsoil was then reportedly redeposited as core in between an inner and middle wall face (ibid.352) where it was found in association with cultural material evidenced by find spots 8 and 7 (figure 1.14).

The triple wall structure contained two types of core material, the outer-most core being mostly composed of pure peat ash which in places was stratified with fine brown soil (Calder, 1956). This ashy material also contained cultural material, mainly pot sherds but also carbonised barley grains (from which the radiocarbon dates were taken, Barcham 1980), a broken quern and stone tools. Elsewhere in Shetland, such as the nearby Stanydale and Gruting School oval houses, double-skinned wall cores tend to be composed of rubble and soil (Calder 1956) leading to the suggestion that the material may have been chosen as it would act as a strengthening agent to support the walls whilst being less labour intensive than digging out earth (ibid.).

Houses of a very similar type have been described at Whalsay (figure 1.11), where peat-ash was found within the cores of several skins of stone wall (Calder 1960) at Yoxie and Benie hoose. These buildings were involved with earlier phases of occupation as evidenced by pottery, ash and stone tools found beneath the paved floor (ibid.). Ash from the hearth formed spreads across the floors (ibid.) and the buildings may have been infilled with later midden material as evidenced by traces of bone in a recess in the Benie hoose (ibid.). To the exterior of the Benie Hoose, field walls and a heap of soil and stone tools were identified

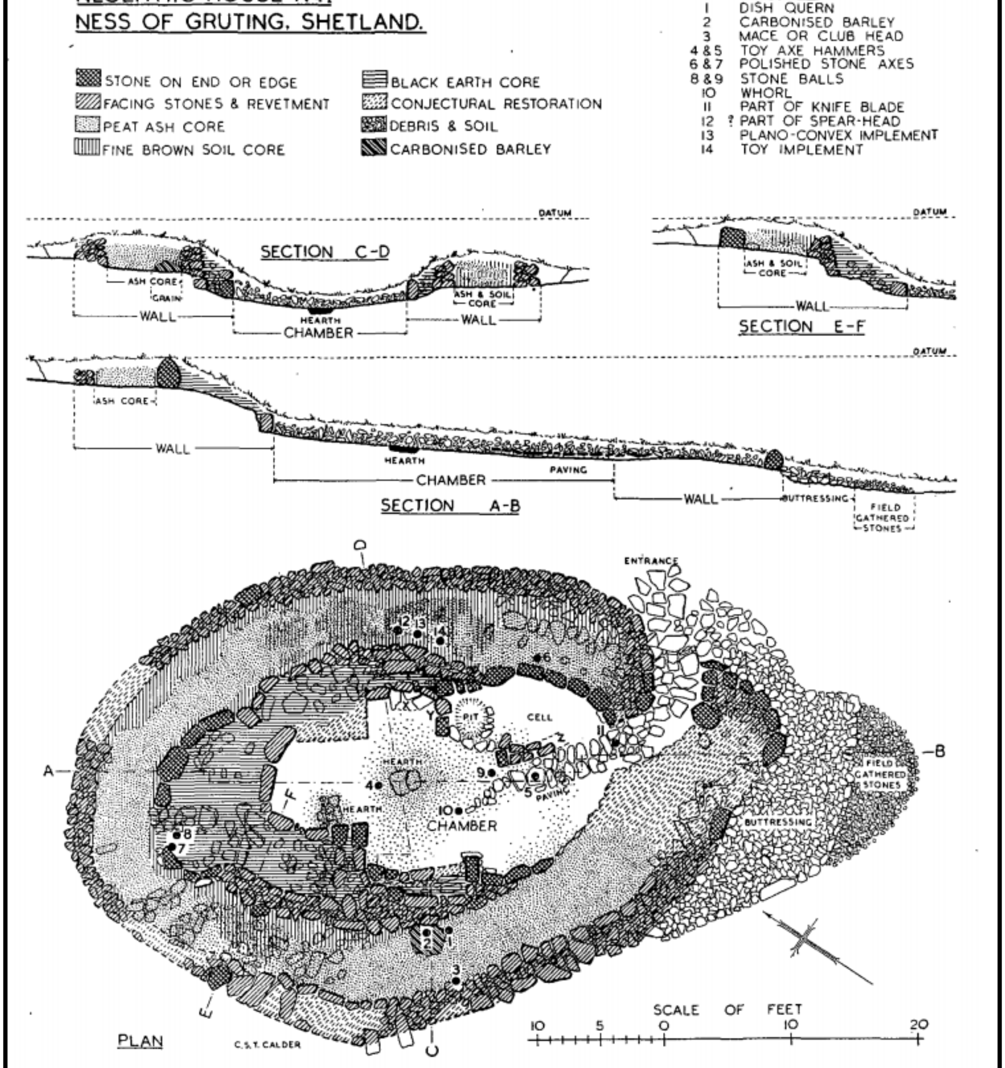


Fig. 5.

Figure 1.14: Plan and sections from excavation at Ness of Gruting. Reproduced from Calder 1956.

1.5.5.2 *Scord of Brouster: Oval house with cultivated fields*

A third oval shaped stone-built house at Scord of Brouster was radiocarbon dated to the Early Bronze Age but demonstrates a clear continuity in architectural style with Neolithic occupation. Indeed later phases of building in house 1 produced a similar radiocarbon date (Whittle 1986) demonstrating continuity of occupation between the Neolithic and Bronze Ages. Architectural continuity is not paralleled however by any cultural material recorded in the wall core or matrix material as described at houses 1 and 2. Instead the 'dump construction' walls contain a rubble core (Whittle 1986). It was surmised that the walls may have been the foundation for a timber, turf or peat super structure and there were post holes for a roof (ibid.). The walls near the entrance to the house appeared to rest upon a brown to reddish brown soil containing carbonised material which overlay the subsoil, the excavator interpreted this as an earlier occupational level.

Internally the house chamber was oval with recesses in the walls and stone lined pits dug into the floor. The floor deposits within house 3 are related to a central, polygonal hearth, with yellow and orange ash spreads in its immediate vicinity. A sticky brown to dark reddish brown soil containing carbonised twigs, stone tools and carbonised grain covered a cobbled floor. Cobbles were placed directly into the subsoil and rested in a brown to dark brown soil matrix (Whittle 1986).

1.5.5.3 *Jarlshof: Floors, midden heaps and cultivation*

Jarlshof (figure 1.11) is a multi-period settlement spanning the Neolithic to late Norse eras (Dockrill & Bond 2006). Early phases of building were evidenced by occupational sediments, midden and structural material (Childe 1938). These have subsequently been radiocarbon dated to the Early Bronze Age (Dockrill & Bond 2006) but there are strong overlaps with Neolithic material culture (Hamilton 1956).

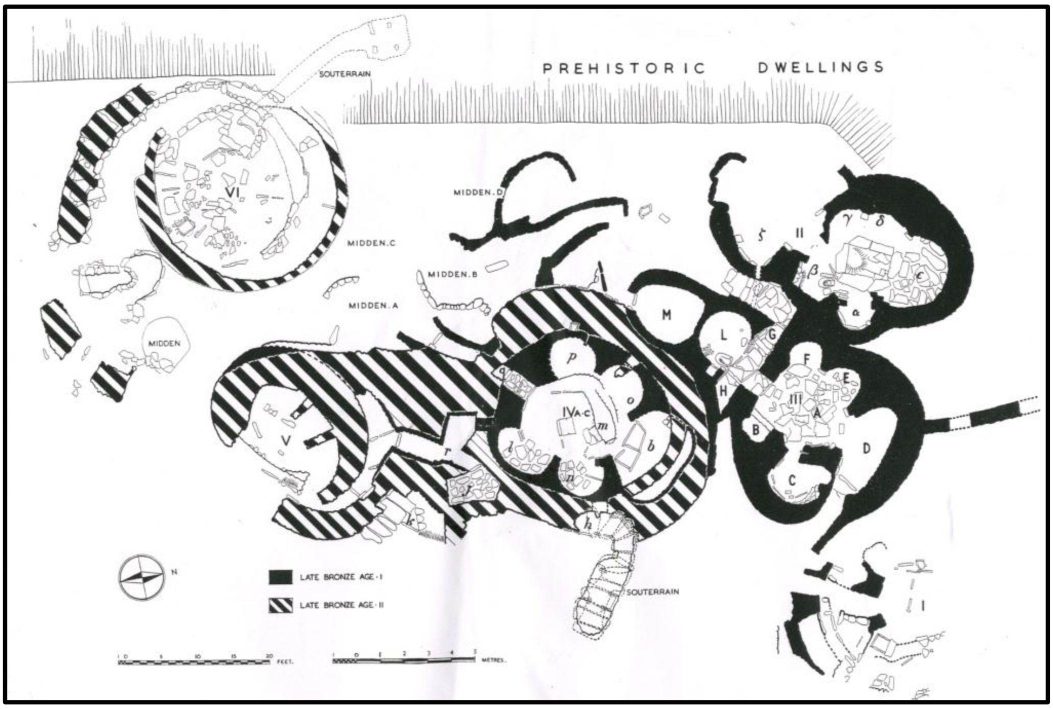


Figure 1.15: Plan of Neolithic or Bronze-Age structures at Jarlshof. Reproduced from Hamilton (1957).

Associated with these structures were a series of stratified occupational surfaces and midden horizons, the earliest of which rested upon clean sand (Hamilton 1957). The first phase of occupation and midden (O III & M III, Childe 1838) contained shells, bones, stone tools and ceramics (Childe 1938, Hamilton 1957). Overlying these layers were a second occupational surface and midden (O II & M II, Childe 1938). O II was accumulated over a constructed floor layer, paved in places and containing yellow clay which was brought in and stamped down (Hamilton 1957, Clarke 1938). The accumulations over this floor contained bone and stone tools, a decorated plaque, plain-ware pottery and shell in stratified layers. These were thought to have accumulated slowly (Hamilton 1957). Further excavation revealed a cluster of four stone built houses (solid black outline, figure 1.15) equivalent to OII and thus built over earlier midden deposits (Hamilton 1956). These structures were stone-built with double skinned, rubble cored walls and contained square hearths, circular recesses and tanks (Hamilton 1956). The floor deposits in each building suggested different uses; for example an animal stable (house 2) and a bronze workshop (House 3) (Hamilton 1956). Domestic wastes including food refuse (animal bones), charcoal and peat ash were incorporated into the floors, but was also deposited in middens to the south west. The midden was separated into four discrete areas (A, B, C & D see figure 1.15) by the excavators based upon their internal compositions (table 1.5), with a line of boulders forming a barrier between A and B (Hamilton 1956).

Table 1.5: Description of Jarlshof Bronze Age middens. Based upon Hamilton 1956

Midden	Components
A	**Blackened soil, shells, fish bone, animal bones & two broken querns. Defined by line of stones.**
B	**Similar to A, with clay molds, stone tools and an articulated dog skeleton.**
C	**Quern, stone tools, ceramics.**
D	**Anvils, stone tools and 'relics of an early date'.**

Two horizons of associated cultivation evidenced to the north west of the settlement by ard marks and abraded pottery, utilised domestic material including bone, carbonised plant and artefacts. These layers were thought to be equivalent with MII and M III (Dockrill & Bond 2006).

1.5.5.4 *Scatness and Sumburgh: Cultivated soil and wall cores*

A Neolithic/Bronze Age settlement at the base of a 5m high mound was associated with cultivated soils dated to the late 3rd millennium BC (Guttmann 2001). Cultivation was evidenced by ard marks and domestic waste material was incorporated into the soil. This included bone fragments, wood charcoal and charred peat/ash. In depth soils analysis demonstrated that this was not a soil which had been manured but was a midden heap which had been cultivated in situ (Guttmann 2001). The presence of both Neolithic and Bronze Age pottery within this material might indicate that cultivation occurred during the Bronze Age.

At Sumburgh Runway soil cultivated during the Neolithic period was stripped to make way for a stone structure built during the later Bronze Age. This was oval shaped and utilised double skinned wall construction. The building contained recesses and a central square hearth associated with a clay or paved floor. A second floor surface was constructed upon the paving consisting of yellow clay (Downes & Lamb 2000). During the use-period of the house midden material including burned clay accrued against the exterior wall and became incorporated within it causing the wall to increase in thickness (ibid.). This was also noted at a second house at Sumburgh, where it was possible to determine that hearth ash was carried from the interior to the exterior, stones were periodically added to this (ibid.).

1.5.5.5 *Tougs: wall core, floors and burnt mound*

A burnt mound containing shattered stone in a grey-black carbonaceous matrix (Hedges 1986) was excavated at Tougs (figure 1.11). This was associated with a rectangular stone-built double skinned structure dated to the early Bronze Age (Hedges 1986). The building was laid on rubble foundations and a clay floor was constructed along with a rectangular hearth and trough. A silty brown layer containing charcoal and burned stones had accumulated upon the clay floor (ibid.). A second structure close by was revealed to be a mid-late Bronze Age construction and conformed to the ‘oval house’ type. The rubble wall core contained ‘agricultural stone implements’ (ibid.) but any fine matrix was not described. The walls were constructed over an old ground surface which also was traced beneath the interior of the building where it contained charcoal flecks and ash (ibid.). The floor was constructed using yellow clay which was up to 70mm thick and contained ash and carbon. Stone lined pits dug into the floor were filled with bright red ash and carbon. No large midden deposits were recorded, but a possibly contemporary field wall was constructed using clay and cultural material (midden) as core between rough stone facing (ibid.). Soil beneath the field walls appeared to have been augmented and clearance of stones is likely to be Bronze Age in date but no ard marks were discovered (Hedges 1986).

1.5.6 *Bronze Age midden in Shetland: a model*

The archaeological distinction between Neolithic and Bronze Age is challenging in the Shetland context. Overlapping architectural, cultural and industrial traditions are strongly manifested and this is particularly relevant to the use of midden. Therefore the model visualized for the Neolithic is equally as relevant to the Bronze Age context.

The archetypal 'oval' house, conceived during the Neolithic era continued, utilising domestic waste within the wall core in both double-skin and dump construction. Floors were constructed using clay and occupational deposits dominated by ash and 'midden heaps' of similar materials were also created out-with the home. Some communities cultivated their midden heaps in situ, but others redeposited domestic waste as manure into cultivated soils. There is evidence for indoor animal stabling in the later-Bronze Age and channels at Jarlshof and Sumburgh may have served to carry effluent but it is not known what happened to used animal bedding and dung outputs during this period.

1.5.7 *Summary*

The transition to the Bronze Age cultural period in the study area is subtle, each archipelago demonstrates continuation of practice preserved in architectural, technological and material styles well into the second millennium bc. Whilst the trade of ideas and technology is evidenced (between Skara Brae and Jarlshof for example) communities remained culturally diverse during the early Bronze Age, with some similarities beginning to appear in architectural and ceramic styles into the middle of the era.

Anthropic sediments are typically well preserved and in several localities (Cladh Hallan, Links of Noltland, Tofts Ness, Jarlshof) preservation is exceptional and demonstrates complex formation processes contributing to sediments containing a range of fuel resides, organic and inorganic artefacts and waste. The deposition of constituents around sites forms a network of activities which have the potential to be reconstructed. However, comprehensive site-wide investigation has not yet been attempted and so the complexities of this material are only understood as a patchwork composed of different geographic localities across a wide expanse of time which erases the possibility of viewing subtle changes.

Across the study area anthropic sediments occur incorporated into or upon floors and are described as accumulated next to buildings, collected in heaps and exploited as crop fertiliser. Material was also allowed to accumulate within structures upon abandonment. In Orkney and Shetland key components of anthropic sediments were utilised in wall core construction and Orcadian communities cut into and built upon sediments generated by previous dwellings.

1.6 Discussion: Midden and its uses through time

The architectural and cultural styles of the Neolithic period were carried on into the Bronze Age, leading to many Bronze Age dwellings in Shetland being misidentified as Neolithic. Just as early Neolithic communities chose to maintain the traditions of their ancestors, it appears Bronze Age communities continued the architectural, industrial and cultural traditions of the Neolithic. Tracking the transition from the Late Neolithic to the Early Bronze Age is a recognised challenge in archaeology. It has been argued that any attempt to define the 'Neolithic' or 'Bronze Age' is to produce a reification (Johnson 2004) which ignores the diversity of human experience and the influence of regional environment and culture through time (Downes & Richards 2000).

The critical self-evaluation by Downes & Richards (2000) has demonstrated that construction of a model for either Neolithic or Bronze Age styles can be misleading and the Ness of Gruting site is considered 'Neolithic' by many authors (Calder 1956, Barclay 2002) as radiocarbon dates straddle the traditional 3rd to 2nd millennium divide. Therefore, instead of adopting these cultural reifications it may be more productive to consider the different uses of midden material in response to local variations in cultural practice, environmental pressures and climactic conditions.

Anthropic sediments occur abundantly in Orkney and to a lesser extent in Shetland and the Outer Hebrides during the Neolithic and Bronze Age but, in keeping with other cultural aspects. Strong regional and local variations in their post-depositional functions are evident.

The subtle changes in the selection of cultivation plots and manures over time may have been instigated by soil erosion (e.g. Scord of Brouster, Eilean Domhnuill) or sand inundation (e.g. Tofts Ness, Skara Brae) and so environmental pressures may have been the key instigators in cultural change as innovation or adaption had to occur in order for communities to continue agricultural operations and maintain habitation.

In the absence of good building timbers, stone, augmented by bonding material which often took the form of occupation debris, fuel residues, kitchen waste etc was used in construction. The diversion of this material onto cultivated land surfaces would reduce its availability for building fabrication and so may have triggered communities to seek ways of maximizing the usefulness of different materials such as animal manure, fuel residues and peat.

The body of available evidence suggests that anthropic sediments are well preserved at the majority of prehistoric sites in the study area and that intensive and extensive analyses of deposits from different archaeologically resolved zones of activity (such as floors, hearths, fields etc) around prehistoric settlements has the potential to allow reconstruction of the distribution of materials across not only the settlement site but also into the wider landscape. This in turn offers the opportunity to gather evidence for the social regulations which may have controlled the management of 'midden' material as a resource.

Investigation of discrete anthropic sediments such as occupational floors, wall cores, cultivated land surfaces and midden heaps could help elucidate whether different materials were selected for their individual properties. This led to the identification of 'recipes' for wall core, fertiliser, land-stabilisation or floor construction. These concepts may be given a temporal dimension with the examination of which midden components were important at Neolithic and Bronze Age settlements. This would help establish whether changing environmental factors influenced resource selection and use. Review of published records of anthropic sediments and midden presented above has allowed some preliminary indications of recipes (table 1.6), but further investigation is needed to support and elucidate these very broad findings.

Table 1.6: Desk-based review: The forms of 'midden' in the North Atlantic seaboard - Neolithic & Bronze Age 'recipes'.

Type	Description
Coastal	Shell middens begun by Mesolithic hunter-gatherers. Used by culturally Neolithic groups who deposited ceramics, bones and other artefacts. Sometimes used as a settlement site.
Foundations	Occupational deposits (similar to floors), including fuel residues, ash spreads and lenses.
Floors	Fuel residues, mainly ash spreads. Also compacted 'soil' including broken artefacts.
Walls	Clay, earth and ash, broken artefacts and carbonised cereal grains. Animal bones.
Dumps	Mixed occupational deposits, in discrete dumps including fuel residues, animal manure, bones and artefacts. Sometimes flattened out and cultivated in situ.
Infill	Mixed occupational deposits including fecal waste, and occasional 'special deposits' such as articulated skeletons and figurines.
Cultivation	Burned turf/peat fragments and other fuel residues, ash, domestic waste including bone and night soil. Changes over time.
Stabiliser	Burned and unburned turf/peat and other fuel residues and domestic waste.

1.7 Research opportunities

Review of current knowledge of anthropic sediments across the Orkney, Shetland and Hebridean Islands has identified that the in-depth study of the formation and use of these types of deposit has enhanced academic appreciation of past land management and cultural activities whilst allowing consideration of associated environmental processes. However, the network of deposits created by these behaviours and the perceptions which they represent is still poorly understood as research has tended to focus on just one or two types of archaeologically resolved contexts (e.g. dumped deposits or cultivated fields).

The preservation of different types of anthropic sediments in the study area (figure 1.1) is exceptional and presents the opportunity to engage with the possible origins and reasons for the creation of these deposits (Milek 2012).

The foundational spatial analysis of anthropic sediments completed at Skara Brae (Simpson et al 2006) has demonstrated that there are visible differences in their composition; anthropic sediments are not homogenous. This indicates that there is the potential to explore how Neolithic communities perceived the suitability of different materials for different functions by studying the spatial distribution of different components across settlement sites.

The discovery at Tofts Ness of very different arable land management practices during the Neolithic and Bronze Age utilising midden material has provided reason to believe that knowledge of the highly fertile properties of domestic waste in the Neolithic may have been developed later (in the Bronze Age) as a response to environmental pressures and allowed cultivation to continue into the Iron Age despite the odds.

To date no attempt has been made to explore the links between these key discoveries despite the powerful opportunity they present to address some of the current principal questions surrounding the symbolism of midden in the North Atlantic and environmental pressure during the Bronze Age.

Archaeologists have long been aware of a possible symbolic element to midden in Orkney (Jones 2005, Garnham 2004) and this has become an important aspect of excavation (e.g. Moore & Wilson 2011a) and research (e.g. Carey 2012). However, why people were placing structured deposits into midden and what the significance of filling up abandoned buildings with it was is still utterly unknown. This has led some to ponder whether the nutrient rich properties of highly organic waste was recognised but poorly understood, enticing communities to imbue it with mystical powers (Case 1969 cited in Thomas 1999). Assessment of the extent to which Neolithic communities recognised their own ability to control the properties of midden has not yet been attempted, providing the opportunity to develop the body of knowledge from Tofts Ness and Skara Brae.

During the Bronze Age, midden continued to be an important resource and little change is noted in dumped material where continuity of deposition is observable at Tofts Ness.

However, subtle changes are suggested for constructional uses as evidence by the use of yellow clay mixed with ash in floor manufacture at the same site. Changes in the rules governing use of midden in cultivation may also have occurred in Bronze Age Orkney, as animal manure became a more important ingredient and domestic waste less so. By the pre-modern era resource management for agricultural fertilisers were manufactured by importing peat mould into animal byres as bedding. This material once nutrient enriched by excreta was redirected onto fields (Fenton 1997: 281, Davidson and Carter 1998, McKenzie 2006).

1.8 Conclusion

Anthropic sediments are an integral facet of prehistoric settlement in the North Atlantic Scottish seaboard and retain exceptional preservation. Their detailed study has led to a greater appreciation of land management, cultural activities and palaeoenvironments.

Characterisation of anthropic sediment components and the archaeological contexts in which these are found can help disentangle the cultural behaviours which lead to their formation. Application of earth science analytical methods to amended agricultural soils can reconstruct prehistoric land management practices.

Preliminary desk-based assessment carried out in this chapter by collating data from a range of sites has given an early indication that there is potential for 'recipe' identification within anthropic sediment. However, the differences demonstrated in other archaeological facets such as architecture and ceramics indicate that such a broad range of sites introduces idiosyncratic cultural variables.

The addition of a temporal dimension, spanning the Neolithic and Bronze Ages has demonstrated that cultural change happened gradually in the study area and anthropic sediments reflect this with subtle differences in their composition and use but again, this information is collated from a wide range of sites.

As yet there has been no study which has characterised the different types of anthropic sediments across a settlement to examine how different components are distributed and explore the concept of 'recipes' critically, nor has any attempt been made to link this type of knowledge with anthrosols and anthropic sediments in the associated wider landscape.

To begin to tackle these gaps, two basic competing hypotheses are proposed which will form the foundation of this research;

1. Anthropic sediments are by-products of human occupation which were opportunistically exploited for a variety of purposes with no selective storage of materials for specific purposes.

2. Anthropic sediments were deliberately managed, with specific components such as fuel residues or organic materials selected for spatially arranged deposition in order to perform specific functions around the settlement.

1.9 *Summary*

This thesis employs geoarchaeological methods to explore the different 'recipes' for anthropic sediments and how their uses changed as communities dealt with increased storminess during the Late Neolithic and Early Bronze Age.

To date no attempt has been made to explore any relationship between the presence of specific domestic waste components in Neolithic and Bronze Age cultivated fields and the spatial variations in anthropic sediments around related settlement sites.

As yet no investigation into Neolithic and Bronze Age floors has been attempted and no study has been able to elucidate whether midden was purposefully generated for specific functions around settlement sites or whether the detritus of occupation was opportunistically exploited in whichever way seemed appropriate at the time.

In exploring this crucial knowledge gap, the present research seeks to provide a narrative for continuity and change in land management practices set within their archaeological and palaeo-environmental contexts which will contribute to understanding of cultural responses to environmental changes in the Neolithic and Bronze Age Scottish North Atlantic seaboard.

Table 1.7: Uses of 'midden' at sites reviewed

	Site	Cultural Period	Deep Foundations	Built over earlier occupation surfaces	Wall core	Floors	Infill	Cultivation in situ	Spreading into fields	Mound outside structures			Extensive Spreads	Significant finds
										Without animal dung	With animal dung	Dung content Unknown		
Orkney	Knap of Howar	Early-mid Neolithic (Ritchie 1985)	X		X								X	
	Skara Brae	Mid Neolithic (Simpson et al 2006)	X		X	X	X				X			
	Rinyo	Late Neolithic - Early Bronze Age (Childe & Grant 1938)	X		X	X								
	Links of Noltland	Mid Neolithic - Early Bronze Age (Moore & Wilson 2011)	X		X	X	X					X	X	X
	Stonehall	Neolithic (Carruthers & Richards 2000)		X	X	X	X							X
	Crossiecrown	Early Neolithic – Early Bronze Age (Card & Downes 2000)	X	X	X							X		
	Barnhouse	Neolithic (Richards 1986 & 1989, Cluett 2007)	No	No	X							X	X	
	Ness of Brodgar	Neolithic (Card & Cluett 2005)				X	X					X		
	Tofts Ness (Guttmann et al 2006)	Neolithic				X		X		X			X	
		Bronze Age				X			X					
Outer Hebrides	Eilean Dòmhnuill	Early-late Neolithic (Mills et al 2013)	?			X					X			
	Northton	Mesolithic – Late Neolithic (Simpson, D.D.A et al 2006)	?					X			X		X	X
		Bronze Age (Simpson, D.D.A et al 2006)		X		X	X						X	X
	Allt Chrisal	Mid-Late Neolithic (Gilbertson et al 1995)	?											
	Cladh Hallan	Bronze Age (Parker-Pearson et al 2004)		X		X	X					X		
Shetland	Ness of Gruting	Neolithic/Bronze Age(Calder 1956)	No	X	X	X						X		
	Scatness	Neolithic-Bronze Age (Guttmann et al 2006)						X						
	Scord of Brouster (Whittle 1986)	Neolithic		X		X			X			X		
		Bronze Age			X									
	Sumburgh (Downes & Lamb 2000)	Neolithic		X					?					
		Bronze Age		X	X	X								
	Tougs	Bronze Age (Hedges 1986)				X			?					
	Jarlshof	Bronze Age (Dockrill & Bon 2006)			X			X				X		

Chapter Two

Chapter 2 Developing a research framework for the investigation of anthropic sediment formation and management: midden – a human ecodynamics perspective

2.1 Introduction

This chapter will be concerned with developing a model for the flow of materials around a settlement site and landscape based upon review of archaeological sites presented in chapter one, archaeological concepts of midden and a geoarchaeological approach to cultural and environmental processes. This will set up the research framework for investigating the ways in which anthropic sediments were formed and managed on the Scottish North Atlantic seaboard during middle prehistory. Engagement with human ecodynamics theory allows this framework to incorporate the social and environmental fluidity which defines archaeological deposition over time.

In Chapter one three key concepts which this thesis relies upon were established; first, that studying anthropogenically modified soils and sediments allows engagement with past land management practices at prehistoric sites (e.g. Tofts Ness, Scourd of Brouster). Second that communities influence and are influenced by their environments, for example islet settlement in the Western Isles and stabilization of sand blow at Skara Brae and Tofts Ness; thirdly that all the sites reviewed demonstrated that soils and sediments are potential archives of information representing both human activity and the environment.

The form and preliminary indications of 'recipes' were presented for anthropic sediment formation and use in middle prehistory based upon the accumulated evidence from both archaeological and soils based research (table 1.6), building upon the thesis aim; to provide a narrative for continuity and change in land management practices set within their archaeological and palaeo-environmental contexts which will contribute to the understanding of cultural responses to environmental changes in the Neolithic and Bronze Age Scottish North Atlantic seaboard.

The distinctions between Neolithic and Bronze Age culture in the study were shown to be subtle with many overlaps in architectural style, material culture, tools and resource utilization. Furthermore construction and land management technologies demonstrated locally idiosyncratic tendencies with chronological overlaps and gaps in development.

The competing hypotheses proposed in chapter one provide a basic foundation to the thesis aims but they require expansion to explain the complexities of cultural and environmental interaction and change (human ecodynamics). Multiple-working hypotheses provide a pathway to engage with human ecodynamics theory, and so the aim of this chapter will be to develop a model for the formation and management of anthropic sediments at prehistoric sites on the Scottish North Atlantic seaboard to facilitate the generation of multiple-working hypotheses which will explain any spatial variation of anthropic sediments and why these might have changed over time.

2.2 Midden as part of a culturally ecodynamic system

2.2.1 *Site formation processes*

Chapter one demonstrated that archaeological research in the Scottish North Atlantic seaboard has repeatedly encountered large volumes of anthropogenically deposited materials intimately associated with human settlement. Review of anthropic sediments at a selection of archaeological sites across the Scottish North Atlantic seaboard has shown that the term ‘midden’ which has been traditionally applied in archaeological literature stands apart from the Concise Oxford Dictionary of Archaeology definition of ‘midden’ as a heap of rubbish or occupation debris (Darville 2008). Middens can be heaped refuse, but occupational debris also manifests as floor layers and appears within constructional materials and cultivated soils. Detailed study at Tofts Ness, Skara Brae, Cladh Hallan and Eilean Domhuill have demonstrated that complex cultural activities are involved in its formation.

A similar conclusion was reached following intensive anthropic sediment study at the Neolithic settlement site at Çatalhöyük in Turkey;

[...] It is not sufficient simply to identify the context as "midden" when these deposits have complex formation processes resulting from diverse activities. [...] Shillito & Matthews 2012

Furthermore, there is emerging evidence that midden may have been purposefully managed with different elements being deliberately incorporated into different places.

Redefinition of what is meant by 'midden' is then necessary for the purpose of this research and so the following definitions will be referred to hereafter:

'Anthropic sediment' refers to a sediment which has wholly formed by the transportation or deposition of materials by humans. This includes trampling, deliberate dumping and in situ accumulation. In the context of this research it also includes constructional material which might incorporate boulder sized rocks with a matrix of fine material.

'Anthrosol' refers to a soil which has formed by natural processes upon parent material and has subsequently been amended by human activities. This might include the addition of fertilizer or mechanical disturbance. For the purpose of this research, field banks are included in this category.

The definition of these two key terms helps to contextualize the physical and social circumstances of site formation as it frames the incorporated processes of human interaction (influenced by cultural and environmental experiences) with the physical processes of deposition and accumulation management set in the context of the wider 'landscape'.

2.2.1.1 *Anthrosols and anthropic sediments as archaeology*

The value of anthrosols and anthropic sediments as 'culturogenic compounds' is comparable with ceramics, bones and palynological data for archaeological interpretation (Dincauze 2004:312). Recent critique has identified the strong potential for cultural records to be retained by anthropic sediments of archaeological soils and sediments in Orkney (Cluett 2007) and successful reconstruction of past cultural activities has been achieved by geoarchaeological investigation of these and anthrosol records (Simpson et al 2005, Guttmann et al 2006, Simpson et al 2006, McKenna & Simpson 2011).

Site formation processes are one of the primary concerns of geoarchaeological practice (Butzer 1982, Rapp & Hill 2006) and each site has a unique assemblage of anthropogenic features (Courty et al 1989) which have contributed to this. Furthermore all archaeological materials represent the current phase of a long journey which began with human actions in response to social and environmental influence and underwent subsequent transformations through diverse natural and cultural processes (Bailey 2007, Needham & Spence 1997, Schiffer 1975). The archaeological record is therefore composed of materials which have become relicts of a past cultural system which has spatially and temporally come to an end. Elements of a cultural system might include food, fuel, tools, facilities, technology and people (Schiffer 1972) but essentially comprise all the variable components of a human eco-dynamic system. These elements fall into two main types of context; systemic and archaeological (Schiffer 1972). The systemic context describes the manipulation and use of elements by people. These items eventually pass into the archaeological context through the process of discard (McKee 2013). Once elements become archaeological they then have the opportunity to be exposed to decomposition and post-depositional soil formation processes (figure 16).

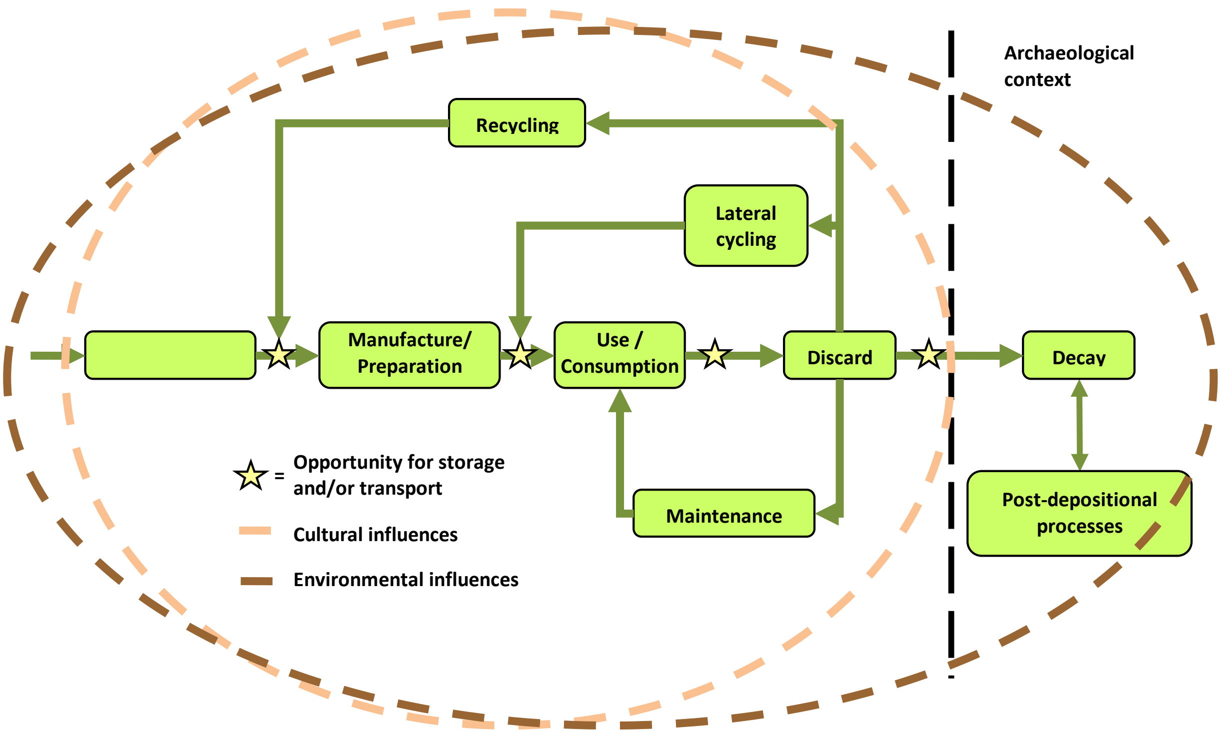


Figure 2.1: The cycling of archaeological materials before deposition as 'refuse' (adapted from Schiffer 1972).

Evidence of the everyday cycles will be preserved according to the events surrounding abandonment and post-depositional changes, for example a site abandoned in a hurry may have more evidence of systemic contexts than one which was deliberately packed up and left (Shiffer 1972). Despite much of the archaeological record being 'garbage' (McKee 2013), many anthropic sediments and anthrosols have reached the 'discard' phase of the process model (figure 2.2) through social or environmental change and have become obsolete or even fossil (Simpson et al 1998) rather than purposefully discarded. This is advantageous for their study as they therefore survive as representatives of the systemic context which is very useful for reconstruction of past activities.

Anthrosols and anthropic sediments make up a vastly diverse dataset, embodying everything from a single episode of stone-knapping (Gamble 2004), through the development of deep sediments over long periods of time, to the involvement of humans with natural soil processes or pre-existing soil profiles (Cluett 2007). They often manifest as an intimate mixture of debris relating to cultural activities, such as ash, charcoal, pottery, organic material and bones

(Courty et al 1989) but can also contain episodes which are readily identifiable as activity surfaces or episodes of standstill (Simpson et al 1999a & 2006). A set of diagnostic micro-remains might point to a specific activity, for example a natural soil with allochthonous flint fragments may be interpreted as a 'flint knapping assemblage'[1] but more intimately mixed sediments and soils present an added challenge as the possible origins of constituents must be considered carefully as well as the *reasons* behind their deposition in a specific place (Milek 2012). This must also be understood within the sphere of changing social attitudes and environmental conditions over time. Therefore, it seems reasonable for the purpose of this study to discuss anthropic sediments in terms of their discrete function or modification ascertained by in depth study of their constituent parts (Courty et al 1989).

2.2.1.2 *Anthrosols and anthropic sediments as soils*

Anthropic sediments and anthrosol are subject to the same natural soil formation processes that affect all soils (Butzer 1982, Courty et al 1989, Waters 1992, Wood & Johnson 1978). These processes are transformation, translocation, addition and loss (Brady & Weil 2008) and are influenced by six factors; parent material, climate, vegetation, soil biota, topography and time (Brady & Weil 2008, Jenny 1941). However, no process or factor occurs independently (Dincauze 2004) and the systems they represent are highly dynamic (figure 2.2). Transformation occurs through chemical and physical modification, destruction and synthesis (Brady & Weil 2008), whilst translocation describes the movement of material in three dimensions (ibid.). Additions and losses occur as allochthonous materials enter the profile, either from natural or anthropogenic sources (French 2003), or are eroded, leached or decomposed (ibid.).

[1] An archaeological assemblage can be defined as 'an associated set of contemporary artefacts that can be considered as a single unit for record and analysis' (Darvill 2008).

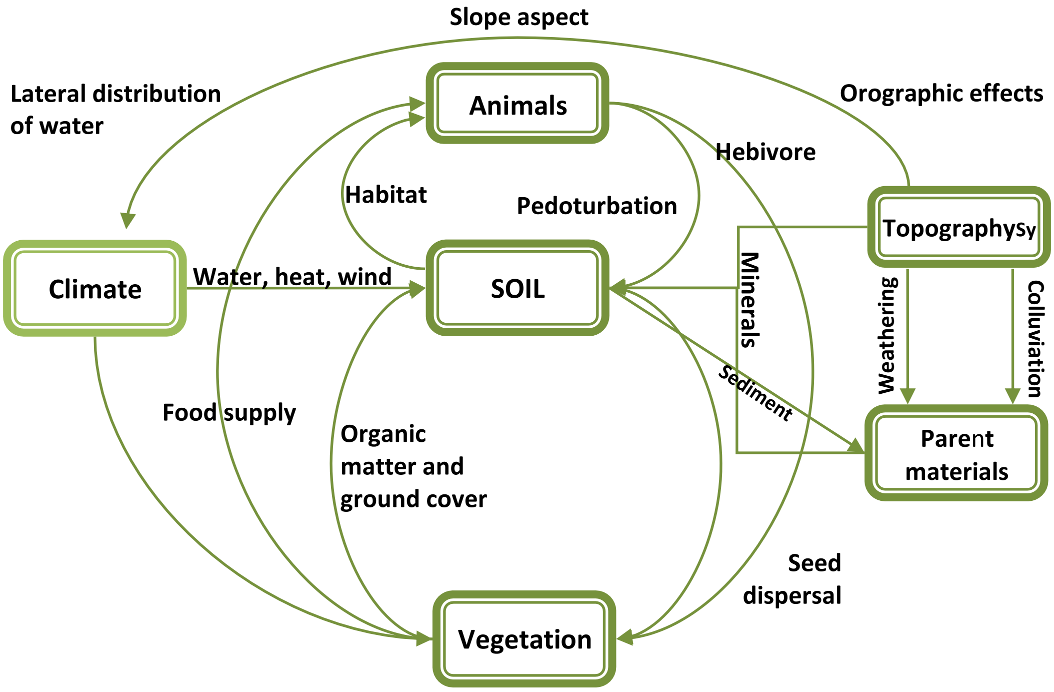


Figure 2.2: The links between soil formation factors. All factors influence and are influenced by each other. Time is not shown on the diagram but the arrows could be lengthened or shortened to represent the influence of time as it acts upon each of the other processes (From Brady & Weil 2008: 64).

An anthropic sediment or anthrosol left undisturbed can itself become the parent material for a soil (Holliday 2004) and any subsequent colonization by vegetation is usually linked to climatic conditions, topography (Brady & Weil 2008, Holliday 2004) and available nutrients. Anthropic intervention can modify the natural chemistry and structure of a soil (Dincauze 2004: 285). For example, soil micro-fauna can be attracted by heightened nutrient content in organic anthropic sediments and anthrosols (Courty et al 1989). Although rapid burial through natural or anthropic events or ploughing can halt their activities (Guttmann et al 2003, Simpson et al 2006).

Physical weathering of an anthropic sediment or anthrosol can take the form of freeze-thaw action which can alter internal structures (Brady & Weil 2008, Van Vliet-Lanoë 2010) or abrasion by aeolian, colluvial or fluvial processes (Brady & Weil 2008) depending on the climatic conditions. The particle size of constituents like stone or ceramic artefacts can be reduced in the same way as rocks are physically broken down in natural soils (Brady & Weil

2008) and, in the case of anthrosols or anthropic sediments which include a very coarse (>63mm) mineral fraction, physical weathering of the mineral content may continue. The mechanical disturbance caused by ploughing can also contribute to this type of weathering. Physical removal of fine materials in anthropic sediments or anthrosols due to aeolian transport can lead to their collapse and subsequent mixing of larger constituents and loss of any stratified layers (Griffiths & Ashmore 2011, Rapp & Hill 2006).

Bio-geochemical weathering occurs as a result of the interaction of biological and geological agents, water and oxygen (Brady & Weil 2008), and describes the dissolution and precipitation of elements from mineral sources through oxidation and reduction, hydrolysis, complexation and acid reaction (Brady & Weil 2008). This type of weathering can transform anthropic sediments through dissolution of calcium carbonates (Courty et al 1989, Simpson et al 1996) and formation of ferruginous and phosphatic pedofeatures (Courty et al 1989). The addition of materials rich in nitrogen, phosphate, iron etc by humans contributes to, reverses and transforms this process (Dincauze 2004).

Bioturbation is traditionally defined as soil or sediment reworking by flora and/or fauna, this usually indicates the processes of animal burrowing, micro-faunal activities and plant roots. However, in the case of anthropogenically modified soils and sediments, it could equally be caused by human actions (Dincauze 2004) such as ploughing, animal traction, digging and planting.

2.2.1.3 *Summary*

Anthrosols and anthropic sediments make up a diverse dataset. Their formation is influenced by cultural and environmental processes which in turn influence post depositional soil formation. This is a cyclical and dynamic phenomenon. As anthrosols and anthropic sediments inherently form an 'assemblage' of coarse and fine constituents, they are hypothesized to reach the discard process of the cultural system model by becoming obsolete or fossil and therefore provide applicable evidence for reconstruction of cultural activities. Characterisation of the different types of anthrosols and anthropic sediments found at archaeological sites will enable multiple working hypothesis generation with the aim of establishing the environmental and cultural circumstances surrounding their formation.

2.3 Developing a human eco-dynamics based research framework

[…] Human ecodynamics...is concerned with the dynamics of human-modified landscapes set within a long-term perspective, and viewed as a non-linear dynamical system. Human-environmental relationships are thus defined as involving the co-evolution of socio-historical and natural processes, and their time-space intersection. […]

(McGlade 1995:126)

The interaction of humans with their natural environment is at the centre of geoarchaeology (Brown 2008) and thus this research and, as such, anthropic sediments and anthrosols must be understood in terms of the social behaviour they represent. The importance of linking innumerable social and environmental components such as politics, economy, resource use, crisis/reform and climate has long been appreciated (Binford 1965, Butzer 1982, Gronenborn 2012) but all archaeological evidence must also be understood as being charged with meaning (Shanks & Tilley 1992) and the place of human agency recognised (Johnson 2006). This holds particular resonance within concepts of symbolic or ritualistic midden deposition and use in the North Atlantic (Gregory & Simpson 2006, Garnham 2004, Jones, 2005, Thomas 1999).

To begin to understand the human beings that occupied an archaeological site, the wider landscape must be experienced and understood in a three-dimensional and sensory manner (Tilley 1994). Although the present is far removed from the past both temporally and culturally (Johnson 2004), Bordieu's concept of the 'habitus' allows consideration of human reactions to material conditions of existence (Jusseret 2010) and provides a link between biological disposition and the surrounding world (ibid.).

These concepts can be brought together using human eco-dynamics, this approach stresses that human ecosystems and the environment in which they exist are so intrinsically linked that they must be considered as 'socio-natural systems' (McGlade 1999). This is a co-evolutionary relationship where the interactions between humans and non-human variables change as a consequence of their mutual interaction (Bailey 2000). Anthrosols and anthropic sediments have been shown to be both a product and component of the dynamic system formed by interactions between natural, cultural and social phenomena. Therefore, they are perhaps the purest manifestation of co-evolutionary cultural and natural processes available for archaeological study.

Flow models which give a visual representation of the movement of archaeological materials around a site have been successfully applied to site formation processes (Binford, Golding 2008, Schiffer 1972, Waters 1992) and spatial analyses of refuse deposits has helped elucidate underlying structured deposition (Hayden & Cannon 1983). Processual models have however been criticized for invoking 'linear, deterministic relationships as well as privileging concepts such as stability and an assumed cumulative evolution towards increasing complexity' (McGlade 1995). Instead, the human ecodynamic framework emphasizes that socio-natural systems are 'nonlinear' and 'dynamic', have the ability to fluctuate based upon stimulus and feedback (McGlade 1999) and are inherently unpredictable (Bailey et al 2000). Within this framework, the 'uniqueness of historic trajectories' and the 'large consequences that flow from quite small actions and events' (ibid.) are emphasized. This could help to interpret the idiosyncrasies between the components of archaeological sites across the Scottish North Atlantic seaboard, especially the soils and sediments.

Human ecodynamics is a useful framework for modeling anthrosol and anthropic sediment formation as it incorporates the cultural and environmental fluidity which results in the formation of the different types of material and the 'reciprocal relationship between people and landscape' (Johnson 2004:23).

2.3.1 *Modeling systems of anthrosol and anthropic sediment formation in the Scottish North Atlantic seaboard*

To borrow from social mathematical theory, modeling human socio-natural systems must begin with the 'formulation of a reasonable set of assumptions regarding the mechanism of the phenomena studied' (Kruskal & Neyman 1995). Human-ecodynamics theory necessitates a model capable of dealing with unpredictability and complexity and so a stochastic model seems most appropriate. A stochastic model should be capable of 'generating a range of outcomes in an unpredictable way from a single state' (Winder 2000:2). In the case of anthropic sediments and anthrosols the single state is the convergence of a range of unpredictable processes and so the purpose of the model is to formulate a hypothetical framework for investigation of the social and natural trajectories which led to this particular convergence.

The location and forms of anthropic sediments presented in table 1.6 (chapter 1) allow a basic hypothetical model for the distribution and changing uses of anthrosols and anthropic sediments over time (figure 2.3).

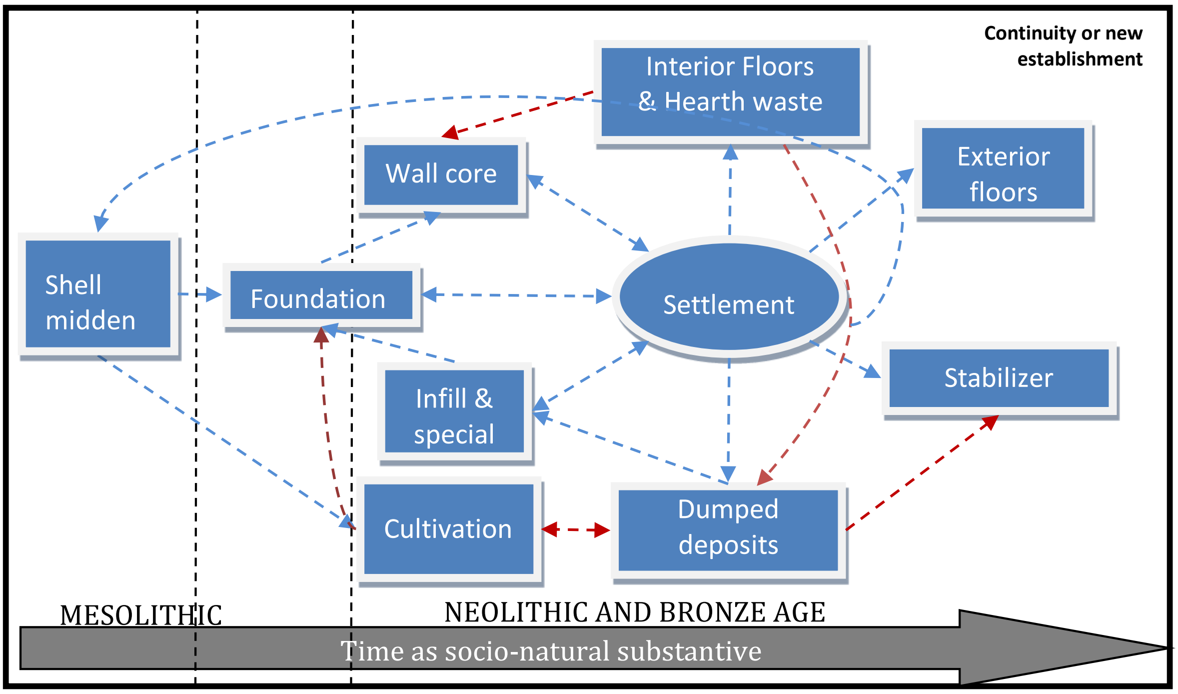


Figure 2.3: A model demonstrating the hypothesized flow of ideas in the Scottish North Atlantic seaboard with cultural chronology

In this model, time moves from left to right but at a speed dictated by socio-natural processes (McGlade 1999). The blue arrows demonstrate the flow of ideas; Mesolithic shell middens appear first in the archaeological record and their presence can attract further activities leading to the generation of an anthropic sediment or anthrosol which acts as a foundation for building. This then might also be banked up into wall core. Dashing the lines recognizes that historical trajectories are unpredictable. A shell midden does not predict a later settlement and later settlement situations are not necessarily determined by the presence of shell midden. Some settlements are not built upon an anthropic sediment or anthrosol foundation and not all of the elements of this model are present at every settlement. Arrows with points at either end indicate potential reversal or cyclical process, for example wall core in a Shetland 'dump construction' came from within the structure itself and a structure 'filled in' by anthropic sediments might indicate abandonment, but can also indicate the beginning of a new settlement or structure. Once a settlement is established, a pattern of procurement, manufacture, use, recycling and discard begins (Schiffer 1972). The settlement oval represents houses and all the activities which take place within and without from heating to hunting. Artefacts, organic and inorganic waste, fuel residues etc generated by these activities are chosen or allowed to flow within and around the house or selected and used for specific purpose. The people who produced these materials would understand them as having a potential further use and so the red dashed arrows represent the further directions in which they may be directed based upon previous research in the North Atlantic (Davidson & Simpson 1994, Milek 2005, Milek 2012, Milek & Roberts 2013, Simpson et al 1999a).

If the settlement were to pass from the systemic to archaeological context at any stage in the process, archaeologists would then be presented with anthropic sediments or anthrosols.

This model illustrates changing and idiosyncratic cultural systems as interpreted through archaeological investigation. It demonstrates that ideas may change over time and elements of a system which is culturally Mesolithic, Neolithic or Bronze Age are intrinsically linked and may converge or develop new (and spontaneous) pathways over time. It illustrates that, although the presence of one element does not necessarily determine the presence of another, real and alternative trajectories may be inferred (Winder 2000) based upon the presence of all of these elements across the study area.

It does not indicate the possible reasons why a community might choose to direct materials in one way or another or why change occurs. This is where human ecodynamics theory can offer some insight.

2.3.1.1 *Stabilizer anthrosol case study*

Isolation of a single anthrosol type, 'stabiliser', into an illustrative flow model demonstrates the interrelatedness of dynamic socio-natural systems (figure 2.4) which could have led to its formation.

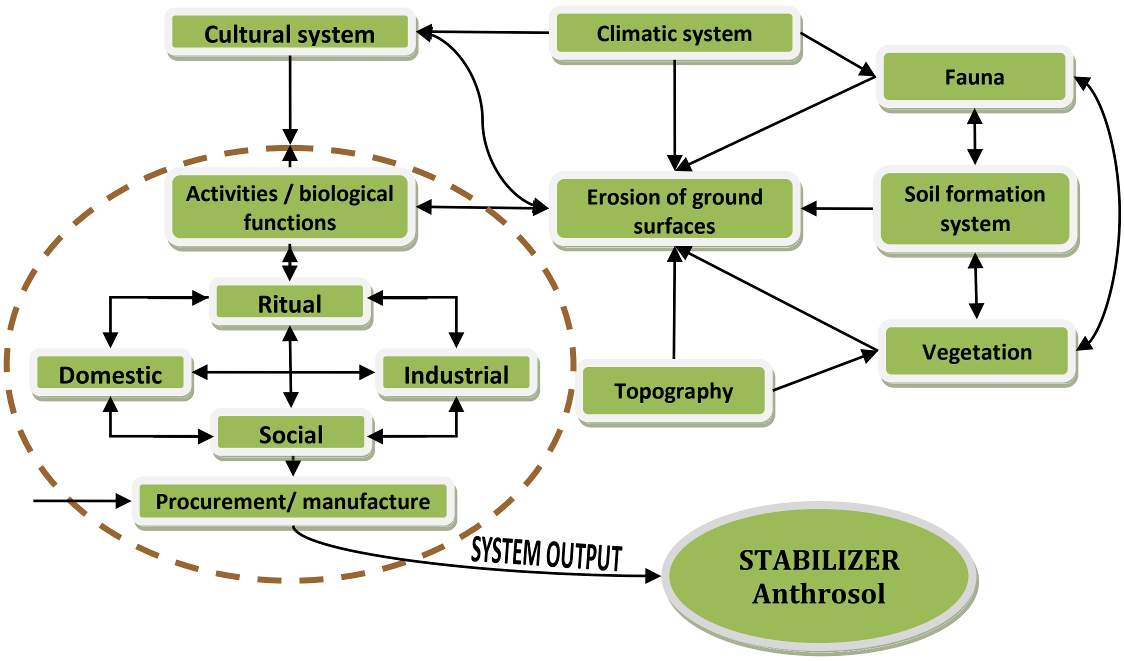


Figure 2.4: A human ecodynamics perspective on the formation of a land surface stabilizer anthrosol. Time is assumed to be a functional part of this model but does not move at the same speed for every element. Topography is operating within a geological time scale, whilst human activity cycles may take minutes (McGlade 1999:464).

It is reasonable to assume that stabilization of a land surface indicates an actual or perceived threat of erosion which might be caused by wind, topography, flooding or human or animal activities. Stabilization could also be carried out as damage control to recover from a catastrophic erosion or inundation event. The soil formation process will influence erosion/deposition as some parent materials are easily friable or can develop into loose soils. Human activities such as ploughing can cause a land surface to destabilize and so the erosion/deposition event can be caused by, and controlled by, human interaction with the natural and physical systems which control any geological event.

The cultural system in which all human activities and biological functions operate influences the attitude and perception of communities and individuals to erosion and thus affects any mitigation efforts. The set of existent circumstances at the time action is necessary affects the 'system output'. In the case of communities on the Scottish North Atlantic seaboard, the decision to stabilize land surfaces subjected to sand-inundation using fuel residues and organic matter is reflected in the archaeological record (Gilbertson et al 1999, McKenna & Simpson 2011, Simpson 1998, Simpson et al 2006). Therefore the catalyst event (sand blow) and the system output (anthrosol) act as known start and end points which could then be placed onto a hypothetical decision making chain to offer insight into the reasons why the materials present in the anthrosol were selected for use (figure 2.5).

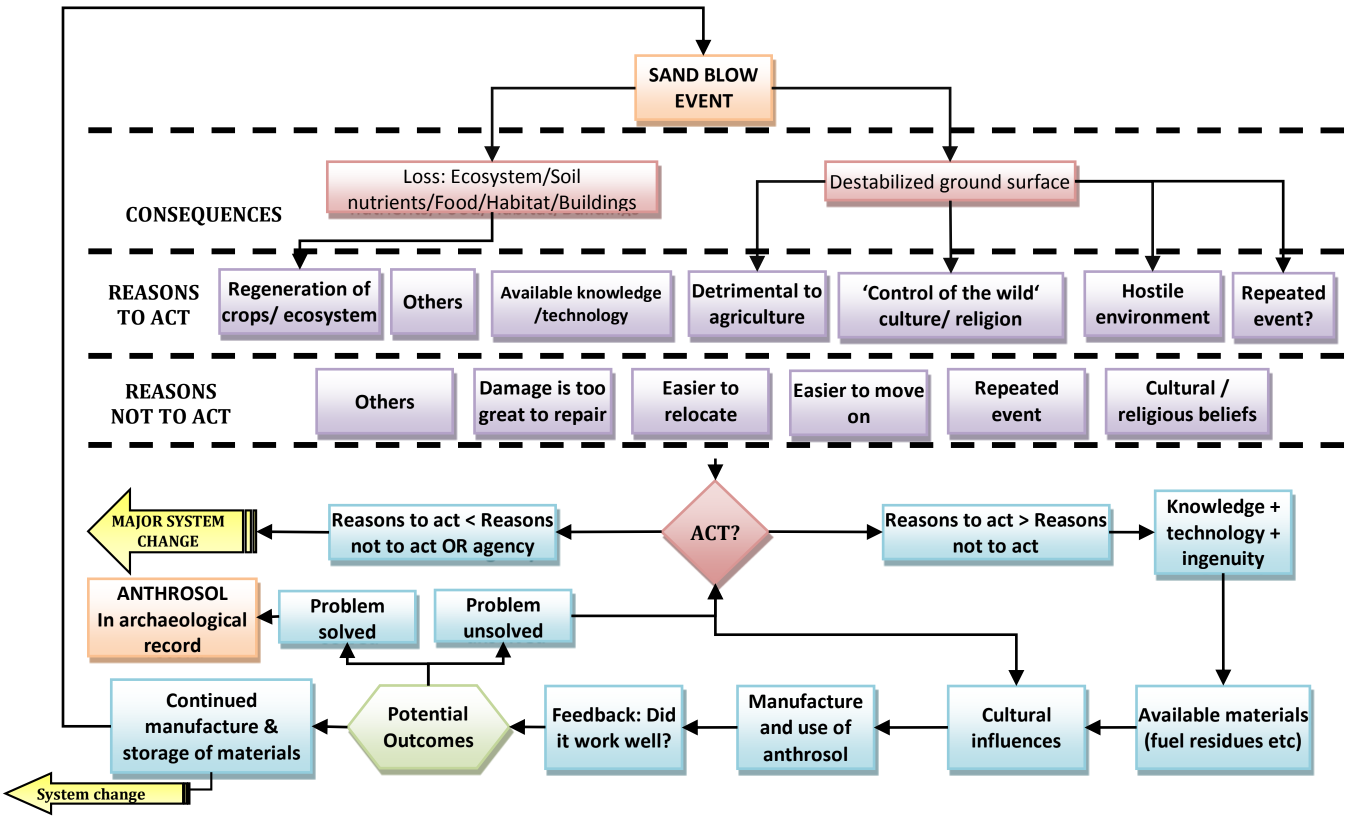


Figure 2.5: A hypothetical decision making chain based upon known start and end points at Neolithic Skara Brae (Simpson et al 2006). Consequences of a sand blow event are hypothesised using known economical, geological and environmental information on the Neolithic Period in Orkney (eg, Renfrew 1985a).

This decision chain assumes that the natural systems described above have led to the sand inundation event and continue to influence the community which has co-evolved alongside them. Reasons to act/not to act (to create an anthrosol) are based upon practical, cultural and religious influences, for example the cultural urge to 'domesticate' during the Neolithic (Hodder 1990). 'Other' reasons are included to account for the unpredictable nature of human decision making, and include further environmental influences such as the availability of resources and climatic conditions. The fundamental decision, to act or not to act follows this line of reasoning, but must be considered in light of social structure, agency and group cooperation. If the decision is taken not to act then it is assumed the landscape and/or economy will be changed and so a new system emerges. The final out-put follows the community decision to act, the knowledge, technology and ingenuity they possess and the materials available to them (plus the cultural influence on which materials are appropriate).

2.3.1.2 *Critique*

Although a system model and decision making chain framework work well to describe the formation of an anthrosol where the start and end points are known, it is limited as the removal of either of these two factors will create a stochastic process which can be almost infinite. The bifurcation in a stochastic model created every time an element of the human ecodynamics system necessitates a decision to be made (McGlade 1995) may lead to the generation of so many possible outcomes that it runs far beyond the ability of the evidence to interpret. This is particularly relevant to anthrosols and anthropic sediments which were created through a social impetus which leaves a much more subtle impression upon the archaeological record than an environmental catalyst (such as sand inundation).

This situation can be mitigated using detailed geoarchaeological reconstruction. For example characterisation of an anthrosol or anthropic sediment based upon spatial, archaeological and composition information will allow reconstruction of the systemic context in which it entered the archaeological context. This data will successfully allow analysis of the types of activity anthrosols and anthropic sediments represent, including waste disposal, cultivation or composting (different 'recipes'), thus supplying the culmination of anthropic intervention and the commencement of natural post deposition processes. The 'start point' is harder to detect, but analysis of the microscopic components of 'midden material' elsewhere has shown that events like hearth fires, cleaning and maintenance etc are often recognised within anthropic sediments, supplying key details required by the research framework.

2.4 References for anthrosol and anthropic sediment composition and interpretation

2.4.1 *Evidence from the Scottish North Atlantic seaboard*

Chapter one identified that four in-depth studies of anthrosols and anthropic sediments have been conducted at Neolithic and Bronze Age sites on the Scottish North Atlantic seaboard (Guttmann et al 2006, Guttmann et al 2008, Simpson et al 1998, Simpson et al 2006) but no comprehensive study has been carried out to characterise or interpret their relationships to each other and the system to which they belong. The following review brings together the data for the micromorphological properties and interpretations of anthrosols and anthropic Sediments from Tofts Ness, Skara Brae and Old Scatness.

Data was collected from published semi-quantitative thin section description tables. The percentage of coarse (>63µm – international convention scale) mineral abundance for each context is displayed in table 2.1 along with the source of data for each archaeological context. Archaeological contexts have already been described in chapter one.

Table 2.1: Percentage coarse minerals present in Neolithic and Bronze Age archaeologically resolved contexts in the Scottish North Atlantic seaboard

Archaeological interpretation	Wall core	Foundations	Stabilizer	Edge of settlement dump	Neolithic cultivated anthropic sediment	Bronze Age cultivated anthrosol
Source	**Simpson et al 2006**	**Simpson et al 2006**	**Simpson et al 2006**	**Simpson et al 2006**	**Guttmann et al 2006**	**Guttmann et al 2006 & 2008 Simpson et al 1998**
Coarse minerals	**20-45%**	**7-30%**	**7-20%**	**10-40%**	**15- > 50%**	**5 - >50%**

Coarse mineral percentages were achieved by reviewing all of the descriptions for each anthrosol or anthropic sediment and recording the minimum and maximum percentage value described in the literature and so is illustrative only. The table allows a basic representation of the expected percentage coarse minerals present in anthrosols and anthropic sediments for each archaeological context (figure 2.5). However, micromorphological description of coarse mineral abundance relies on a visual measure (Stoops 2003) and so is semi-quantitative. Slight differences in the description of materials makes the 'recipe' effect difficult to quantify using this table. For example, although the full suite of coarse minerals were described at Tofts Ness (Simpson et al 1998), only 'lithic clasts' and quartz were recorded at Skara Brae (Simpson et al 2006). Therefore caution should be exercised with the application of coarse mineral semi-quantitative abundance measures to hypothetical modelling of anthrosol and anthropic sediment formation. Instead presence/absence may be more helpful in discerning a recipe effect at this stage.

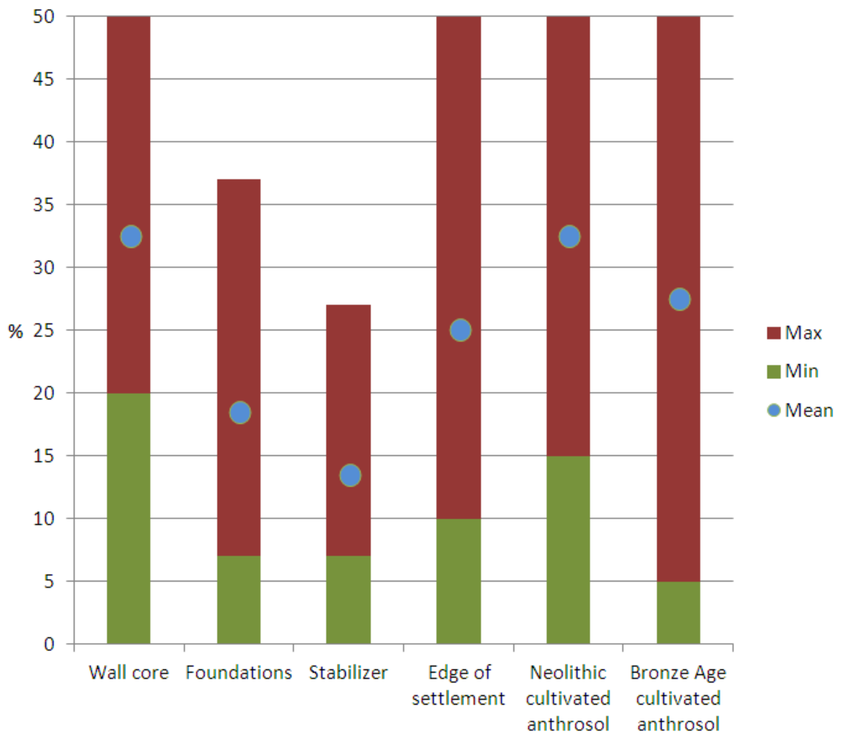


Figure 2.6: Illustration of the % coarse minerals in Neolithic and Bronze Age archaeological anthrosols and anthropic sediments (Guttmann et al 2006, Simpson et al 1998, Simpson et al 2006).

2.4.2 *Presence/absence and indications of recipes*

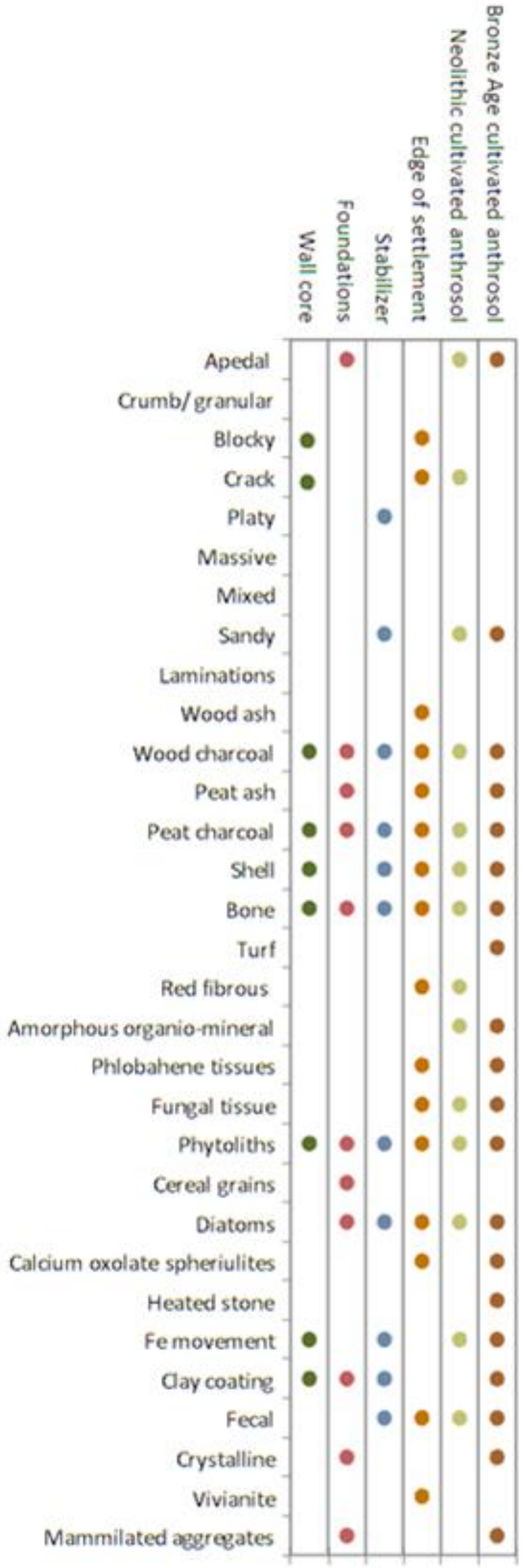


Figure 2.7: Presence/absence chart for microscope observations of anthropic sediments described in published literature

Figure 2.7 indicates that foundation anthropic sediments and cultivated anthrosols typically exhibit apedal microstructures. In all cases this is related to soil faunal activity. Wall core and stabilizer anthrosols present platy microstructures, whilst dumped deposits at the edge of the settlement tended to have a blocky or cracked microstructure. As Neolithic cultivated anthrosols were typically created by flattening out and cultivating a dumped deposit it is unsurprising that some share a cracked microstructure. As cultivated anthrosols were subject to ploughing, mixing and natural mineral accretion away for the immediate settlement they often exhibit sandy microstructures. This is also true of stabilizer which inherently contains the windblown sand it was intended to balance.

Figure 2.7 allows the following recipes to be proposed:

Wall core

Clay mixed with shell, bone, plant remains and fuel residues (wood and peat charcoal), no identifiable ash.

Foundations

Bone, cereal grains, plant remains, and fuel residues (wood and peat charcoal) including peat ash. Clay movement, crystalline and mammilated aggregates are post-depositional features representing disturbance up profile, moisture movement (also indicated by diatoms) and faunal activity.

Stabilizer

Bone, shell, plan remains, diatoms, wood and peat charcoal (but no ash). Soil wetting and drying, disturbance and faunal activity are represented.

Dumped deposit

Material dumped at the edge of the Skara Brae settlement contained shell, bone, peat and wood ash and charcoal, plant material, fungal tissue, red fibrous material and animal dung. The sediment was subject to bone dissolution and faunal reworking.

Neolithic cultivated anthrosol

The dumped material which was flattened out and cultivated contained wood and peat charcoal, shell, bone, amorphous organic material, plant remains, red fibrous material, fungal tissue and diatoms. Soil wetting and drying and faunal activity are represented.

Bronze Age cultivated anthrosol

Wood and peat charcoal, peat ash, shell, bone, heated stone, turf, animal dung, amorphous organic material and plant tissues are represented. Soil wetting and drying, disturbance and faunal activity affected this type of context.

2.4.2.1 *Limitations*

The absence of some features does not take into account post-depositional processes which may have led to their total decomposition or removal (e.g. wood ash may blow away or become subject to alkaline decomposition, Canti 2003), although review of several samples from the same archaeological context reduced the chance of features 'disappearing'. Some materials may have been redirected, ended up in the sea or been destroyed by sea level change and erosion.

Wood and peat charcoal are differentiated in some research papers (Guttmann et al 2006, Simpson et al 2006) but charcoal is described as a single entity in others (e.g. Simpson et al 1998) depending on the objective of description. For the purposes of this review this disparity did not have great impact because the context under analysis was described in two different papers. However it remains unknown whether features which may have been relevant to this review were left out of the published data because their description was not necessary to the original research objectives. Therefore the objectives of the original research must be taken into account. It is anticipated that additions and amendments to this list will be made during analysis of anthropic sediments and anthrosols.

Two major Neolithic and Bronze Age contexts identified in chapter one, occupational floors and structural infill, have not been subject to investigation within the study area and so could not be reviewed.

2.4.3 *Patterns of deposition*

Recipe identification must be considered in terms of the pattern of deposition they represent. The materials identified in anthropic sediments and anthrosols are frequently referred to throughout the literature as refuse or waste based but this is limiting (Needham & Spence 1997), especially when considered in terms of human ecodynamics theory. Organic refuse is described as faecal matter, sewage, bones, meat and offal waste and waste plant materials of all kinds (O'Connor 2000) whilst inorganic waste may include fuel residues (Macphail & Goldberg 2010) or broken items such as ceramics, jewelry, ornaments and stone tools (Schiffer 1972). To more effectively describe the flow of 'refuse' around a site, a flow model is presented below (figure 2.8).

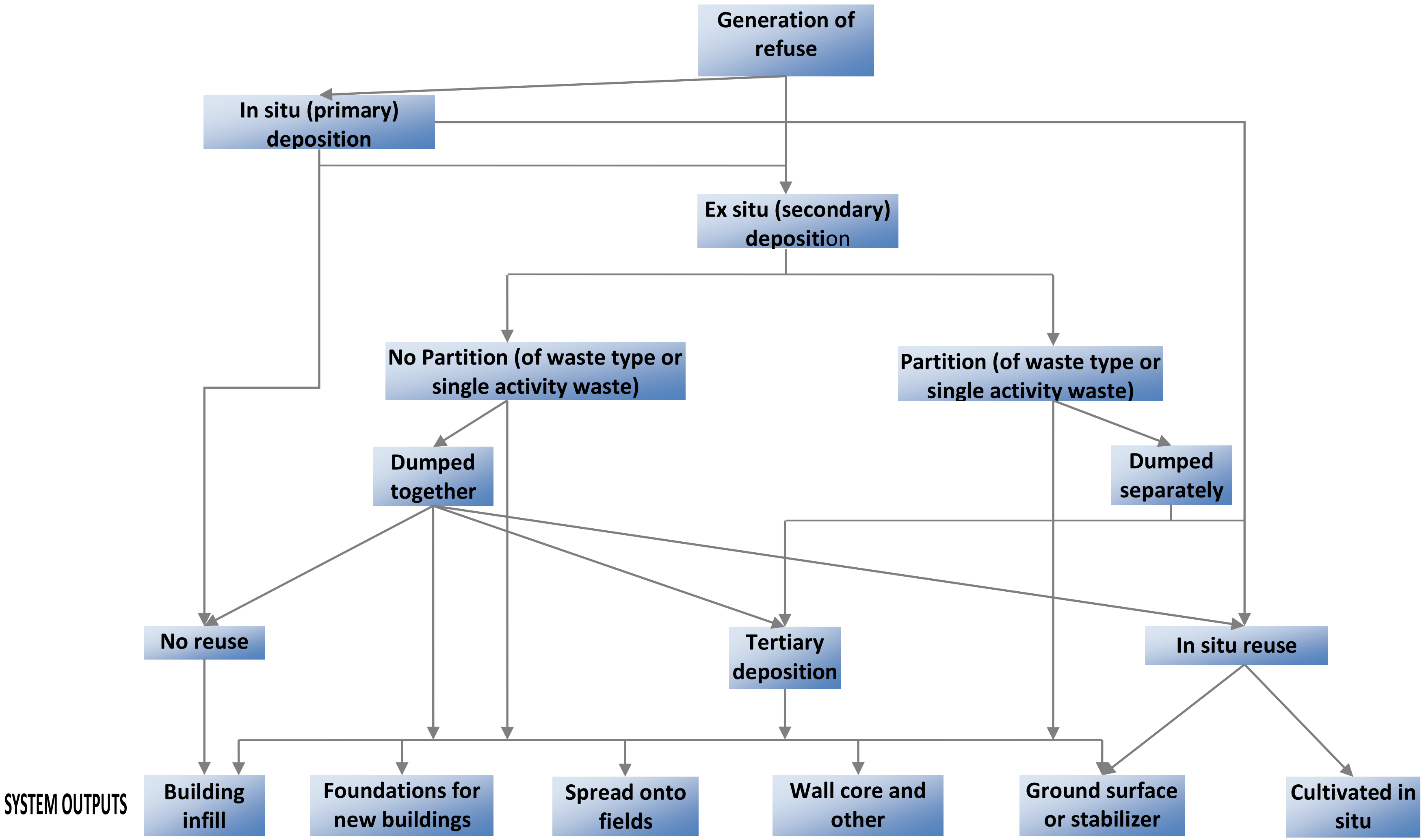


Figure 2.8: A flow model describing the types of deposition which could lead to the formation of archaeological contexts defined in chapter one

In this flow model the system outputs along the bottom line correspond to the main archaeological contexts defined for anthrosols and anthropic sediments in the Scottish North Atlantic seaboard. At any stage of this flow the elements could pass from systemic to archaeological context and each element and stage is assumed to be subject to the human ecodynamics network described above.

Refuse is produced and distributed as a product of human domestic and industrial activities. In the prehistoric setting of the Scottish North Atlantic seaboard these activities include but are not limited to those presented in table 2.2:

Table2.2: Possible economic and domestic activities at Neolithic and Bronze Age settlements on the Scottish North Atlantic seaboard (based upon archaeological interpretations)

Event	Expected Residue	References
Cooking and eating meat, dairy and marine or plant derived foods	**Organic and fuel debris, bone, shell and burnt grains and other foods**	**Renfrew 1985b, Craig et al 2005, Wickham-Jones 2010, Hastie 2011**
Burning fuel for warmth	**Ash, charcoal, bone, burned peat and turf**	**Simpson et al 2006, Wood 2000, Hastie 2011**
Burning fuel to boil water with hot stones - as in the case of burnt mounds	**Fuel residues, occasionally bones**	**Wood 2000, Øvrevik 1985, Davidson et al 1976**
Making tools and other artefacts	**Quartz, flint, beach pebbles, bone, antler 'rough-outs' and fragments**	**Foster et al 1995, Rice 2011, Saville 2011, McLaren 2011**
Butchering animals	**Organic and unburned bone debris**	**Fraser 2011**
Making, firing and discarding ceramics	**Fuel residues, wasters & sherds,**	**Craig et al 2005**
Cereal processing	**Fuel residues, burnt cereals, & chaff**	**Hastie 2011**
Building, maintaining and decay of structures	**Turf, clay, stone, midden material**	**Whittle 1986, McKenna & Simpson 2009, McKenna & Wilson 2011, Simpson et al 2006**
Decorating houses, people and material goods	**Pigments, beads and bone**	**Rice 2011**
Constructing floors and floor coverings	**Articulated phytoliths, turf fragments, ash and midden material**	**McKenna & Simpson 2009, Dixon 1989**
Accidental loss of items or discard	**Beads, tools etc**	**Rice 2011**

These activities are influenced by cultural ideas and environmental processes (Needham & Spence 1997, Layton & Ucko 1999, Golding et al *in press*) and so the flow of refuse around a settlement site is subject to spontaneous and unpredictable change as well as more predictable changes over time.

As refuse is created, deliberately left or accidently lost it can be subject to a number of possible deposition events. Working through the flow chart in figure 23, the primary deposition event describes leaving refuse in situ as it is generated (for example flint chippings from knapping or food debris dropped whilst eating, Schiffer 1987 cited in Needham and Spence 1997). Over time this becomes incorporated into the ground surface or could also be deliberately buried by sand, ash or some other material to 'clean up' (Milek 2012). This may then be left in situ with no further reuse or reworked in situ (such as becoming a trampled ground surface, mixed with more material to form a deliberately constructed hard-packed floor or forming the foundations of later buildings). If in situ material continues to build up then theoretically it could form building in-fill (as the roof level becomes gradually lower, Milek 2012) but this is differentiated from deliberate dumping of material into abandoned buildings.

If refuse is collected and then taken to another location to be deposited (for example swept, carried in a basket or by hand, Barber 2011) then this is called ex situ or secondary deposition (Schiffer 1967 cited in Needham and Spence 1997). Secondary deposition could also be incidental, such as the transportation of debris carried on the soles of the feet (Milek 2012) or through wind action (McKenna & Simpson 2011). As deliberate ex situ deposition is carried out, the opportunity to partition waste is created. The debris of specific activities (flint knapping or butchering animals) or specific wastes (just ash and charcoal or just organic materials) may be separated and deposited in different locations, on the diagram this is called 'dumped separately'. If no partition occurs then the deposit is described as mixed or 'dumped together', this could include basket loads or shovels full of material (Macphail & Goldberg 2010).

Dumped deposits can be subject to re-use, the in situ cultivation of midden heaps is a typical example in the Scottish North Atlantic seaboard (Guttmann 2005) but deliberate burning events have been described within midden heaps in Turkey indicating that midden heaps were a location for activity themselves (Shillito & Matthews 2012). Burned bones at Skara Brae have been interpreted as a similar event (Heizer 1963)

Dumped deposits can be redistributed for use in construction (walls, floors and foundations), manuring cultivated fields or stabilizing eroding ground surfaces (Simpson et al 2006, McKenna & Simpson 2011). Redistribution of dumped deposits is known as 'tertiary deposition'.

The more times materials are recycled or redeposited, the more fragmentation, abrasion and/or degradation is to be expected (Needham & Spence 1997). The pathways described in the model are not exclusive, several different outcomes can occur simultaneously. For example, a surface constructed within a dumped deposit which had also been the site of in situ fires (Shillito & Matthews 2012). Perceptions of usefulness are also recognised as an important feature of waste deposition (Needham & Spence 1997). Primary deposits can still have a perceived use value and have been referred to as 'de facto refuse' (Needham and Spence 1997, Schiffer 1987).

Major secondary or tertiary deposition can occur due to environmental or faunal processes such as wetting and drying (Lindbo et al 2010), cryoturbation (Van Vliet-Lanoë 2010) and weathering for example. Dogs and other scavengers may have picked through middens (Fraser 2011) and latterly, rodent burrowing in some areas (ibid.). Refuse also becomes a habitat for detritivores, scavengers and their predators (O'Connor 2000).

2.4.4 *Multiple working hypotheses*

Stochastic modeling and multiple working hypotheses (Chamberlain 1965) provide a basis for a more balanced discussion incorporating human ecodynamics systems. However, development of a working model has been restricted to a single anthrosol type (stabiliser) for the sake of brevity. Nevertheless, the final section of this chapter will demonstrate how archaeological context and anthrosol or anthropic sediment characterisation can be used to generate multiple working hypotheses which will aid interpretation.

2.4.4.1 *Multiple working hypothesis model for interpretation of occupational floors*

Occupational, or 'living floors'(Courty et al 1989) of the Neolithic and Bronze Age period have not yet been studied as anthropic sediments in the study area despite their archaeologically recognised potential (Carey 2012, Moore & Wilson 2011, Parker-Pearson et al 2004). However, descriptions of Iron Age to Medieval occupational floors and related hearths are available for the Western Isles (McKenna & Wilson 2011, McKenna & Simpson 2009), Shetland (Bond et al 2013, Guttmann et al 2003, Larsen et al 2013) and Iceland (Simpson et al 1999a). Intensive study of the spatial distribution of materials in more modern constructed and living floors in Iceland has given insight into anthropic sediments formed in a similar environment to those on the Scottish North Atlantic seaboard (Milek 2012).

Gé et al (1993) identified three zones which are widely used as signatures of occupational deposits (e.g. Davidson et al 1992, Simpson et al 1999a and Hutson & Terry 2006):

The 'passive zone'

Where material has been trampled and compacted but remains unaltered by subsequent activity. Trampling modifies the passive zone, the lowermost unit, in only one way; the weight of foot traffic horizontally compacts voids at the top of the unit.

The 'reactive zone'

Usually described as a disaggregated layer containing both materials from the underlying 'passive zone' and fine material from the 'active zone' which has been incorporated into the voids (Hutson & Terry 2006). The reactive zone lies between the active zone and the passive zone and contains material from the passive zone that has been disaggregated by trampling and material from the active zone that has been incorporated into the voids between the disaggregated particles due to compaction.

The 'active zone'

Where domestic waste materials accumulate such as bone, charcoal, shell etc. The active zone, the uppermost unit, consists of materials that accumulate on top of floors, such as bone, shell, plant material, ceramics, coprolites, etc.

Ethnographic evidence from Iceland warns that floor maintenance practices may be reflected in occupational deposits rather than use of space and ash is not necessarily diagnostic of cooking activities but rather of floor maintenance (Milek 2012).

An illustration based upon review of the properties of occupational floor anthropic sediments within the North Atlantic literature is given in figure 2.9. Microstructures reflect trampling and biological reworking (Courty et al 1989) and all floors are

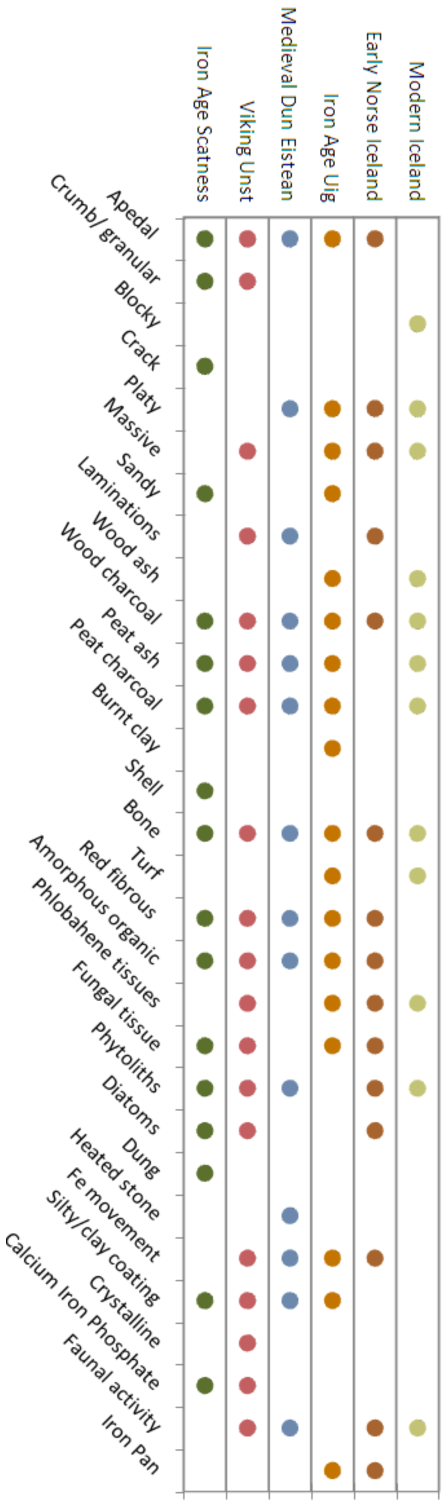


Figure 2.9: Presence/absence (recipe) chart for microstructures, inclusions and pedofeatures described in previous geoarchaeological description of occupational floors at sites on the wider North Atlantic seaboard

typified by inclusions of fuel residues and bone and contain turves cut from local soils (in the older samples this is represented by red fibrous material, diatoms and phytoliths interpreted as peat).

For this information to be useful in Neolithic and Bronze Age contexts, the assumption that communities on the Scottish North Atlantic seaboard lived in houses containing a hearth is made. It is also assumed that hearths and floors which were in use over long periods of time were probably maintained in some form (Guttmann et al 2003). A multiple working hypothesis for the flow of materials from a domestic setting is formulated as shown in figure 2.10.

Fuel residues are generated in a domestic hearth; the decision is then taken to clean out the hearth or not. If no maintenance occurs then hearth layers accumulate one on top of the other with the resultant build-up of materials in situ (Hypothesis 1). Assuming that the structure is in use for a long period, the hearth is cleaned out (Hypothesis 2). What to do with the hearth material is the next decision (influenced by the socio-natural system); in the case of coastal sites on the Scottish North Atlantic seaboard, it might for example be appropriate to dispose of hearth waste into the sea (Hypothesis 3). If destruction occurs, no archaeological evidence is available. Thus, assuming the fuel residues were not destroyed they may then be removed from the structure and become a secondary deposit (Hypothesis 4) requiring a new flow diagram. If the deposit remains within the structure then it could either be mixed with other debris (Hypothesis 5) or not (Hypothesis 6). Following the path of hypothesis six, fuel residues might then be spread over the floor unmixed (Hypothesis 7) but perhaps they were subject to another culturally defined use (Hypothesis 8). Fuel residues spread over the floor may then be deliberately stamped down to create a firm surface (Hypothesis 9) or left to be trampled naturally (Hypothesis 10). Following this, the floor may then be subject to further treatment, for example thresh or peat matting (Hypotheis 11) or not (Hypothesis 12).

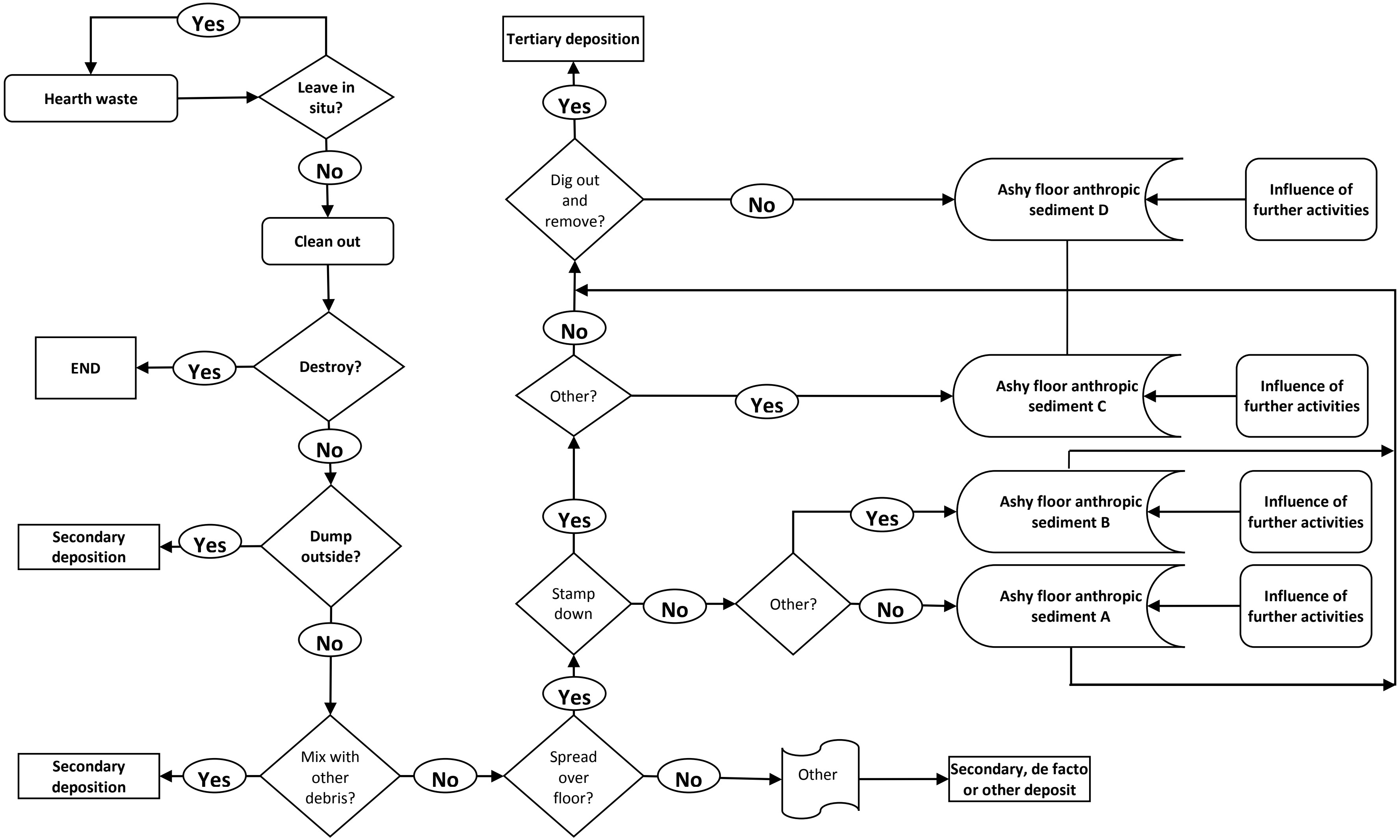


Figure 2.10: Decision chart for developing multiple working hypotheses for the flow of refuse material from a domestic setting across a settlement and into the wider landscape.

Hypothesis 12 results in ashy floor anthropic sediment A. Ashy floor deposits were formed by cleaning out the hearth and spreading it over the occupational floor, this was then deliberately stamped down but was not subject to mixing or other processes.

Following the decision chart will lead to multiple working hypotheses which are not listed here for sake of brevity. However, by characterizing anthropic sediments through geoarchaeological research, reversal of this model (starting with ashy floor anthropic sediment A for example) is possible. Each element in the system must be considered by the linkages outlined in figure 23 but its fluidity is assumed and modifications should be expected following discussion of findings.

2.4.5 *Summary*

Anthrosols and anthropic sediments represent the culmination of anthropic intervention as they enter into the archaeological context. Reconstruction of the systemic context in which they were originally formed can be achieved through reverse system modelling using theoretical and actual data from the palaeo-environmental and archaeological record alongside human ecodynamics theory. A 'best-fit' model is not the aim of human ecodynamics. Indeed the inherent unpredictability of the systems which it describes indicate a successful model is in fact one which does not 'fit' (Winder 2000). Thus a framework dealing with socio-natural systems needs to be capable of producing multiple (reverse) outcomes and changing course based upon unknown variables such as religious or political influence. This can be aided by characterizing each anthrosol or anthropic sediment by identification of its individual components to determine where materials were formed, how they were deposited and what their functions were.

2.5 Thesis aims and Objectives

Chapter one concluded with two basic competing hypotheses based upon the observations of previous archaeological research;

1. Anthropic sediments are by-products of human occupation which were opportunistically exploited for a variety of purposes with no selective storage of materials for specific purposes.

2. Anthropic sediments were deliberately managed, with specific components such as fuel residues or organic materials selected for spatially arranged deposition in order to perform specific functions around the settlement.

These hypotheses were designed to address emerging ideas of anthrosol and anthropic sediment 'recipes' which desk based assessment has highlighted. However discussion of the theoretical explanations of human ecodynamics, site formation processes and cultural discard patterns has demonstrated that a rigorous conceptual framework is necessary to explain the reasons for a possible recipe phenomenon.

2.5.1 *Aims*

The broad aims of this thesis are to characterise and understand anthropic sediment and anthrosol formation and management in prehistoric communities on the Scottish North Atlantic seaboard and, to *p*rovide a narrative for continuity and change in land management practices set within their archaeological and palaeo-environmental contexts. This will contribute to understanding of cultural responses to environmental changes in the Neolithic and Bronze Age Scottish North Atlantic seaboard. Whether anthropic sediments were purposefully generated for specific functions around the site or whether the detritus of occupation was opportunistically exploited in whichever way seemed appropriate at the time is a key gap in knowledge and so will be addressed.

2.5.2 *Objective 1*

Chapters one and two identified that anthrosols and anthropic sediments occur associated with both Neolithic and Bronze Age archaeological settlements and their wider landscapes. Therefore the first objective of this study is to identify the range and extent of anthrosols and anthropic sediments at Neolithic and Bronze Age settlements.

2.5.2.1 *Rationale*

Anthrosols and anthropic sediments are expected to occur in association with Neolithic and Bronze Age settlements and across their associated wider landscapes.

2.5.3 *Objective 2*

The contexts in which these anthrosols and anthropic sediments are found provide essential information about their formation, management and post-depositional changes. Archaeological context will reveal much about the systemic contexts which materials passed through providing a frame of reference for function. Understanding the environmental influences upon the deposit is essential to detecting post-deposition and post-abandonment changes. In the Scottish North Atlantic seaboard the cultural context in which anthrosols and anthropic sediments are found may influence their composition but this is poorly understood. Therefore the second objective will be to provide an environmental, cultural and archaeological context for anthrosols and anthropic sediments identified in the study.

2.5.3.1 *Rationale*

Archaeological context assists deduction of systemic function (e.g., infill, wall core etc).

Environmental context (e.g. soil parent material, vegetation, climate etc) can establish post-depositional changes affecting the anthrosol or anthropic sediment.

Cultural context influences the distribution of anthrosols and anthropic sediments.

2.5.4 *Objective 3*

The properties of anthrosols and anthropic sediments reflect the socio-natural systems in which they were formed. Characterisation based upon individual components will allow 'recipe' identification and elucidate different socio-natural activities influencing formation and management. Therefore it will be necessary to identify the materials that were used to form anthrosols and anthropic sediments (fuel residues, turf materials, bone etc) and, features diagnostic of the palaeo-environment (parent materials, weathering, soil moisture, vegetation, bioturbation etc).

2.5.4.1 *Rationale*

Characterisation of anthrosols and anthropic sediments can reveal the differences between them.

Anthrosol and anthropic sediment diversity can be related to archaeological, cultural and environmental context.

2.5.5 *Objective 4*

The final objective, to establish functions of anthrosols and anthropic sediments together with intensity of use, builds upon the achievements of objectives one to three and relies upon the theoretical framework established above. It is assumed that observed recipe differences will be influenced by socio-natural systems and so the function could be practical or social.

2.5.5.1 *Rationale*

Prehistoric communities existed within socio-natural systems (human ecodynamics) and this will be reflected in the procurement and manufacture/preparation of materials for a designated use/consumption. Anthrosols and anthropic sediments can enter the archaeological record in systemic states of reuse, recycling, storage and discard.

Chapter Three

Chapter 3 Detecting resource management in the field: a geoarchaeological approach to site selection and sediment recovery

3.1 Introduction

This chapter describes the methods used to characterize anthrosol and anthropic sediments and reconstruct their formation processes at sites on the Scottish North Atlantic seaboard. Firstly, the selection of a suitable field site is discussed along with the appropriate field methods needed to achieve thesis objectives 1 & 2 (figure 3.8). Further analytical methods including geospatial analysis, soil micromorphology, point counting and on-slide chemical analysis required to resolve objectives 3 & 4 are then explained.

3.2 Site selection

Desk based survey and modeling of anthrosols and anthropic sediments in the Scottish North Atlantic seaboard has demonstrated that they occur in association with settlement sites and across the wider landscape (hinterland). There is no ‘one size fits all’ model for either Neolithic or Bronze Age settlement economies in the study area as idiosyncrasies in the archaeological record have shown (Chapter 1). However, it is clear that there is potential for cultural activities to be recorded in anthrosols formed adjacent to, or nearby settlements, for example, cultivated surfaces. Therefore the selection of a field site was based upon a strong potential for preservation of an archaeological settlement and its adjacent and related palaeo-landscape.

Identification of such as site necessarily had to embed within a large-scale landscape based research project in order to avoid a lengthy prospection process, and so the opportunity to carry out the aims of this thesis rested upon the discovery of a site fulfilling the following criteria (figure 3.1);

→ Fossil or relict anthropic sediments containing a well preserved cultural record in close association with well preserved, culturally resolved archaeological remains

→ Fossil or relict anthrosols containing a well preserved cultural record within a landscape containing criteria 1

→ Neolithic and Bronze Age settlement falling within criteria 1 in the same landscape falling within criteria 2

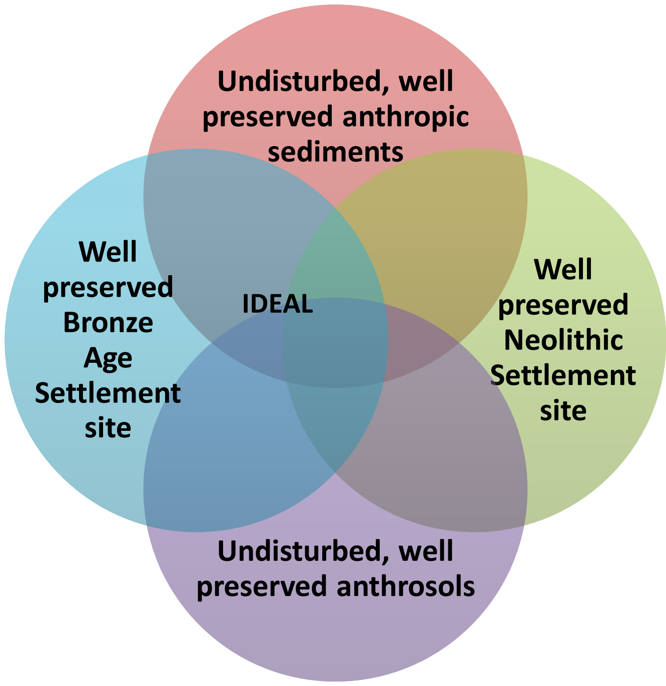


Figure 3.1: Venn diagram depicting the four criteria necessary to meet the thesis aims and objectives. The 'ideal' field site occurs where the four criterium are met.

Although many geoarchaeological field methods are minimally invasive, it is widely accepted that any physical disturbance of the archaeological record is destructive (Barker 1996, Drewettt, 2001, Lucas 2001). Strict rules are therefore in place limiting excavation, especially at protected sites.

A preliminary field assessment of anthropic sediments and anthrosols at Links of Noltland, Westray, Orkney (figure 3.2) was carried out to evaluate the potential for integrated palaeo-landscape interpretations (Simpson & Wilson 2011). The exceptional preservation of anthropic sediments related to both Neolithic and Bronze Age settlements in close association was noted along with anthrosols associated at the same locality. The site emerged as a unique location in Orkney because of this and fulfilled the criteria outlined above, 'allowing the first opportunity to consider relationships between midden material and cultivated areas' (ibid.). Rare permission was granted by Historic Scotland for extensive intervention through excavation to preserve the site 'by record' due to the deflation of sand dunes and subsequent erosion of the site at a scale too large to successfully stabilize.

3.3 The field site: Links of Noltland, Westray

The Links of Noltland (figure 3.2) is described as a deflated coastal dune and machair system along the shoreline of the bay of Grobust on the Orcadian island of Westray (Bromley 2009). Since their formation, the dunes have undergone several cycles of erosion and regeneration (Mather et al 1974) and are composed of aeolian marine shell originating from offshore supplies (Farrow et al 2984, Mate 2007). Aeolian erosion and rabbit burrowing have created a 'badlands' topography (Mather et al 1974) with tabular turfed talards (Figure 3.3) being the only remains of dunes in some areas. Attempts at stabilizing erosion have been carried out by Historic Scotland and included planting of marram grasses *(ammophila arenaria)* and consolidation of sands (Moore & Wilson 2009a) within the area marked out as a Property In Care (PIC) (figure 3.4).

3.3.1 *Sand movement*

During the late Neolithic period there is evidence for an increase in sand movement at Tofts Ness (figure 1.3) dated to 2260 ± 100 BC (Somerville 2003) and machair development at Skaill around 3800 BC (Davidson & Jones 1985). The palaeoclimate at the Links of Noltland is outwith the remit of this work, but Farrell (2009) provides an overview for Orkney during the prehistoric era. Farrell (2009) builds a convincing case for a reasonably stable environment in Neolithic and Bronze Age Orkney but does cite an increase in windspeed evidenced by sand blow at the Loch of Skaill from c.4950 cal BC.

The more recent climatic data from the met office shows that mean annual temperatures fall within the 7.5-8.5°C category, with minimum 4-6°C and maximum 10-11°C. This is much milder than other landmasses on the same latitude thanks to the gulf stream. Precipitation falls amongst the lowest values in northern Scotland at 500-1200mm annually. Present day wind speed data is not available for the field site itself, and this is highly localized, however Mather et al note that 'the general pattern which emerges from the climatic statistics for Kirkwall Airport is of strong winds from most directions during any season in the year' (1973:17). The Links of Noltland experiences strong winds regularly which has been a large contributing factor to the erosion of dune sands (Mather et al 1973). It seems likely this has been a notable aspect of the landscape since the Neolithic period.

3.3.2 *Geology*

The underlying geology is of Upper Stromness Flags of the Mid Devonian epoch characterised by siltstone, mudstone and sandstone, this is capped by glacial till and dips towards a syncline (Moore & Wilson 1998). Bedrock is exposed in discrete areas across the site. Superficial deposits of blown sand of the quaternary period overlie buried soils, archaeology, glacial till and bedrock.

3.3.3 *Geomorphology*

The site is low lying (<10m above sea level, Moore et al 1998) and reaches from Narr Ness in the East to Queen O' Howe broch to the West. The ground level to the west of the site rises to a maximum of 105m at Couters Hill and 27m to the east. To the south there is a small, boggy loch known as the Loch of Burness which is locally known to flood in winter time and produce a seasonal stream running across the central area of the site so creating a linear scar (Mather et al 1974).

3.3.4 *Soils*

Soil development pathways in the past originated from glacial till or boulder clay which is derived from red marl and sandstone, and therefore likely to be alkaline implying the probable soil development pathway to begin at rendzina (Askew et al 1985 cited in McCullagh & Tipping 1998 and Acott 1993). Prior to dune formation soils may have more closely resembled the near-by Canisbay association, peaty and non-calcareous gleys to the West or the Thurso association, brown rankers and noncalcareous gleys to the East (Soil Survey for Scotland 1982 see figure 3.5).

Modern soils at the Links of Noltland are of the Fraserburgh association and have developed from shelly sand to become mostly calcareous regosols (ibid.). The presence of aeolianite outcrops at the coast edge attest to early dune formation upon glacial till in places and suggests that climatic conditions at the Links of Noltland were very wet and, although water was able to permeate through loose sand, it would collect upon the less permeable till allowing aeolianite to develop, this is as yet undated.

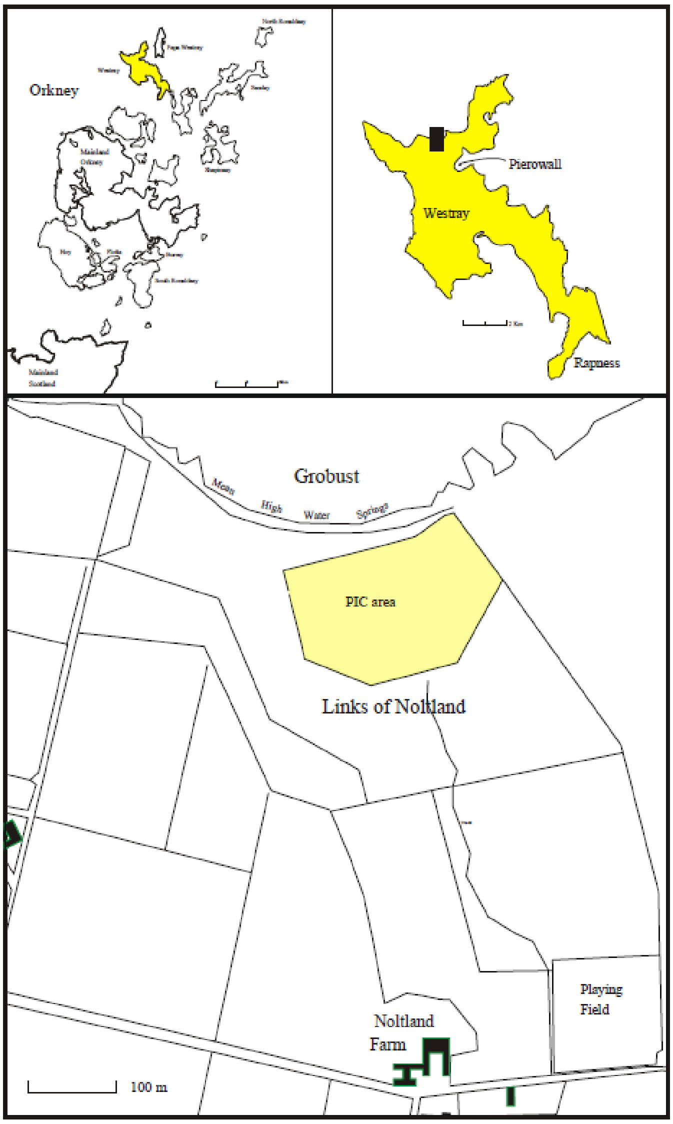


Figure 3.2: Field site location: Links of Noltland, Westray in the Orkney Archipelago (Moore & Wilson 2011b)

Figure 3.3: Links of Noltland, Central Area Facing South East. Kelp pit in foreground and collapsing dunes in middle distance.

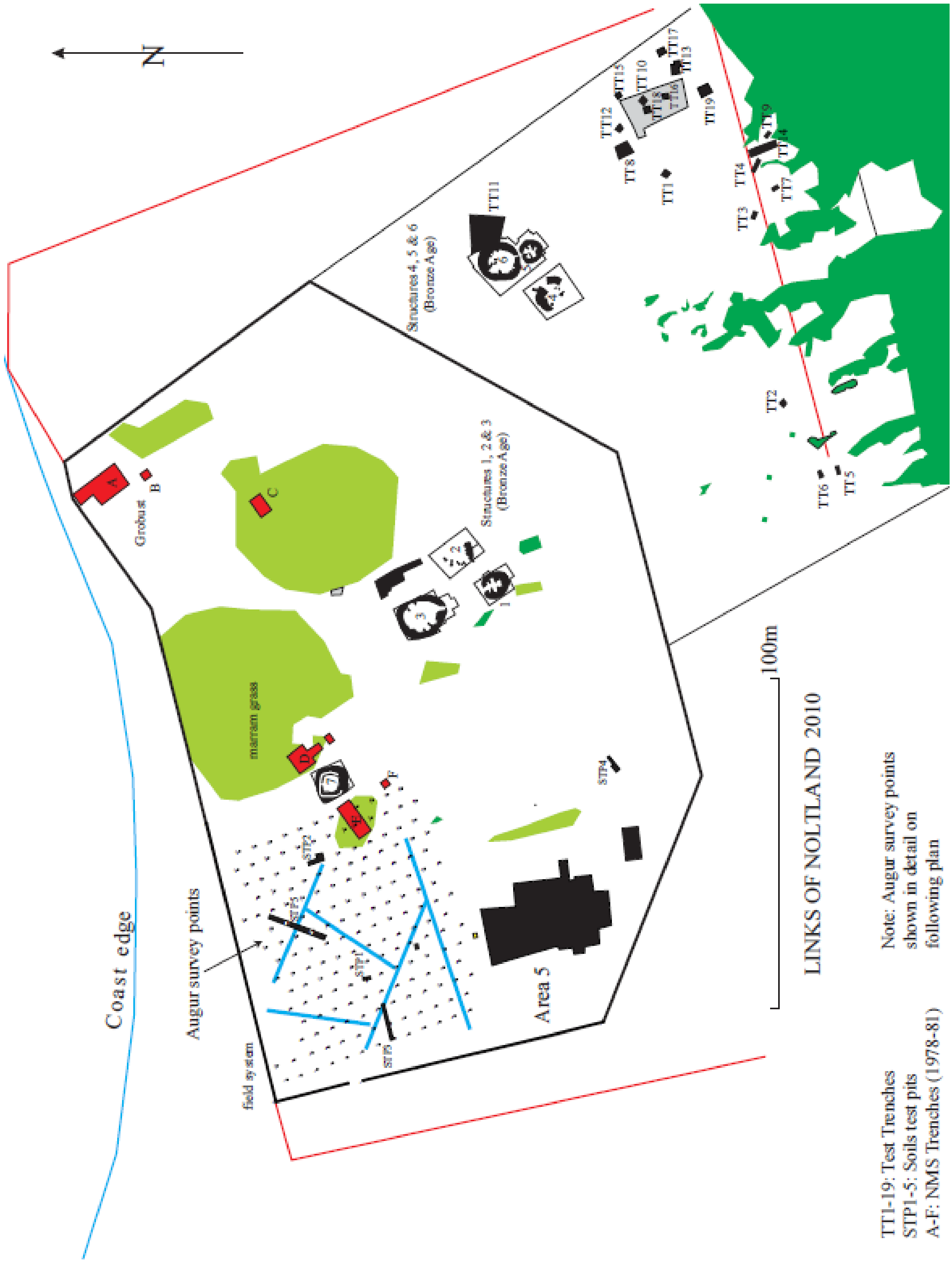


Figure 3.4: Links of Noltland, location of archaeological remains. The heavy black line designates the area taken into care by Historic Scotland (Moore & Wilson 2011b)

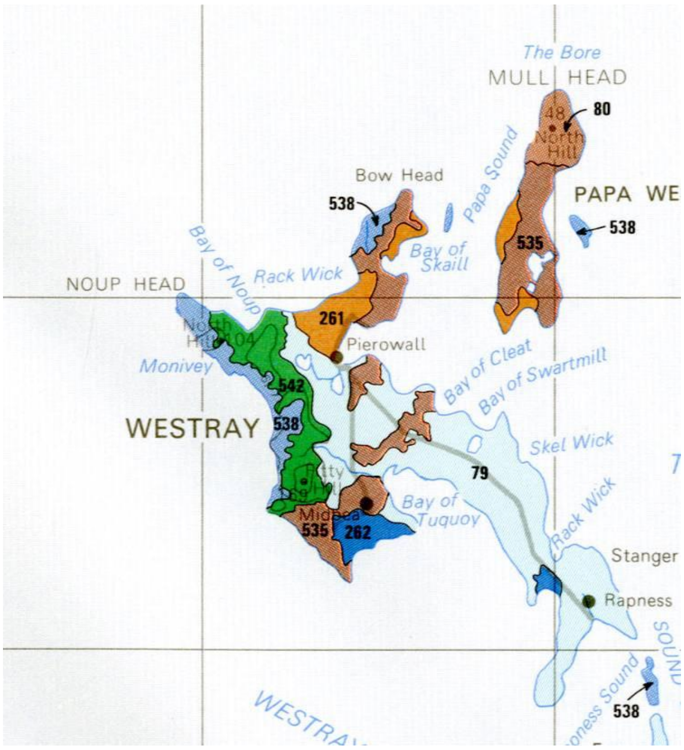


Figure 3.5: Soil Survey of Scotland 1982 showing soil associations on Westray. 261: Fraserburgh, 079: Canisbay, 535: Thurso.

3.3.5 *Vegetation & Fauna*

Modern vegetation cover is minimal at the Links of Noltland. Patches of marram grass *(ammophila arenaria)* cover the remaining dunes and rare sea sandwort (*Honkenya peploides)*, seapink (*armeria maritima)* and plantain (*plantago maritima)* colonies offer some stabilization of lower ground surfaces. At the time of writing marram grass plantation is underway to stabilize wind erosion.

3.3.6 *Erosion*

In the year 2000 a note was lodged in 'Discovery and Excavation Scotland' (Moore & Wilson 2000) stating that extensive archaeological remains at the Links of Noltland were 'under threat from continued deflation of the dunes in which they are located and from disturbance by rabbit burrowing'. Based upon a twenty year monitoring program (Bromley 2009) it was concluded that although the dune system which buried and protected archaeological remains had once maintained a cycle of deflation and regeneration (Mather et al 1974) this had now ceased and despite efforts to stabilize erosion it had become an immediate threat to the archaeology (Moore & Wilson 2009).

3.3.7 *Archaeological research*

The first record detailing the discovery of archaeological remains at the Links of Noltland was made by George Petrie who in the 19th century noted the presence of Grooved Ware pottery and skaill knives eroding from a dune system (Petrie notebook No. 9, 1859-73, 26-29, SAS 554: MSS 11. Consulted in the society of antiquaries' library, Edinburgh). The site was not investigated archaeologically however until 1978 when David Clark and Niall Sharples of the National Museums of Scotland excavated and recorded details of the prehistoric settlement and landscape (Clark & Sharples 1985). This followed a contribution to the 1977 'Discovery and Excavation in Scotland' gazetteer (Clarke et al 1977). whereby comparison was made to Skara Brae (now part of the 'Heart of Neolithic Orkney' UNESCO World Heritage Site) and Rinyo Through this program of excavation the buried prehistoric landscape beneath windblown calcareous sands came to be appreciated as being exceptionally well preserved and although comparisons with Skara Brae and Rinyo continued to be made, it was noted that following partial excavation 'ready parallels at Skara Brae or Rinyo' could not be found in the structure at Grobust (Clarke 1981), alluding to the presence of a potential third 'culture' in Neolithic Orkney. Clarke & Sharples trenches are marked out in red on figure 3.4.

The importance of the site and the risk presented by the erosion of sand dunes and subsequent exposure of midden material (1100sq m at that time) was recognised by 1983 (Lamb 1983) which led to the area being taken into state care in 1985 and dune management/planting undertaken in an attempt to protect the archaeology (Bromley 2009).

A topographical and archaeological survey was commissioned in 1994 by Historic Scotland in order to supply information for ongoing management of the site. It noted eroding old soils, kelp kilns, midden related to the Grobust structure and new exposures of probable prehistoric buildings (Dunwell 1995). Data from this survey was used to track vegetation cover, erosion and exposure of archaeological remains and used comparatively with further reviews taking place in 2001 and 2006 which prompted action to record exposed archaeological remains (Moore & Wilson 2007). In 2001 a geophysical survey (figure 3.6) identified possible field boundaries to the south west of the PIC (the area outlined in black, figure 3.4) and a few other anomalies but deep sand made interpretation difficult.

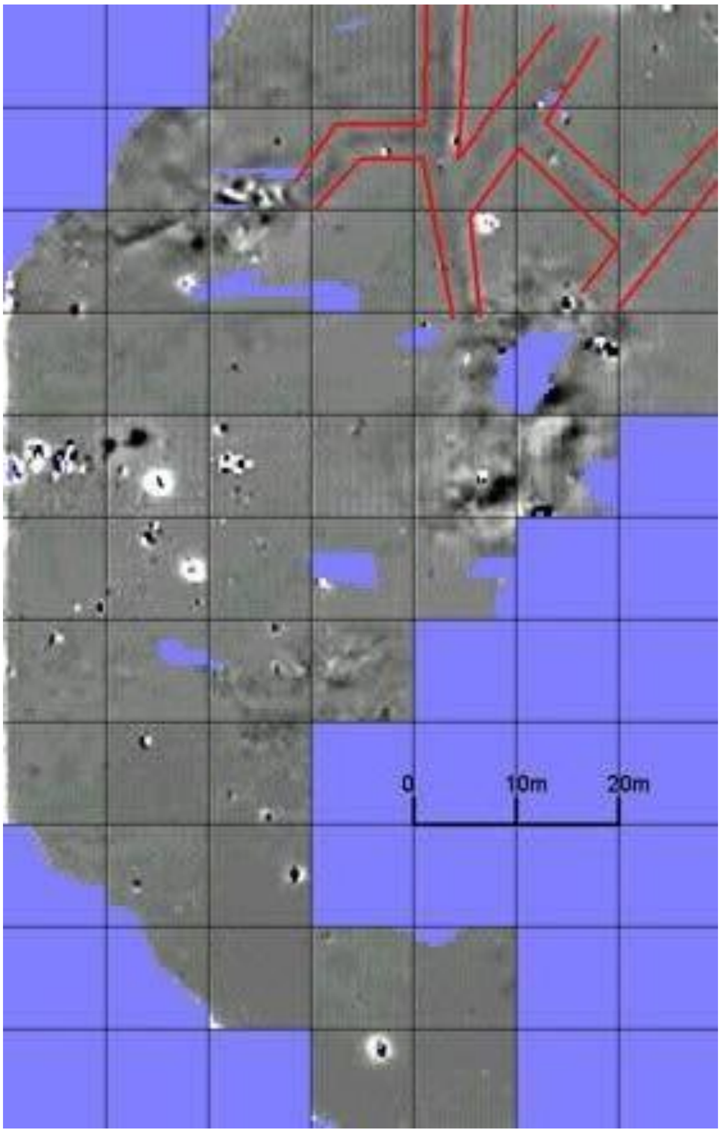


Figure 3.6: Results of 2001 geophysical survey with anomalies thought to be field boundaries highlighted (south west area in PIC). Courtesy of EASE archaeology.

By 2007 new exposures were identified as being at risk which lead to the commission of a range of field-methods by Historic Scotland and Orkney College so a 'large scale assessment could be used to build up a more comprehensive picture of the landscape and thereby discern connections between the various disparate remains' (Moore & Wilson 2007). These included rapid rescue excavation, geophysical survey, augur survey, topographic survey and test pitting. The Grobust structure excavated by David Clarke was also re-opened to assess its state of preservation.

During 2007, six structures interpreted as Bronze Age were investigated, three of these lay within the PIC. Structure 3 was noted as of special interest as it provided an uninterrupted stratigraphic record through Neolithic and Bronze Age contexts. It was recorded that, by the time excavation was carried out on the Bronze Age structures, their interiors had been mostly scoured out by previous exposure events (ibid.). However, they were clearly built onto anthropic sediments which infilled and were accumulated around earlier structures and paved surfaces (Moore & Wilson 2007). The Bronze Age horizons included dumped anthropic sediments and associated cultivated anthrosols (Moore & Wilson 2009b). The results from geophysical survey were difficult to interpret but three areas of potential archaeology were identified and this led to the discovery of substantial Late Neolithic settlement in Area 5. Decorated stone and a yellow clay foundation platform alerted archaeologists to the importance of the main structure found in Area 5 (ibid.). This became the main focus of excavation in subsequent years and has been the source of some of the most important discoveries in Scottish archaeology during recent times. For example, the earliest known anthromorphic figurine known in Scotland (found in the infill of kiln feature, see figure 3.42) and the 'cattle skull house' (structure 9, figure 3.9) (Moore & Wilson 2009b).

In summary, archaeological fieldwork has so far discovered and recorded five key areas of exceptionally well preserved structural remains, associated anthropic sediments and anthrosols contemporary with the Neolithic and Bronze Age periods in the Orcadian context. As structures pertain to settlement, a rare opportunity presents itself to investigate daily life and intrinsic cultural, social and technological transitions across time.

3.3.8 *Palaeoenvironmental Research*

The importance of preserved cultural soils at the Links of Noltland was first recognised during the excavations of Clarke and Sharples. In addition to their investigations at Grobust, an area of 'midden' was recorded to the west (this came to be referred to as the West Midden, Clarke 1980) along with ard marks and walling, the first account of field systems at the site.

A survey using a Dutch auger was carried out around structure 7 in 2007 to characterize and record the extent of buried soils documented by EASE (Moore & Wilson 2007). Two transects of 76m and 30m were set out roughly aligned north to south and a third 42m transect joined the first two together. The results are presented in the 2007 field report and can be summarized as follows:

Transects one and two identified two midden horizons distinguished by their texture and inclusions and separated in places by a sandy deposit. The latest, 'midden 1' was measured at 0.30m at its maximum thickness. It was described in the field as a dark greyish purple brown medium compact friable silty clay and contained bone, shell and charcoal. 'Midden 2', a dark reddish brown silty clay deposit was 0.15-0.60m thick and contained more inclusions than 'midden 1'. A possible cultivation zone was identified between the two middens, described as dark greyish purple brown sand 0.07 – 0.28m thick. Below midden 2, golden yellow sand was detected in places as well as a relict ground surface (reddish brown sandy loam) directly over subsoil. Interpretation of soils noted in transect three demonstrated a third dark reddish brown sand 0.05-0.20m thick described as 'midden 3', this may be on the same horizon as 'midden 2'.

These findings indicate that differences in colouration and inclusions can occur in the same sediment and that periods of anthropic sediment accumulation could be separated aeolian sand and possible cultivation horizons. It was noted that 'Structure 7 is isolated and surrounded by midden to the north and south' (Poller in Moore & Wilson 2007). Settlement discovered in Area 5 was also encircled by anthropic sediments which likewise filled in abandoned buildings. Furthermore, these Neolithic structures were built into accumulated anthropic sediments (Moore & Wilson 2008).

Test pitting in the area of the West Midden in 2007 demonstrated that discrete variations in texture and colour could be identified. The boundary between anthropic sediments and the surrounding soils was not easily defined and appeared to fade gradually into anthrosols interpreted as old ground surfaces (Moore & Wilson 2007). This was also the case within Area 5, where anthropic sediments graduated into anthrosols to the North and South of the settlement, these were described as probable cultivation horizons (Moore & Wilson 2008 & 2009a). The excellent preservation of anthropic sediments and anthrosols was appreciated and the potential for the contribution of specialist soils examination recognised. In 2008 an evaluation of buried soils and their stratigraphic relationships with sand deposits and structures at the Links of Noltland was enacted by Simpson & Wilson (2008). Findings indicated that the 'range and extent of anthropic sediments and anthrosols associated at the same locality' presents the fortuitous prospect to consider the relationships between anthropic sediments and cultivation horizons. The juxtaposition of Neolithic and Bronze Age settlement was also affirmed as 'an outstanding opportunity to consider the dynamics of landscape change across the Neolithic to Bronze Age transition'.

A preliminary soils investigation was carried out between 2008 and 2009 (McKenna & Simpson 2011) using material collected as part of rescue excavations carried out by EASE in 2007. A column sample using six 8x5x5 cm Kubiëna tins was recovered from a 4m² sondage (figure 3.7) located to the east of structure 3 with the objective of establishing through thin section micromorphology analyses the formation processes of contexts [7096] and [7079]. Three of these tins (numbered 1-3) were centered upon context [7096], extending to the interfaces with the soil layers above and below. Three (lettered A-C) were centered upon context [7079], extending to include the interfaces with the soils above and below.

To briefly summarize the findings; all samples share a similar coarse mineral component, either dominated by or largely composed of well sorted marine shell and sandstone fragments, interpreted as various intensities of calcareous windblown sand consistent with the coastal location of the site. The earliest soil formation context [7096] investigated in thin sections 1-3 displays evidence of rapid formation through windblown sand accumulation and anthropogenic contributions. These contributions start with the use of imported turf and develop to incorporate domestic wastes that included charcoal, bone fragments and pottery. The most likely explanation for these soil amendments was to stabilize a dynamic and shifted land surface for cultivation. Evidence of enhanced vegetation cover and reduced windblown sand movement is found in the upper part of context. A similar deposition process has been identified at Tofts Ness where sharp boundaries between fossil soil cultural horizons and the underlying natural horizons have been interpreted as the result of the initial deposition of considerable volumes of material (Simpson et al 1998). As determined at Tofts Ness, windblown sand episodes at Links of Noltland were rapid and sand blow (context [7095]) rapidly covered context [7096]. These deposits were subsequently slightly homogenized with context [7079] as intensive anthropogenic deposition began again and the two contexts were initially worked together. Micromorphological indicators of cultivation, ‘textual pedofeatures’ were found in these two contexts implying that the soils were worked through cultivation activity. The later cultural soil formation process visible in thin sections A-C indicate a mixture of domestic waste material and introduced turf alongside animal manure (evidenced by the presence of calcium spherulites, Canti 1998), again used to stabilize the windblown sand which buried earlier phases of cultivation represented in context [7096].

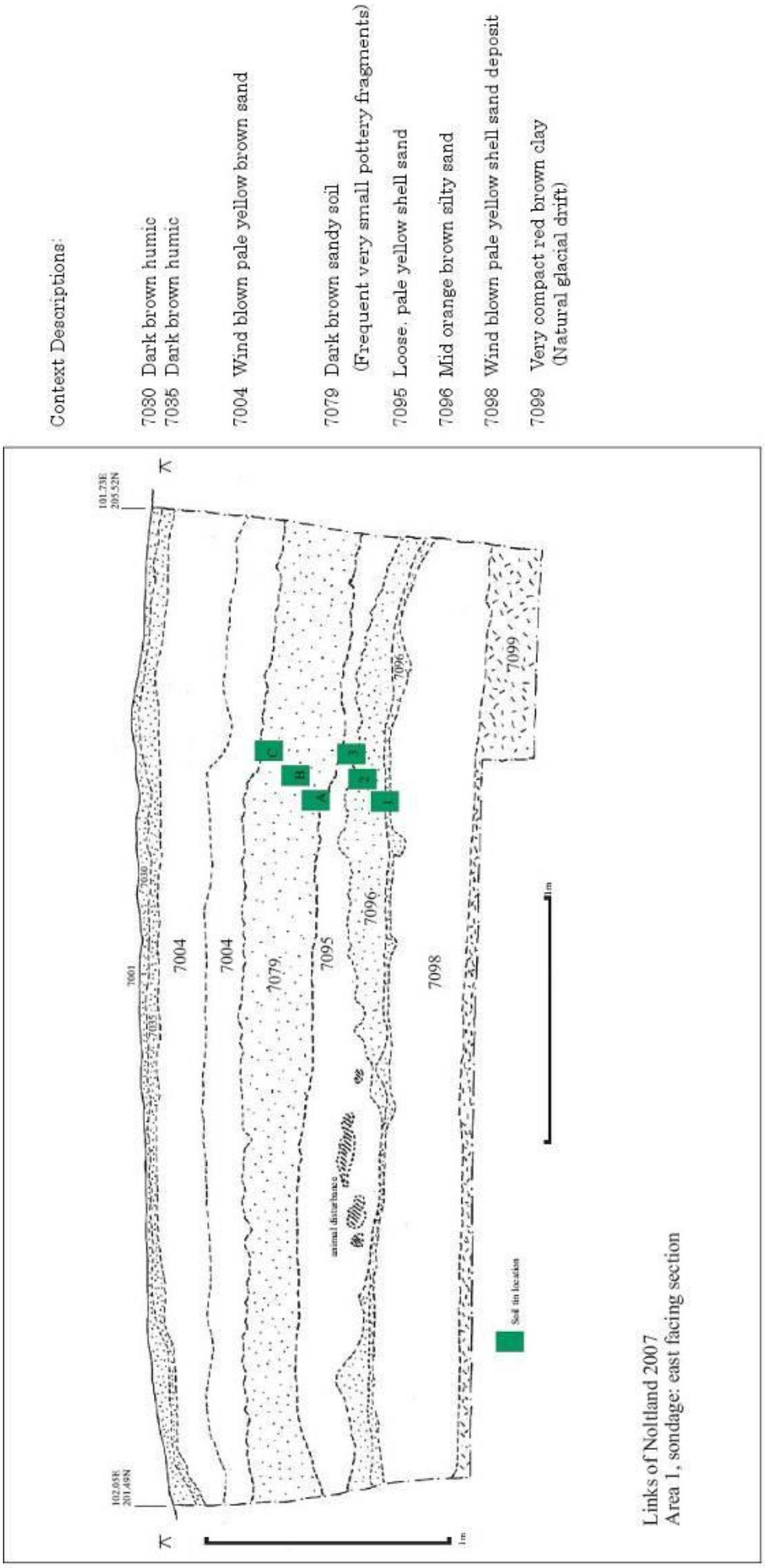


Figure 3.7: Links of Noltland, Area 1 sondage, east facing section stratigraphy and context descriptions

The findings of this preliminary investigation into soil micromorphological properties of archaeological contexts at the Links of Noltland partially support the manuring strategy model for the Northern Isles. Domestic wastes and turves used from the Neolithic through to the middle Iron Age where after the systematic use of domestic animal manures becomes more prevalent (Guttmann et al 2006). However, the presence of calcium spherulites in contexts which have been cultivated might indicate that animal dung was employed as manure much earlier than previously thought.

3.3.9 *Summary*

The Links of Noltland is established as a unique archaeological site in the Scottish North Atlantic seaboard due to the preservation of an uninterrupted stratigraphy of anthropic sediments surrounding settlements spanning the Neolithic to the Bronze Age. Neolithic structures are clustered together and built into anthropic sediments which continued to accumulate during the lifetime of the settlement. Upon abandonment buildings were filled up with anthropic sediments. Upon the commencement of this current research, excavation had not yet reached the level of floor surfaces or underlying material within the Neolithic settlement areas .

The Bronze Age structures occur in pairs and are more dispersed than Neolithic settlement. Anthropic sediments include poorly preserved floor layers, wall cores and pathways, anthrosols associated with them were subject to cultivation (Moore & Wilson 2009b).

The range and extent of these sediments clearly expands into the wider landscape, with field systems and expansive anthrosols. Therefore, the site offers the opportunity to investigate a series of anthrosols and anthropic sediments including stabiliser, cultivated soils, occupational floors, deep anthropic sediments, construction material, foundations and infill. The opportunity to explore any changes over time is also presented at this site allowing fulfillment of all research objectives (figure 3.8).

3.4 Field Design

Geoarchaeology (the application of earth-science techniques to archaeological research questions) offers a holistic approach to investigating soils and sediments over a range of scales from landscape to archaeological structure (French 2003, Rapp & Hill 2006). The geoarchaeological toolkit accommodates coarse and fine data collection; both are required to understand relationships between settlement and landscape (Waters 1992).

A range of geoarchaeological methods is now available for this type of study but the most widely appreciated is thin section micromorphology. This microscope based technique is able to provide information on sediment formation processes by allowing examination of sediment composition and stratigraphy which can be too thin to accurately record during excavation. It is also a powerful tool for the identification of cultural activities which may not be visible in the field, particularly fuel residues, fragments of other allochonthous soils and sediments and information about the pre-settlement environment (Courty et al 1989). For these reasons it is at the core of this research.

The approach to identifying the extent of anthropic amendment of soils in the wider landscape is described through auger survey and test pitting. The challenge of using auger survey bore hole data in conjunction with geophysics had to be dealt with in the field and so the decision making process is discussed.

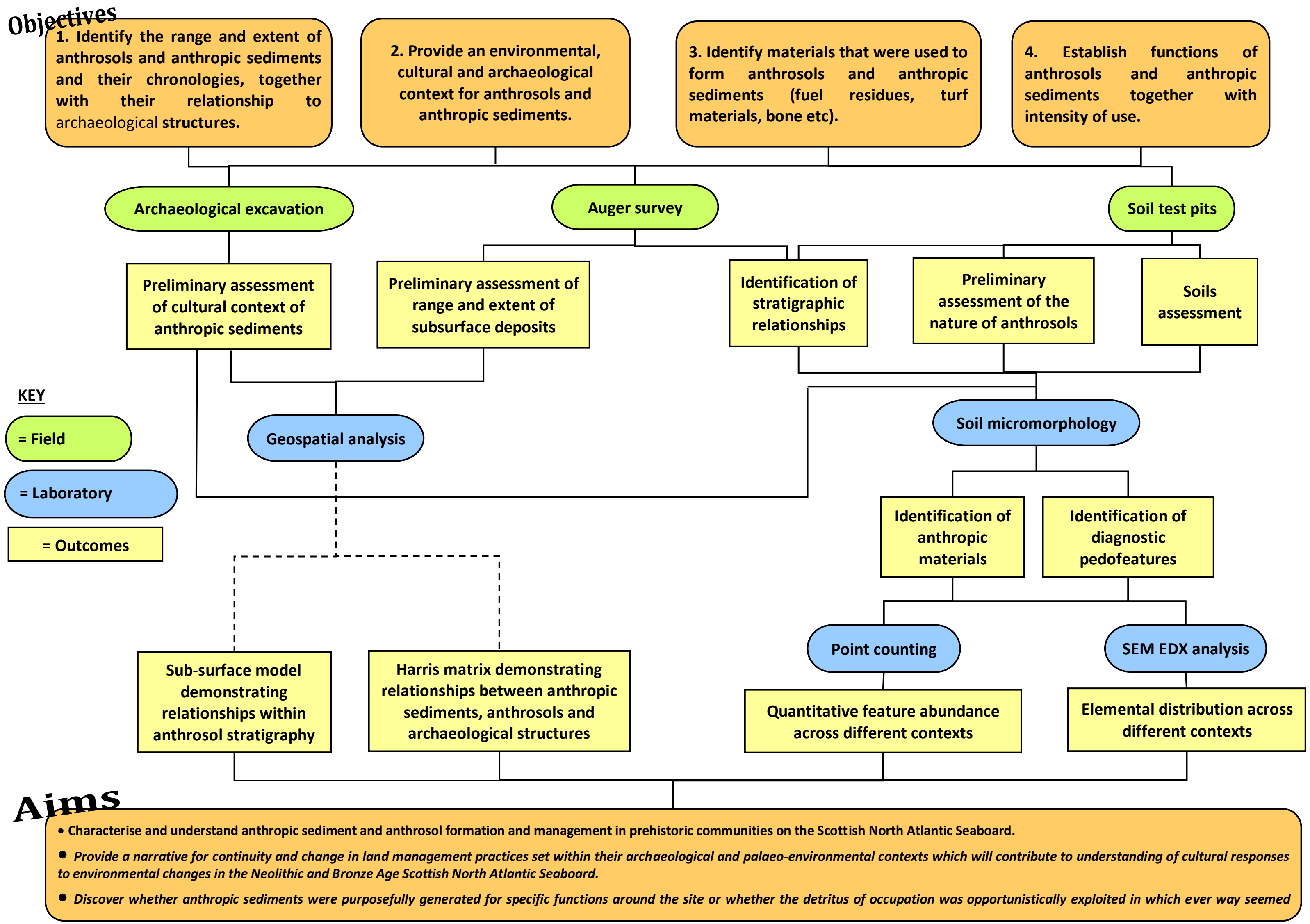


Figure 3.8: Quick reference diagram showing how objectives influence selection of the most effective geoarchaeological methods to achieve the research aims

To meet this challenge and provide a convincing demonstration of the relationships between the soils and sediments identified in the landscape and the sediments in the immediate vicinity of archaeological structures, spatial analyses using Geographical Information Systems (GIS) was explored back in the lab. Limitations and suggested improvements are discussed.

Kubiëna tins for thin section micromorphological analyses were recovered from key features of interest in test pits but also opportunistically alongside archaeological excavation of Neolithic and Bronze Age settlement sites. The processes involved are explained, including interactions with archaeologists to identify and sample anthropogenic sediments.

An explanation of laboratory methods to quantify anthropic sediment components is given. This includes thin section manufacture, description and interpretation and protocols used for SEM EDS analysis of artefacts and fine materials.

Geoarchaeological fieldwork was carried out alongside Environment and Archaeology Services Edinburgh (EASE) on behalf of Historic Scotland during three field seasons between 2010 and 2012.

3.4.1 *Site specific research questions*

The first field season pursued all four research objectives (figure 3.8) to provide a solid foundation for the research program. Building upon previous archaeological, geophysical and palaeoenvironmental observations the broad aims of the field season were to investigate anthrosols/field systems in the north-west section of the Property in Care (PIC) and gather samples from key archaeological contexts alongside excavation of Neolithic and Bronze Age settlement areas.

Archaeological excavation was limited in the 2011 field season and so the extent of anthrosols in the wider landscape was mapped, fulfilling objective 1. Samples were recovered for micro-scale analysis in the lab.

The final field season concluded the anthropic sediment sampling program, carried out alongside archaeological excavation, providing a complete sample set for thin section micromorphological and chemical analyses, providing the raw data to fulfill objectives 2, 3 & 4.

3.4.2 *Auger Survey*

The Area 5 anthrosols and field system were buried beneath aeolian sand and so a bucket auger was used in conjunction with plastic piping in areas of very deep sand to allow prospection through this without it collapsing. Once a depth of approx 20cm was reached with the bucket auger, the plastic pipe was inserted into the hole and hammered in using a 2oz hammer and a hammer top. A Dutch auger was then inserted into the pipe to carefully remove the sand at the base of the pipe, this increased the depth to which the pipe could be driven. This process was slow, but once a depth of around 1m was reached the sand overburden provided sufficient compaction to allow normal Dutch auger prospection. An extendable handle was required to compensate for the depth of up to 3m of aeolian sand in some areas. Changes in the colour of the sand were recorded using a Munsell chart and the depth of changes recorded. This method is seen to be an approximation of depth as the action of the Dutch auger is known to mix the profile to some extent. To minimise this, only 5 turns of the auger were made before it was taken out and the soil/sediment examined. Again, this was slow but provided a greater level of accuracy. Testing whether the depth of the recorded changes in the colour and/or texture of the investigated materials was accurate involved digging a hole around three auger boreholes where the depth of aeolian sand was safe to do so (<1m, Drewett 2001) to measure the stratigraphy in section. This showed that that results were accurate to within 3cm.

In 2010 a survey grid (grid 1) of 15 transects (figure 3.14) was planned across an area of c.70 x 65m in order to retrieve fine resolution data across the landscape to the North of Area 5, taking in the whole area of field system identified by geophysics and exploring the buried soil and sediment profiles between Area 5 and structure 7. The boreholes were planned to be placed at 5m intervals along each transect line but in practice the presence of hard surfaces or stones within the hole meant these occasionally had to be shifted to the left or right, when this was encountered the hole was resituated either 1m to the left or right of the original hole. A large sand dune happened to fall in the eastern extent of the grid and so a 3.5m handle was required on the Dutch auger, despite problems of compaction the buried sediment was encountered successfully.

A second survey grid (grid 2) was set up in the same way in 2011, investigating the area between the sand dune to the east of structure 5 and Bronze Age structures 1, 2 and . The decision not to auger through this sand dune was made due to its instability and proximity to Area 5 archaeology and the bedrock outcrop visible to its eastern extent. This second survey grid consisted of 10 transects covering an area approx. 70 x 50m.

A series of prospective auger transects were made with the Dutch auger to the west of the property in care, to the east of Bronze Age structures 1, 2 & 3 and south of Bronze Age structures 4, 5 & 6. These transects explored the extent of anthropic amendment further away from the settlement sites.

Each auger point was 3D referenced using the site Electronic Distancing Meter and their positions plotted onto the site plan shown in figure 3.9.

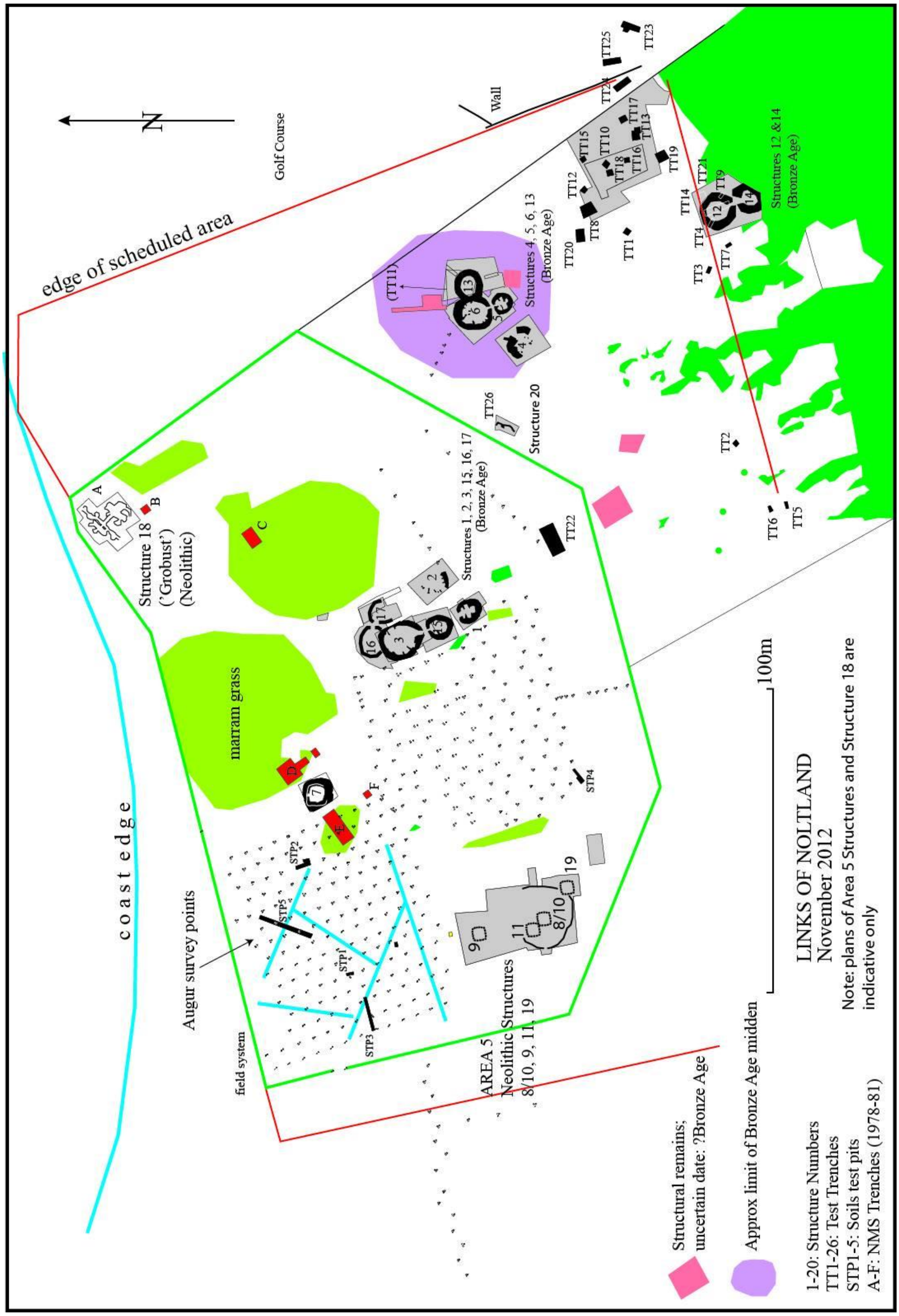


Figure 3.9: Links of Noltland archaeological results 2012, showing position of auger points across Area 5 field system (grid 1) and between Area 5 and Bronze Age structures 1, 2 & 3 (grid 2). Further exploritory transects are marked to the west of the PIC, to the south of grid 2, north east of test trench 22, east of structure 2 and north west of structure 6 (from Moore & Wilson 2012).

3.4.3 ***Results***

Auger survey data is available as supplementary data, field interpretation follows below.

Grid 1: Area 5 Field System

The auger survey identified the presence of buried soils beneath white or light grey aeolian shell sand across the survey area. The aeolian sand depth shifts on an almost daily basis as deposition and erosion occur due to wind and water action. During the survey sand depth was recorded at a mean of 43cm and a maximum depth of 308cm through dunes and 1cm in areas most exposed to the elements. Within this horizon and resting upon its surface were several kelp pits or the remains of such (figure 3.10). At borehole 32 a kelp pit was discovered in situ 7cm below the modern ground surface with several layers of burnt ashy horizons resting upon a further 40cm of windblown sand. Glacial till (figure 3.12) was encountered at 148 of the boreholes at a mean depth of 66cm, once this sediment was struck the borehole was considered completed so glacial till depths were not recorded. A discussion of possible till depth for the area is available elsewhere (Dry & Robertson 1982). Across the extent of the survey 16 discrete stratigraphic sequences were identified.

Figure 3.10: Auger survey grid 1 area, modern ground surface [001] and kelp pit, left.

The most frequently manifested is stratigraphy number 2 (coloured dark red on the simplified GIS generated figure 3.11), which comprises of aeolian sand covering loamy sand [009] with clayey sand [010] forming a B horizon which seals a yellowish brown (10YR 5/4) clayey sand C horizon [006] with orange, pink, red, green and blue mottles which is characteristic of the glacial till or boulder clay found throughout Westray (Leather, 2006). Occurring at 79 auger points, the stratigraphic units (contexts) associated with this sequence vary in thickness across the survey area. In places the 'B-horizon' is absent, with loamy sand resting directly upon till or rock these variations are labelled sequences 6, 9, 11, 12, 13, 14 and 15. Sequence 6 is the most commonly occurring of these and is colored green on figure 3.11. Loamy sand [009] was generally free from inclusions. This is in contrast with the windblown sand horizon [001] which contained charcoal fragments, modern artefacts such as wire fencing and rope and frequent (c.10%) marine shells, these were perhaps dragged onto the site attached to sea weed for kelp burning (Thomson 1983). Therefore loamy sand [009] differed sufficiently from windblown sand to be interpreted in the field as an old ground surface/palaeosol (figure 3.13), it is very similar to contexts [9178], [9088] and [9002] etc which were interpreted by EASE as an old ground surface (Moore & Wilson 2011b). Background levels of shell fragments may be represented in context [009] as they were present in 10 boreholes to the centre and west of the survey area (7, 8, 17, 18, 48, 75, 96, 100, 108 and 119) and in five to the east (153, 159, 162 and 164), it was unclear at this stage whether they were signatures of anthropogenic amendment.

The sandy clay [010] was found to be present over a wide area, to the east where it was clearly associated with structure 7 and Clarke's trench it was interpreted as an in situ anthropic sediment. Simplified it can be separated in to sandy clay with inclusions and sandy clay without inclusions (figure 3.11). Where it contained inclusions (bone, flint, shell, charcoal and pot sherds) it was interpreted as anthropic sediment or anthrosol, the results indicate a possible relationship between structure 7 and Area 5 based upon the continuation of horizon [010] between the two areas.

Table 3.1: Results of grid 1 auguer survey, stratigraphy descriptions

Stratigraphy Number	Allocated Number	Stratigraphy Description:	Number of Occurrences
1	**(001) (011) (009) (010) (006)**	**Windblown Sand Loamy Sand Clayey Sand Loamy Sand Glacial Till**	**1**
2	**(001) (009) (010) (006)**	**Windblown Sand Loamy Sand Clayey Sand Glacial Till**	**79**
3	**(001) (009) (010) (012) (006)**	**Windblown Sand Loamy Sand Clayey Sand Clayey Sand Glacial Till**	**1**
4	**(001) (009) (015) (010)**	**Windblown Sand Loamy Sand Loamy Clayey Sand Clayey Sand**	**1**
5	**(001) (010) (006)**	**Windblown Sand Clayey Sand Glacial Till**	**1**
6	**(001) (009) (006)**	**Windblown Sand Loamy Sand Glacial Till**	**47**
7	**(001) (009) (017) (010) (006)**	**Windblown Sand Loamy Sand Clayey Loamy Sand Clayey Sand Glacial Till**	**1**
8	**(001) (009) (018) (010) (006)**	**Windblown Sand Loamy Sand Clayey Loamy Sand Clayey Sand Glacial Till**	**1**
9	**(001) (006)**	**Windblown Sand Glacial Till**	**1**
10	**(001) (019) (006)**	**Windblown Sand Very Compact Sand Glacial Till**	**9**
11	**(001) (020) (009) (006)**	**Windblown Sand Loamy Sand Loamy Sand Glacial Till**	**1**
12	**(001) (020) (006)**	**Windblown Sand Loamy Sand Glacial Till**	**4**
13	**(001) (009) (020) (006)**	**Windblown Sand Loamy Sand Loamy Sand Glacial Till**	**16 (Dune)**
14	**(001) (020)**	**Windblown Sand Loamy Sand Hard Stone**	**3**
15	**(001) (025) (020) (006)**	**Windblown Sand Silty Loamy Sand Loamy Sand Glacial Till**	**2**
16		**Compact Sand Silt**	**4**

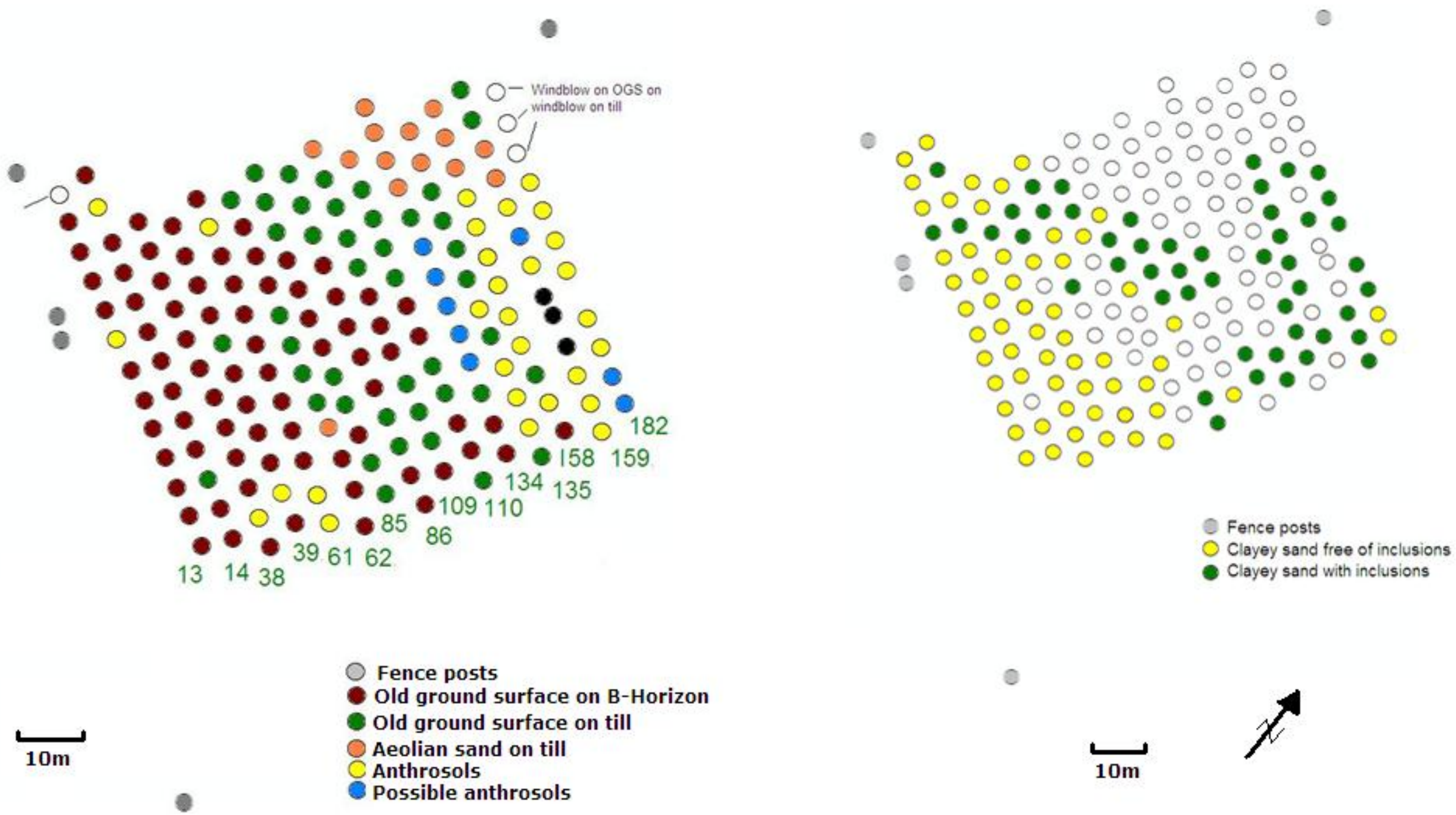


Figure 3.11: Left - Auger survey, simplified results generated in arcGIS from MS Excel database (OGS = Old ground surface). Right -Auger survey results generated in arcGIS from MS Excel database showing the possible relationship between structure 7 and Area 5 based upon the extent of context [010]. Where context [010] contains anthropic inclusions it is coloured green and where is is does not contain anthropic inclusions it is marked as yellow. This analysis was used in the field to determine locations of test pits and is given here for illustrative purposes only. It may be used alongside figure 39 and table 3.1.

Figure 3.12: Auger survey - an example of glacial till/boulder clay [006]

Figure 3.13: Auger survey - an example of loamy sand palaeosol [009]

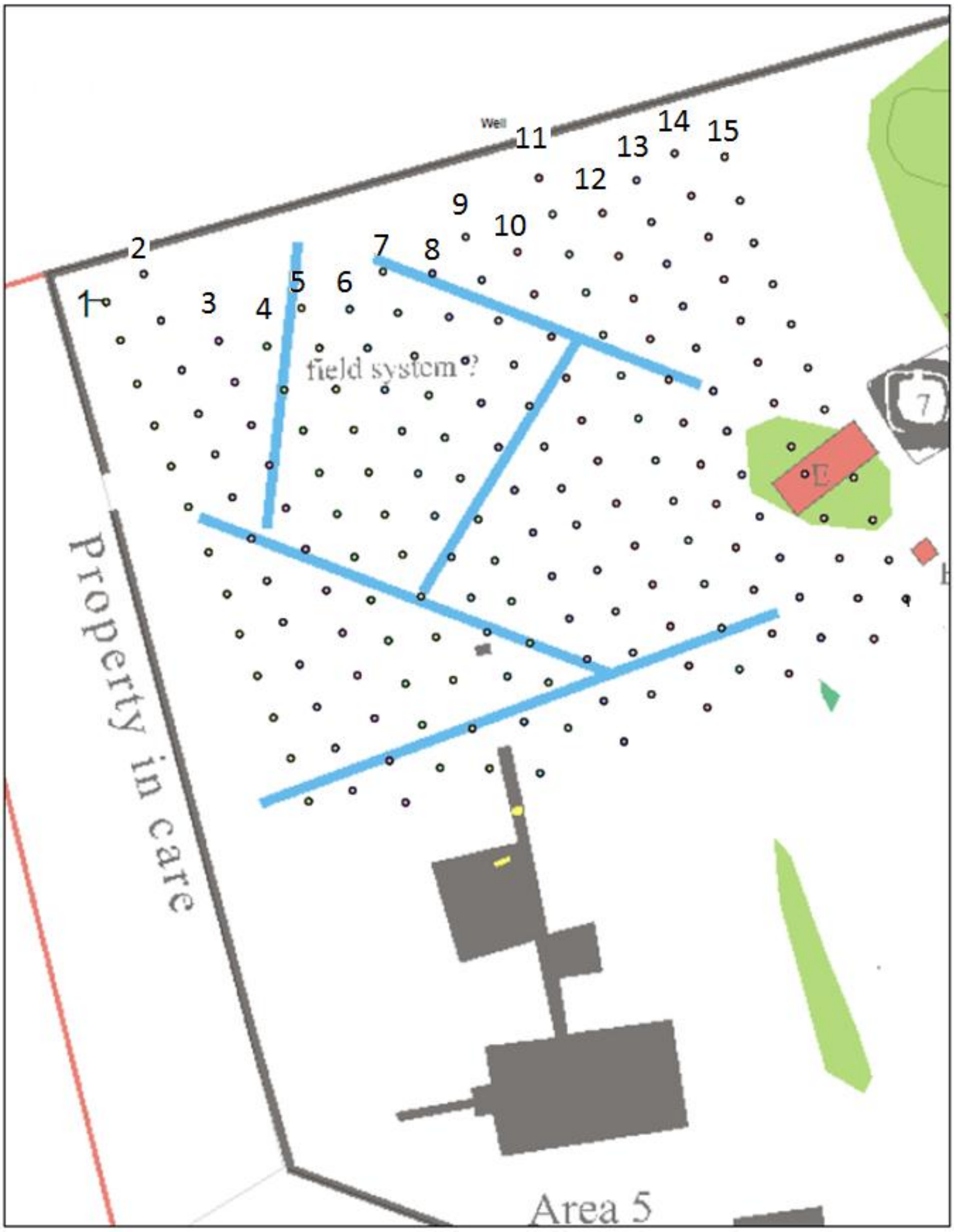


Figure 3.14: Auger survey points map. Courtesy of Richard Strachan, Historic Scotland

Grid 2: area in between Area 5, Structure 7 and Structures 1, 2 & 3

Anthrosols were detected across this area with six soil and sediment profiles identified by colour, texture and inclusions. The windblown sand overburden was typically white, composed of coarse shell sand which often graduated to loamy or silty sand with depth. The average depth across the survey area was 38cm with a range of 0.5-157cm. The basal depth of each bore hole was recorded when either glacial till [006] or rock was encountered. Stone may indicate bedrock or archaeology and was intercepted with greatest frequency nearby archaeological structures (figure 3.16). Two kelp pits were encountered at or immediately below the surface and so sub surface stones may be associated with this period of activity. Highly moist sediments were intercepted across the site (figure 3.17) at depths ranging between 3 and 70cm above glacial till or bedrock. This occurred both in association with and separately from anthrosols. Seasonal pools were noted to develop at the site during the 2010 field season (figure 3.18) and so a similar relict feature may lie beneath the sand overburden.

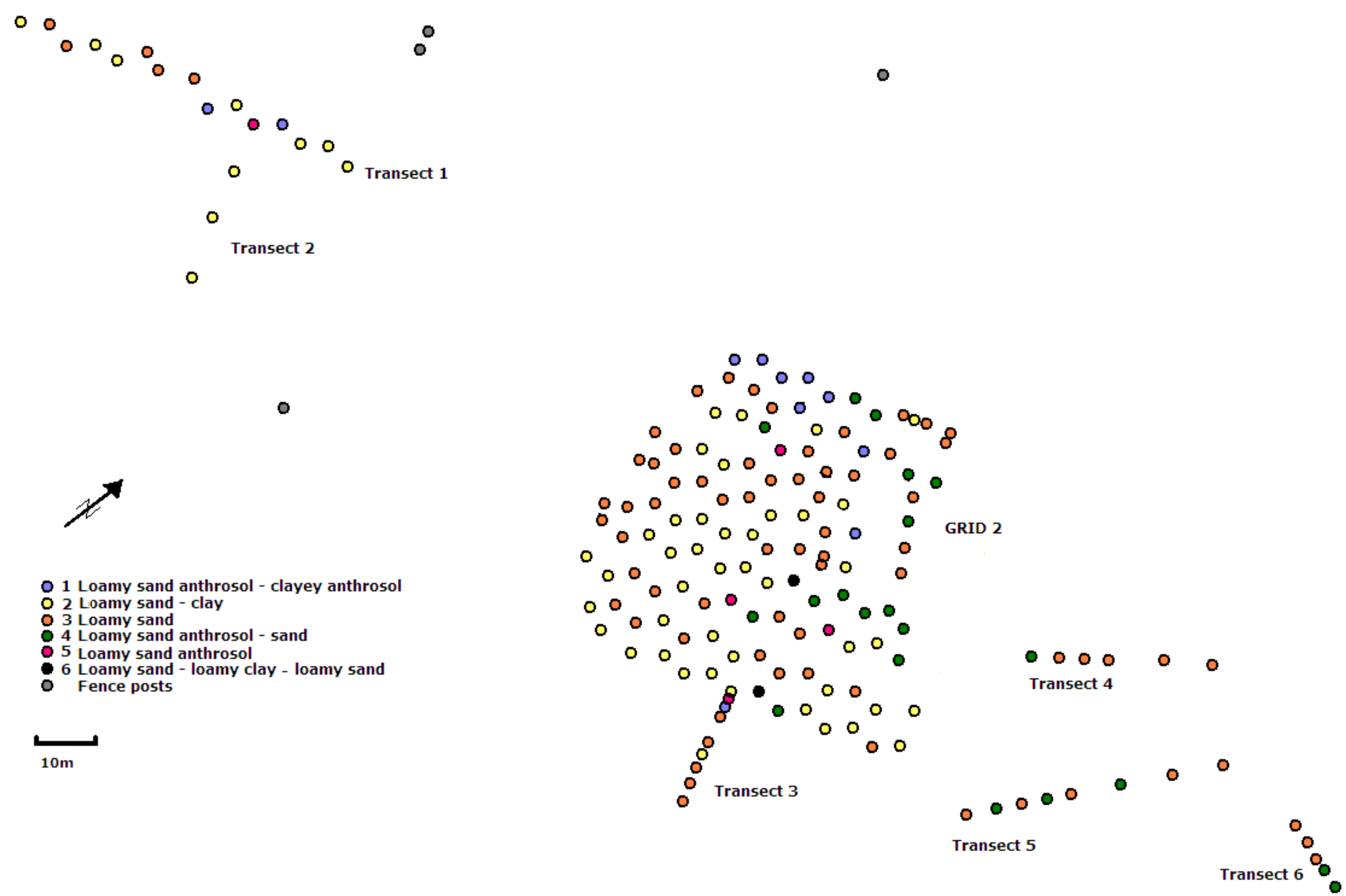


Figure 3.15: Auger survey results, grid 2 and exploratory transects 1-6

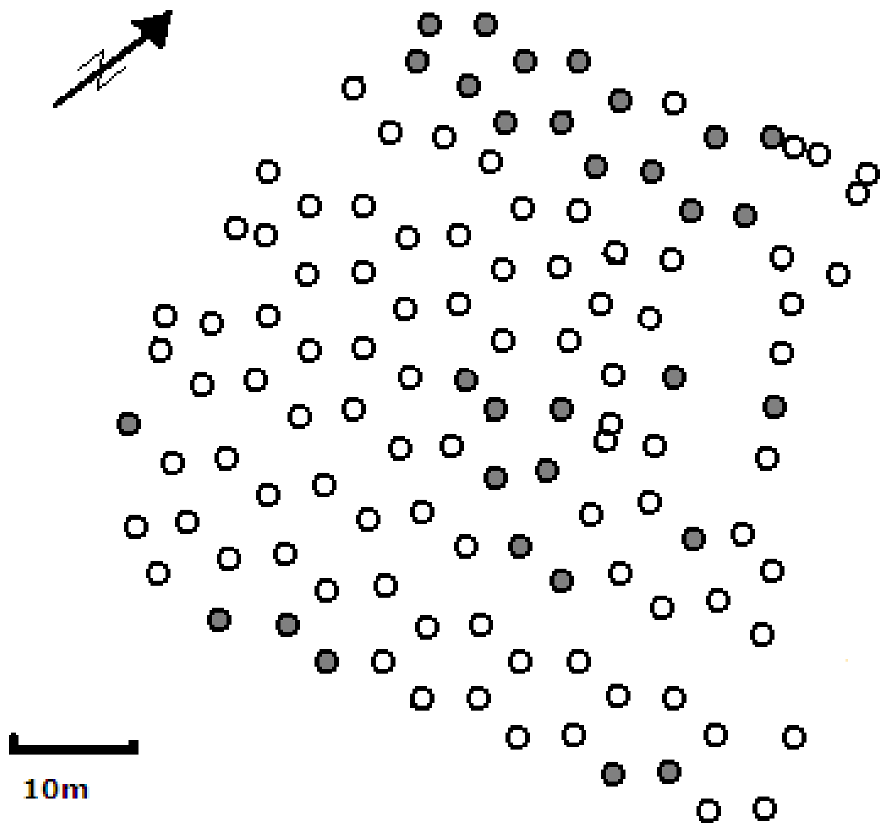


Figure 3.16: Locations of intercepted stone

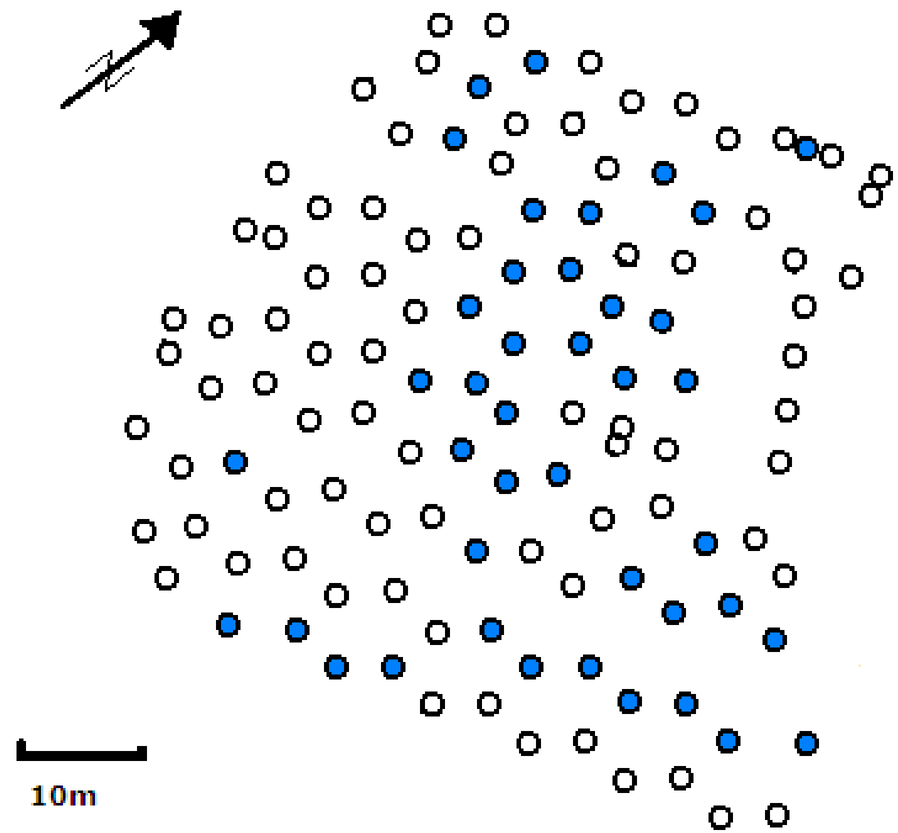


Figure 3.17: Highly moist sediments or intercepted water-table.

Figure 3.18: Seasonal flooding at the Links of Noltland site (2010)

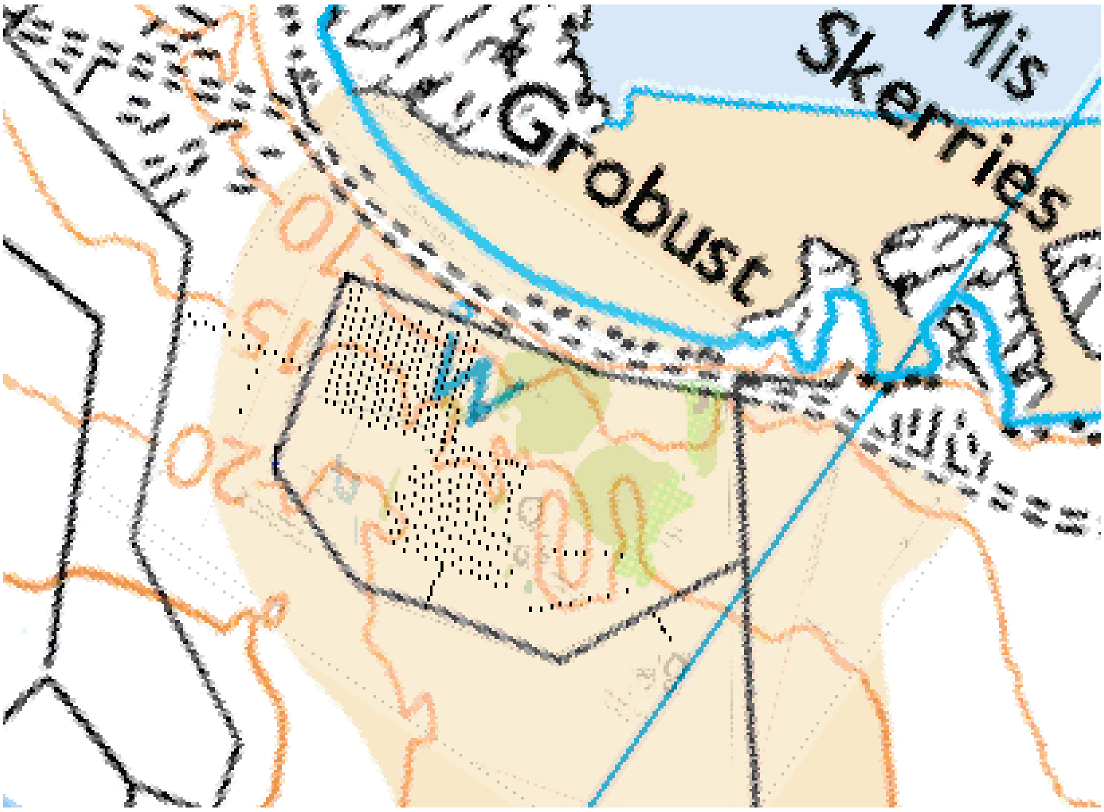


Figure 3.19: All auger points displayed in relation to the ordnance survey of the area.

An intricate network of loamy and silty sand was recorded over the full extent of grid 2, representing aeolian transport and truncated surface development. Anthrosols occur to the area immediately south of structure 7 varying from brown sandy loamy clay to dark brown loamy clay with <1% sand content sealing stone or glacial till (sequence 1, figure 3.15). Southwards from structure 7 anthrosols become progressively more silty and sandy until at a distance of 35m from structure 7 they fade out. In the south west area of grid 2, loamy sand with varying amounts of silt frequently overlying clean clayey sediment (sequences 2 & 3 figure 3.15) was recorded. Anthrosols were also mapped extending 30m west of structure 3. However in this area they were described as brown or dark greyish brown loamy or silty loamy sand and overlay clean sandy sediments (sequence 4, figure 3.15). These too faded into the area of loamy or silty sand (sequences 2 & 3, figure 3.15). Between structures 7 and 3 anthrosols were intimately related, with the halo of anthrosol material extending out from structure 7 to meet loamy sand anthrosols occurring around the area of structure 3. Some truncation was evidenced, which may be related to a buried boundary wall or structural material (Kainz 2011) or later quarrying activity (Wilson *pers. comms.).*

Exploratory auger transects

Fifteen bore holes were augered to the west of the PIC (transect one, figure 3.15). This revealed basic soil development upon glacial till parent material with coarse shell sand overburden to a depth of between 41 and 164cm. Anthropic material was intercepted 23m west of the fence line, or c.70m north west of structure 8. A further three bore holes (transect two) set at a perpendicular angle to this material revealed it to be an isolated pocket, about 15m across, evidenced by a very dark greyish brown clay containing limpet shell and charcoal flecks.

A pocket of anthropic material was intercepted at the southern extent of grid 2 (figure 3.15). An exploratory transect (transect three) traced a brown loamy sand anthrosol which graded into a dark greyish brown loamy clay in a c.3m spread overlying glacial till.

Two transects (transects four and five) explored the extent of anthrosols to the east of structure 3 and south of a large sand dune. The soil profile just south of the sand dune was recorded as glacial till with an overburden of loamy or silty shell sand to a depth of between 37 and 112cm and loose, coarse aeolian shell sand to a depth of between 20 and 59cm. Anthrosols related to settlement around structure 3 do not extend east further than structure 2.

Test trench 22 was opened in 2011 to investigate a large flat stone and associated pottery spread, cultivated soils were revealed and a possible field boundary (Moore & Wilson 2012). Auger transect 5 traced the cultivation horizon (very dark greyish brown silty loamy sand with shell, charcoal and pottery inclusions) 16m to the east of test trench 22 before it graduated into a clean loamy or silty sand stratigraphic sequence.

A further transect (transect six) was augered to the North of structure 6 to examine the extent of anthrosols related to the settlement mound (G. Wilson *Pers. Comms.*). Anthropic material including winkle and limpet shells and charcoal was recorded in a dark yellowish brown silty loamy sand matrix at a depth of c.50cm. This was covered by <1cm of clean shell sand and overlay yellowish brown silty sand which may represent an old ground surface. This overlay very pale brown sand and glacial till. Anthropic silty loamy sand extended 16m north from structure 6 archaeology where it graduated into inclusion free brown silty sand 25cm thick then greyish brown silty sand.

3.4.4 *Auger survey summary*

Anthrosols were identified across the Links of Noltland landscape based upon inclusions of shell, charcoal and diagnostic artefacts such as prehistoric pottery and stone tools. The matrix in which these inclusions were recorded was distinctive in comparison with the site's natural parent materials, glacial till, flagstone bedrock and marine shell sand. There were two main types of anthrosol/anthropic sediment matrix, dark brown loamy clay which was typically found directly upon glacial till and dark greyish brown loamy sand which occurred within a sandy stratigraphic profile composed of brownish grey sand and silty loamy sand. Loamy clay or very clayey anthrosols were detected across Grid 1 and surrounding structure 7, there were also small pockets to the west of the PIC and south of Grid 2, overlaps were noted between structure 7 and structure 3. These sediments typically contained low amounts of marine shell sand or none at all and exhibited colours and textures similar to anthropic sediments associated with Neolithic sediment. Loamy sand anthrosol was very similar in colour and texture to the Old Ground Surfaces described associated with Bronze Age structures and burials, and were widespread across the landscape. They typically exhibited a high shell sand component.

3.5 Spatial interpolation using Geological Surveying and Investigation in 3 Dimensions (GSI3D)

Relating stratigraphic sequences identified through auger survey to discrete areas of occupation was complicated. Traditional 2D spatial analyses within arcGIS do not allow multiple phases of soil development to be viewed simultaneously. This meant that disentangling the stratigraphic relationships between Late Neolithic settlement in Area 5, Neolithic structure 7, Bronze Age structures 1, 2 and 3 and the cultivation remains across the site area was problematic and so a solution was sought in geological sub-surface modeling.

Within geologic modeling, a methodology and software tool (GSI3D™) has been developed for the investigation of complex superficial and bedrock geology in three dimensions (Mathers et al 2011). GSI3D can produce a 3D sub-surface geological model using a digital elevation model (DEM), borehole and geophysical datasets.

Auger survey data from Grid 1 was input as borehole data into the software following protocols developed by the British Geological Survey. This is the first use of the tool for geoarchaeological investigation.

In 2D it was not possible to ascertain how contexts in each transect were related to each other, but GSI3D uses Delaunay-triangulation (Kessler et al 2009) to project context volumes, providing an accurate distribution map in 3D, refining understanding of context relationships.

Firstly, borehole data was arranged in a MS excel spreadsheet to indicate British National Grid co-ordinates:

Auger Point	BNG_X	BNG_Y
A1	1053.21	261.57
A2	1058.68	261.72
A3	1062.49	258.06

Figure 3.20: Locations of auger points/bore holes of Grid 1 survey and their relationship to sand dunes and archaeological structures (grey). Map courtesy of Ordnance Survey data (MasterMap 1:2000 raster).

This file is then saved in .bid (borehole index) format and loaded into GSI3D and overlain on a geo-referenced site plan (figure 3.20). Polygons can then be drawn to demonstrate the locations of archaeological features. A separate file is generated for borehole depth (governed by depth of either stone or glacial till) and the depth of each unit (context). Units of the same type are given a description and code:

Auger ID	Depth to base of unit (cm)	Description	Context Code
1	2.16	AEOLIAN SAND	100
1	2.3	Loamy sand	200
1	2.45	sand	101
1	2.55	Clayey loamy sand	300
1	2.65	Glacial Glacial Till	400

This file is saved in .blg format and loaded into GSI3D to allow the generation of 'down-hole' data used to render bore-hole stratigraphies. The stratigraphic relationship (or generalized vertical sequence) of each unit is specified within a file saved as .gvs, assigning a unique ID code to the context code (Mathers et al 2011). Lenses are given a code for the base and top:

Name	ID	Stratigraphy	Lithology	Context code
Grass	**5**	**Grass**	**Grass**	**99**
AEOLIAN SAND	**10**	**AEOLIAN SAND**	**AEOLIAN SAND**	**100**
AEOLIAN SAND2 top	**-1000**	**AEOLIAN SAND2 top**	**AEOLIAN SAND2 top**	**100**
AEOLIAN SAND2 base	**1000**	**AEOLIAN SAND2 base**	**AEOLIAN SAND2 base**	**100**

This file is designed to evolve to a final stage which contains all units in their correct and unique stratigraphic order (Kessler et al 2009). Finally, each unit is given a colour using hexadecimal code:

Name	Red	Green	Blue
Grass	131	150	72
AEOLIAN SAND	252	252	175
AEOLIAN SAND2 top	252	252	175
AEOLIAN SAND2 base	252	252	175

Once all files are input into GSI3D, transects can be generated as sections (figure 3.21) using rendered borehole data 'hung' from a digital terrain model (DTM[2]) to give a model cap.

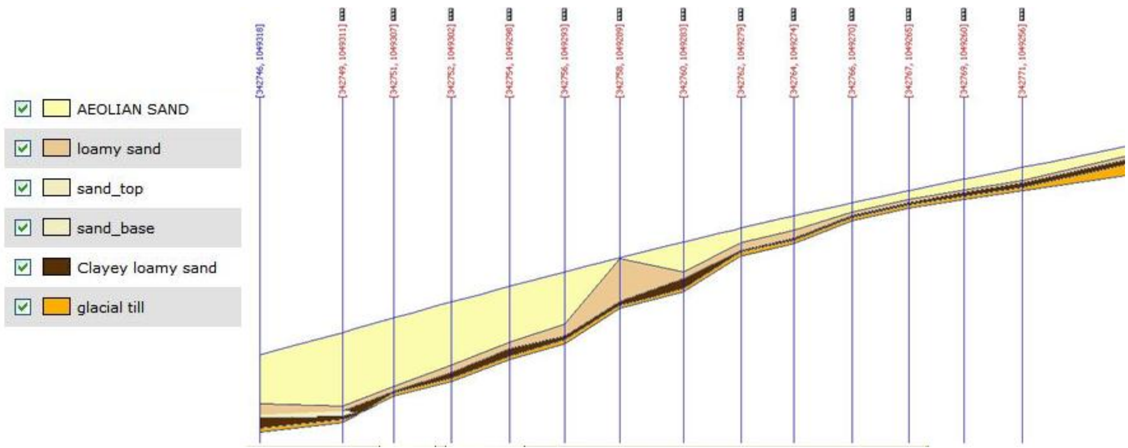


Figure 3.21: Section render of transect 1, Grid 1.

Once all transects are rendered as a section set, a fence diagram is composed with cross sections aligned at 90 degrees to the first set (figure 3.22). Nodes can be created across sections and a snapping tool allows an intricate, orthogonal framework to be generated.

[2] Supplied by Nextmap

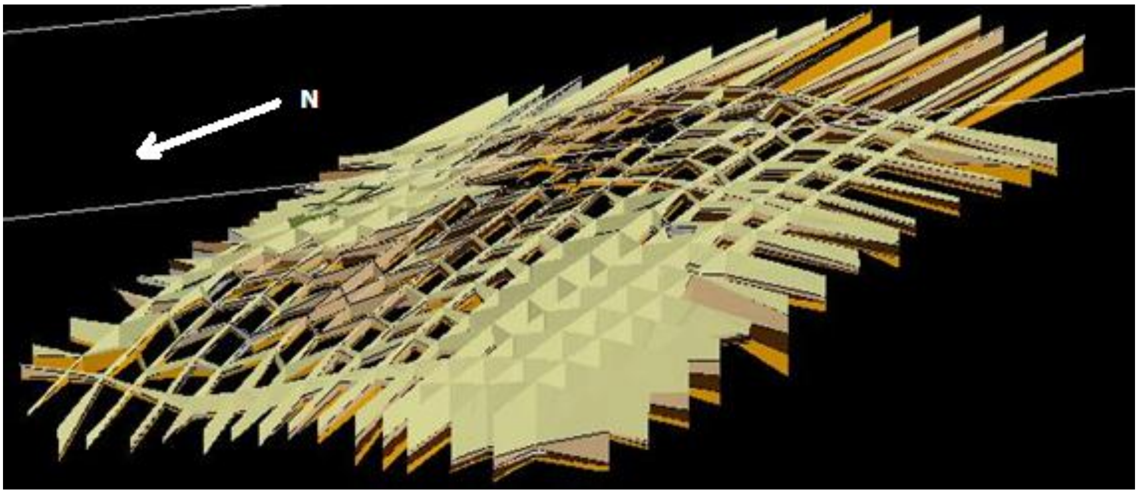


Figure 3.22: Fence diagram in 3D, constructed using sections and cross-sections rendered in GSI3D using Grid 1 auger survey data. At the time of writing the software was in beta mode and the images shown here are screen grabs of an interactive model.

The fence diagram allows a series of triangulated irregular networks (TINS) to be produced based upon x, y and z nodes along the sections and geometric envelopes of each unit. A Delaunay-triangulation algorithm is then employed to generate 3D ‘volume shells’ for each unit (Kessler et al 2009), resulting in a sub-surface model which can be explored in three dimensions (figure 3.23).

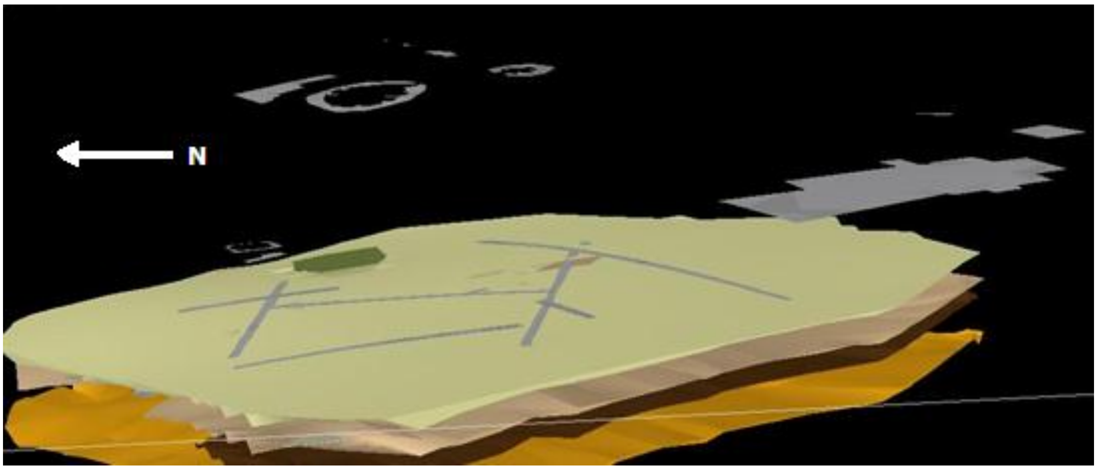


Figure 3.23: An 'exploded' 3D model of sub-surface sediments and their relationships to archaeological structures and field boundaries (identified through geophysical survey) at the Links of Noltland

The 3D model allows the aeolian sand cover to be ‘removed’, exposing the surface of the underlying contexts. Each context can be switched on or off, allowing exploration of the relationships between anthrosols, archaeology and cultivation remains.

Interpretations

The dark brown clayey anthrosol (coloured dark brown on the model figure 3.23 is patchy across the survey area but occurs at the same stratigraphic location as anthropic sediments around Neolithic structures 7 and settlement in Area 5, providing convincing evidence for a Neolithic land surface. This deposit extends over the north western region of the survey area (figure 3.24), indicating that the Neolithic land surface may be preserved over a wider than expected area. Data from the North transect (Moore & Wilson 2009b) was incorporated to further strengthen interpretations.

Figure 3.24: GSI3D interpretation of extent of clayey loamy sand anthrosol (dark brown) over Area 5 field system.

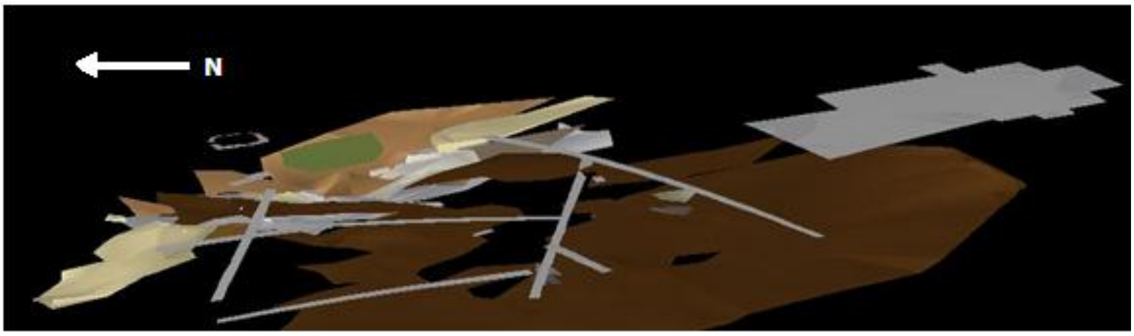


Figure 3.25: 3D sub-surface model with aeolian sand, loamy sand and glacial till 'switched off' to demonstrate the extent of clayey anthrosol and complex network of sediments around structure 7. A thin deposit of aeolian sand is demonstrated in between anthrosol layers

Cultivation remains evidenced by break-in slope and geophysics did not correspond to exceptional features during auger survey. Use of 3D modeling demonstrated that in some of the areas where field boundaries were drawn on the site plan (figure 3.25), the depth of the glacial till below the surface was at its most shallow. Transect 12, shown in section demonstrates that the field boundary features occur both at shallow loamy sand and a thicker clayey loamy sand deposit (figure 3.26)

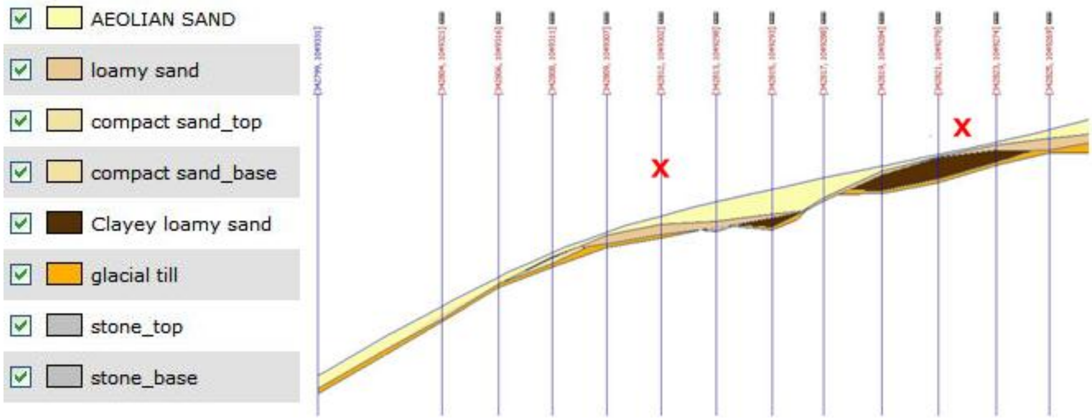


Figure 3.26: Transect 12, Grid 1 (figure 3.14) in section. The red X is used to mark the position of possible field boundaries within the Area 5 field system

Summary

The application of the Geological Surveying and Investigation in 3 Dimensions (GSI3D) software tool to sub-surface soils and sediments modeling has the potential to produce well constrained fine resolution interpretation for geoarchaeological research applications. When twinned with auger survey, a sub-surface soils and sediments model provides a convincing representation of a buried landscape and the relationships between features. The time constraints of research meant that only Grid 1 data was modelled, but this has allowed research objectives 1 and 2 to be met through geospatial analysis (figure 3.8).

In the future it should be possible to use this type of software to analyse buried topographies and the stratigraphic relationships between soils, sediments and archaeology in much the same way as geologists already study complex geodiversity and the stratigraphic relationships between rock formations.

3.6 Sampling for soil and sediment micromorphology

Identifying the range and extent of anthrosols and anthropic sediments (objective 1) was partially met through auger survey. However, to achieve a satisfactory understanding of their formation processes, functions and components (objectives 2, 3 & 4) soil micromorphology has been selected as the most appropriate tool for analysis of both anthrosols in the landscape and anthropic sediments within archaeological contexts (see chapter two).

Soil and sediment samples for thin section micromorphology were recovered using Kubiëna tins to procure undisturbed samples (Courty et al 1989). Tins were marked with the context number, sample number and their orientation. Sediment profiles were exposed, cleaned up and photographed before tins were inserted and photographed in situ. Their locations were then recorded into scale section drawings if applicable. Soils and sediments at the Links of Noltland site were particularly loose and sandy and so tins were removed by excavating around them with a leaf trowel. Once each tin was removed, the sample was padded out with catering film and the box wrapped very tightly with the same material to minimize disturbance in transport. Tins were stored in a refrigerator until they could be transferred to the thin section laboratory. This method was successful and all samples which entered the laboratory were manufactured as undisturbed soil and sediments.

3.6.1 *Sampling I: Soil Test Pits*

Soil test pits were excavated by hand and soil profiles were recorded using digital photography. Measured drawings were made where appropriate (standard plans at 1:20 and section 1:10 scale). Context numbers were given to archaeological features, anthrosols and anthropic sediments using record sheets provided by EASE and entered into the site database, any archaeological finds were given a find number and entered into the site data base as per procedures set by EASE. Cut features were half-sectioned and recorded in section and a bulk sample of each context was stored on site for future wet sieving and bulk chemical analyses.

To reach research objectives one and three, it was recognised that an understanding of the soils across the site was necessary prior to making decisions on where to take samples, so auger survey was used to identify the extent of possible cultivation soils and test pits were dug to investigate features associated with arable farming such as banks, ditches and lynchets.

Results of auger survey Grid 1 were recorded preliminary onto an excel spread sheet to produce a simplified map of the survey area (figure 3.27). This was studied together with the results from a previous season of geophysical survey (Moore & Wilson 2007, 2008, 2009a & 2009b) and observations in the field. Four areas of interest were identified within the survey area and one additional area was decided upon based purely on field observation to test the hypothesis that a wall-like structure was a boundary associated with the Neolithic village in Area 5.

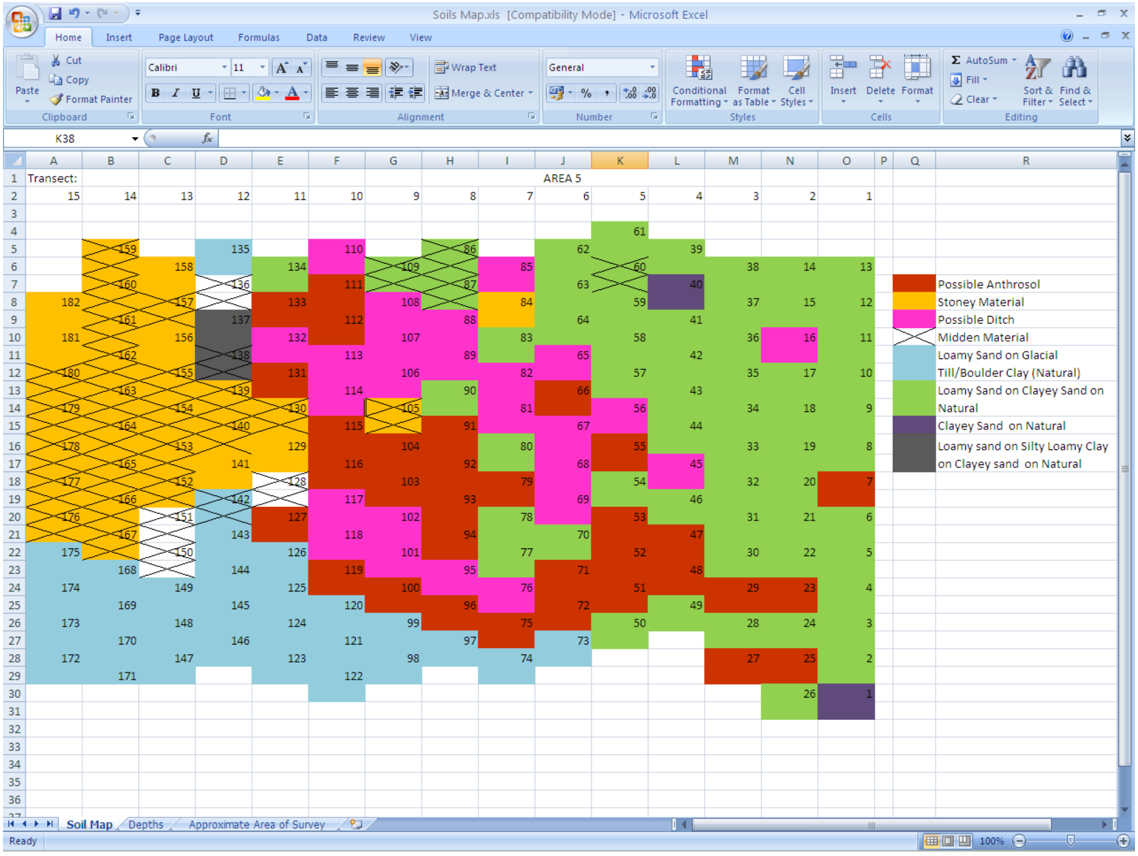


Figure 3.27: Grid 1 auger survey - preliminary field interpretations for soil test pit selection

Test pits 1, 3 and 5 intercepted anthrosols whilst test pit 2 uncovered rich anthropic sediments. Sediment in test pit 4 coated rubble material which rendered coherent sampling impossible but results are recorded below.

3.6.2 *Sampling II: Archaeological excavation*

Intensive and extensive archaeological excavation was carried out as large scale open area excavations investigating the Neolithic settlement in Area 5, the Bronze Age remains in the vicinity of structure 3 and Bronze Age settlements in the area adjacent to the PIC. Geoarchaeological sampling for thin section micromorphology comprised both sediments targeted for analysis by archaeologists and sediments opportunistically collected alongside excavation. The preservation of anthropic sediments and archaeological structures has resulted in a very complex site and review of fieldwork methodology in previous years recommended a familiarization period to gain deeper understanding of the formation processes (Moore & Wilson 2008). Therefore, alongside geoarchaeological auger survey and test pitting, time was spend working alongside archaeologists and opportunistically sampling as archaeological contexts were uncovered and interpreted in the field. Field seasons were long (up to six months continuously) and so it was not possible to continually observe excavation. However, successful sampling was achieved through communication with excavators and the site sample archive was kindly made available for this research.

Excavation methodology varied with location and the nature of deposits. In extremely complex areas such as Area 5, deposits were excavated in 0.1m spits and according to a grid system (Moore & Wilson 2011b) to help discern spatial patterning. All excavation was by hand. Aeolian sand overburden was removed using shovels but thereafter excavation proceeded in plan with deposits removed in stratigraphic order (Moore & Wilson 2011). Baulks and profiles were left in situ to allow plan, section and profile drawings and all contexts, deposits and finds were recorded in detail and registered within a comprehensive site database.

3.6.3 *Sampling III - Anthrosols*

3.6.3.1 *Soil test pit 1*

This soil test pit, measuring 2.5m by 1m and excavated to a depth of 0.4m, was opened up during the auger survey in order to investigate stones intercepted within the loamy sand layer (figure 3.28). For the purposes of correlating results with EASE this horizon was given the context number 9099 and a bulk sample was taken for wet sieving. It was hypothesized that the stone which was impeding auger survey may be structural and thus it was decided to investigate this. Upon opening a soil test pit centred upon auger point 5 (transect 1, figure 3.14), the loamy sand was found to rest immediately on top of bed rock and boulder clay which corresponds to stratigraphic sequence number 6 identified by auger survey. Kubiëna tins 83 and 84 were collected to analyze the loamy sand horizon which was interpreted in the field as an old ground surface.

Figure 3.28: Soil test pit 1, exposed flagstone bedrock

3.6.3.2 *Soil test pit 3*

This soil test pit was opened to investigate auger points 33 and 8 to the south west of Area 5 (figure 3.9) where a slight adjustment had to be made to avoid a modern cow burial. The soil test pit measured approximately 1m by 11m (figure 3.29). Aeolian sand [9113] to a depth of 0.5m covered loamy sand identified in the auger survey [009]. For the purposes of correlation with EASE this was given context number [9108] to the east of the soil test pit and [9109] to the west and interpreted as an old ground surface 0.18m thick. A possible negative lynchet was noted within context [9109]. Flecks of black friable material were present within contexts [9109] and [9108] no internal structure identified this as carbonised material so field-based organic matter and manganese determination was carried out using hydrogen peroxide. No reaction occurred, therefore the material was identified as charcoal (Wilson et al 2007).

Sealed by contexts [9108] and [9109] was a dark loamy clay 0.21m thick, identified at [010] by auger survey and termed [9112] during excavation. This contained shell fragments and was interpreted as a modified B horizon. It was unclear whether shell fragments were related to the close situation of the site with the sea shore or to the settlement rendering identification of this context as an anthrosol problematic. To elucidate this, Kubiëna tin samples 92, 93, 94 and 95 were recovered from contexts [9112], [9109] and the underlying glacial till for thin section micromorphology.

Figure 3.29: Soil test pit 3, during excavation - exposed old ground surface [9108] and [9109]

3.6.3.3 *Soil test pit 4*

This soil test pit was opened to investigate a line of collapsed stone thought to be a boundary wall which runs south east to north west to the East of Area 5. To test whether or not this was a field boundary, a 1m x 1m keyhole was opened up across the stonework to assess the character of deposits to either side of it (figure 3.30). This revealed the stonework to be resting in and on top of windblown sand. There was approximately 10cm of sand beneath the lowest stone before loamy sand was intercepted. Continuing to subsoil [9151] and [9148], more stone work was uncovered stretching 1.5m either side of a rubble spread [9149] and so the soil test pit was expanded in order to investigate this more thoroughly. After removing sand from an area approximately 5m x 1.5m the stones were found to be more complex than anticipated but it was possible to record a further sandy clay [9150] which appeared to be mixed in with the rubble. However, to properly characterise this further exploration would be required.

Figure 3.30: Soil test pit 4 prior to backfilling

Their proximity to the settlement at Area 5 and the presence of flint flakes indicated that this area could be of significant archaeological value but [9150] was unsuitable sampling for thin section micromorphology which was not possible due to the high frequency of large rocks. The soil test pit was photographed and the location recorded before back fill was carried out.

3.6.3.4 *Soil test pit 5*

This soil test pit (figure 3.31) was opened to further investigate auger points 125, 119, 101 and 94 where initial analysis of auger survey results indicated a possible ditch (auger point 101) and anthrosols (auger points 119 and 94). The topography in the area indicated a bank feature. Auger point 125 was included as it did not comprise of any anthropic inclusions so may represent the edge of the extent of anthrosols.

The initial dimensions of this soil test pit were c.1m x c.15m, however as excavation continued it was extended to approx. 1 m x 18m. The stratigraphy of this bank feature was composed of at least two layers of loamy sand [9184] and [9276] both containing frequent shell and bone fragments the earliest deposit in the sequence was dark brown sandy loam [9277] which overlay glacial till. To the south side of this bank an interesting feature which might represent a ditch or negative lynchet [9300] (Moore & Wilson 2011b) was identified based upon soil compaction, it was filled with loamy sand [9301]. The south extension of the test pit as it moved away from [9300] was composed of loamy sands [9184] and [9276] the latter contained winkle, limpet, oyster shell and bone – markings in this were noted and recorded in plan (figure 3.33). They are oriented both north-east to south-west [9180] and north-west to south-east [9181] and thus closely resemble the cross plough marks of a light plough or ard discovered in upper cultivation layers by earlier excavation (Clarke 1980, Clarke & Sharples 1985).

Consideration of the pre-settlement environment is regarded as key to understanding environmental and climatic factors which may have influenced socio-natural systems. A control sample (115) was recovered from underlying glacial till in test pit 5 and this will be used in conjunction with the underlying natural (sample 188) material recovered from a deep sondage at the east extent of Area 5 (Moore & Wilson 2009) to determine what sort of land surface anthropic sediments accumulated upon.

A sample of clean aeolian sand was also recovered (116) to control for inclusions which may become incorporated into a sandy profile through aeolian transport.

Figure 3.31: Soil test pit 5 during excavation.

A series of pits [9182], [9183], [9296], [9297], [9298] and [9299] were identified based upon soil compaction. As they were very subtle, portable OSL techniques were applied in the field to investigate sand [9299] at the bottom of a cut feature [9298]. This was shown to be younger than aeolian sand directly sealing loamy sand [9179], without calibration however this was the extent that could be achieved with OSL.

During the excavation of this soil test pit, sand-blow and other debris including stones and shells measuring c.3cm partially backfilled the excavated area and the soil test pit was flooded with rain water despite having been covered. To the southern end where context [9179] had been removed, fluvial channels scored the underlying stratigraphy, disturbing the profile, a process which probably occurs across the site during rainfall events. At this point the soil test pit was 'cleaned up', a drawing made of the northwest facing section and Kubiëna tins recovered for soil micromorphology (figure 57). Samples 117, 119 and 120 were recovered from the bank feature, whilst samples 121, 122, 123 and 124 intersected the boundaries between horizons containing possible ard marks.

3.6.3.5 *Bronze Age old ground surface*

An area measuring 20m by 10m was opened by archaeologists to the south of Bronze Age structures 4, 5 and 6. It is shown on figure 3.9 as a grey polygon to the northeast of structure 12. Aeolian sand <0.05cm thick covered this area, its removal exposed a series of pits and cuts, filled with fuel residues, cremations and inhumations (Moore & Wilson 2011b) dug into an old ground surface [9274]. This surface, loose brown sand with few inclusions, was sampled (sample 133) as a control for anthrosols. Inhumations have subsequently been dated to the second millennium BC (Moore & Wilson 2012) and so this is the only securely dated contemporary Bronze Age ground surface available.

Table 3.2: Context description for soil test pits 2010

Number	Description	Notes
9099	Loamy clay sand.	Soil Test Pit 1
9100	Sandy mid brown soil.	Soil Test Pit 2
9101	Stone slabs.	Soil Test Pit 2
9102	Firm orange brown clay-rich deposit.	Soil Test Pit 2
9103	Dark brown organic clay.	Soil Test Pit 2
9105	Grey black sandy soil.	Soil Test Pit 2
9108	Mid brown sand. West end of Soil Test Pit 3	West end of Soil Test Pit 3
9109	Same as 9108.	East end of Soil Test Pit 3
9112	Very compact loamy clay.	Soil Test Pit 3
9113	Windblown sand.	Soil Test Pit 3
9178	Loose loamy sand.	Soil test pit 5
9179	Loamy clay sand.	Soil test pit 5
9180	Linear scores cutting 9179.	Soil test pit 5
9181	Linear scores cutting 9179	Soil test pit 5
9182	Pit Cut. Soil	Soil test pit 5
9183	Sandy loam. Fill of cut 9182.	Soil test pit 5
9184	Bank of firm loamy sand	Soil test pit 5
9276	Loamy sand.	Soil test pit 5
9277	Dark brown sandy loam.	Soil test pit 5
9296	Pit cut	Soil test pit 5
9297	Loamy sand. Fill of 9296.	Soil test pit 5
9298	Pit cut	Soil test pit 5
9299	Loamy sand. Fill of 9298	Soil test pit 5
9300	Possible ditch cut	Soil test pit 5

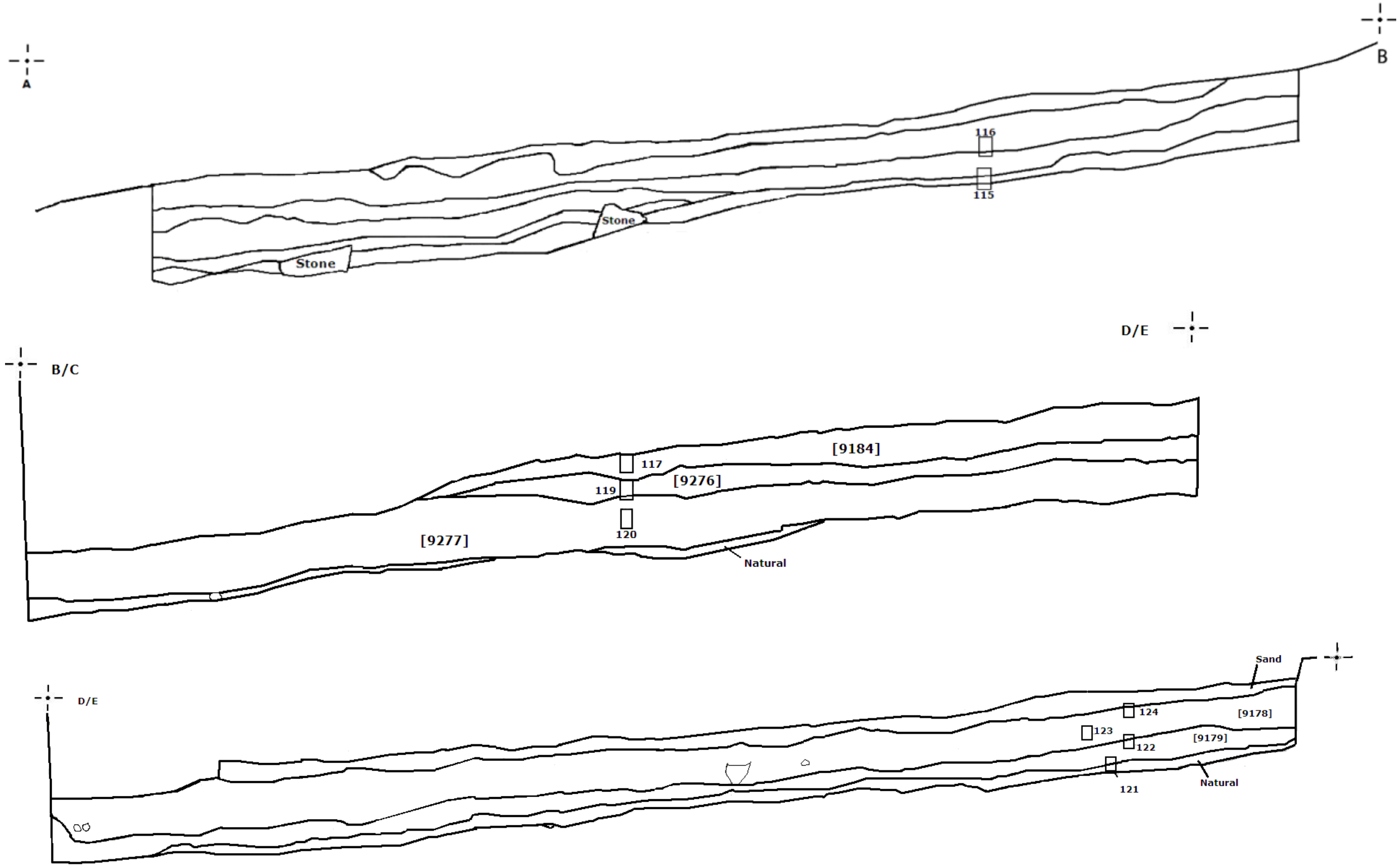


Figure 3.32: Section drawing, soil test pit 5 showing contexts and Kubiëna Tin samples. See table 3.3 for context descriptions. 1:10 scale.

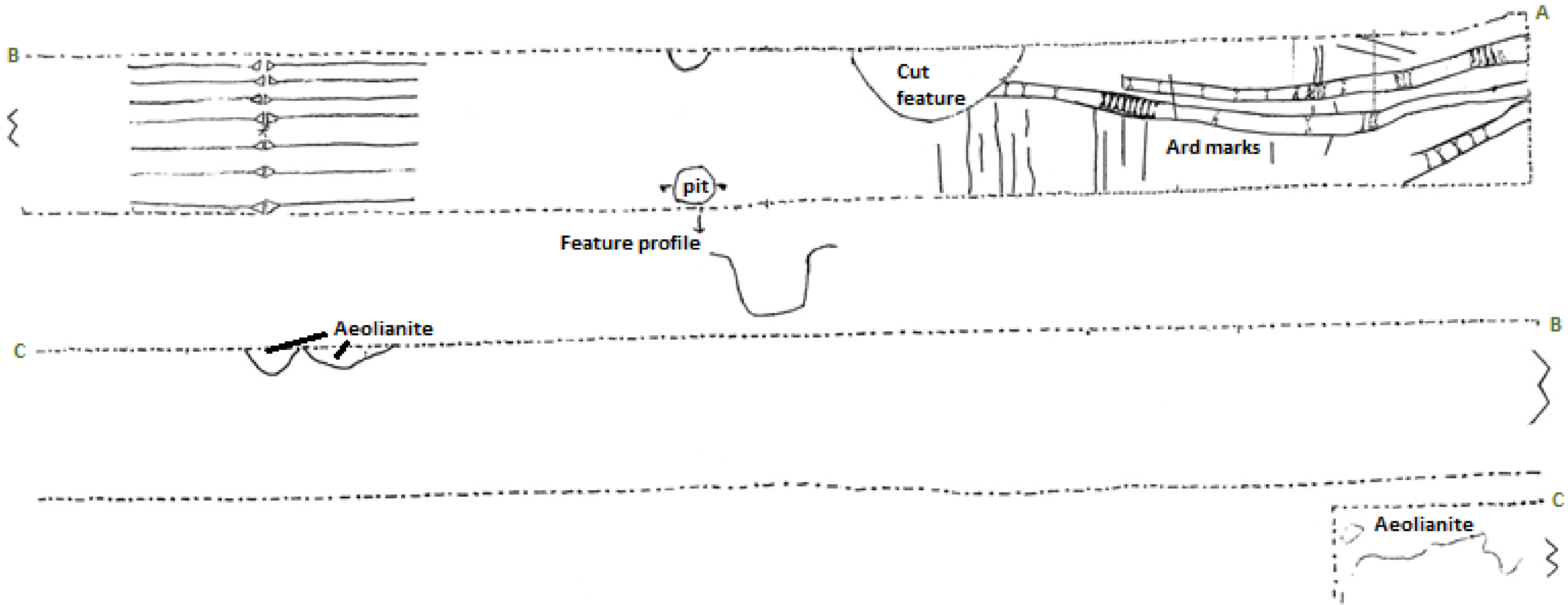


Figure 3.33: 1:20 plan of soil test pit 5 indicating features

3.6.3.6 *Ground surface and disturbed anthrosol*

Anthropic deposits were recorded in a low mound, 10m in diameter and <0.5m high to the south of the open area excavation. This measured 3m by 3m and was cut to a depth of 1m (Moore & Wilson 2011b). The mound was discovered to have eroded from surrounding deposits and was much truncated. Kubiëna tin sample 98 (figure 3.34) was recovered to intersect the boundary between a shell-rich sandy soil [9135] and underlying windblown sand [9138] and sample 99 (figure 3.35) was recovered from a deposit of darker sandy soil [9139] which may represent a fragment of old ground surface (ibid.). These samples will be used to examine the micro-artefacts found in Bronze Age anthrosols at the Links of Noltland but cannot be considered undisturbed.

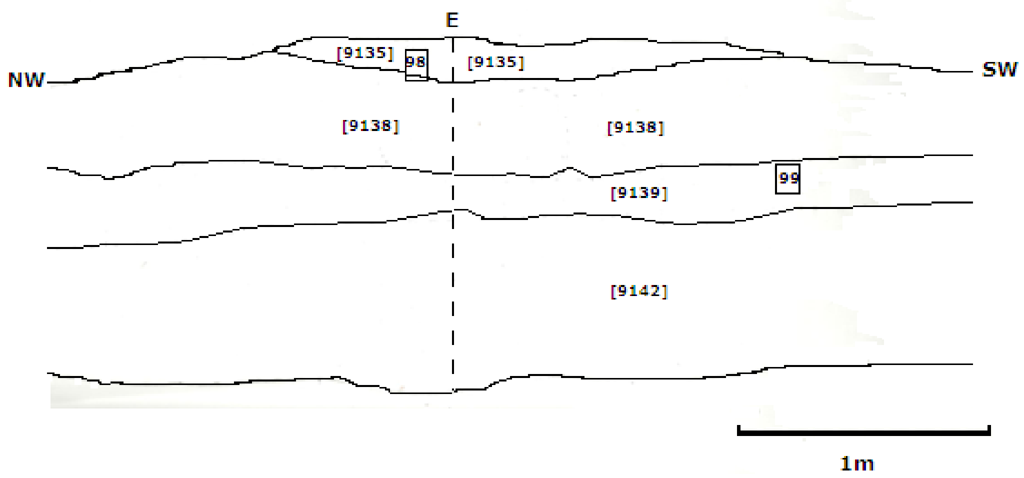


Figure 3.34: North West and South East facing sections of test trench 19 (see fig. 3.9) showing locations of Kubiëna tin samples. Original drawing courtesy of EASE, measurement is approximate.

3.6.3.7 *Area 5 field bank and associated soils*

An old ground surface, [9002], [9088], [9089], [9094] & [9140] and fragments of an earthen bank [9091], [9092], [9096], [9160] were detected across Area 5, overlying the Neolithic settlement (Moore & Wilson 2011b). These features substantially post-date the Late Neolithic settlement and contain typologically dated Bronze Age artefacts (ibid.). The bank extended over a distance of 40m and was 1.1m wide by 0.45m high on average and had a rounded profile (ibid.). An upper layer of dark red brown silty clay [9058] and a lower layer of dark orange-brown silty clay [9073] (figure 3.35) were noted in the field. Kubiëna tins 131 & 78 were recovered from the uppermost layer whilst a further two tins (74 & 82, figure 3.36) were deployed to investigate the boundary between the layers. This will help explain how the bank was constructed and what materials were used.

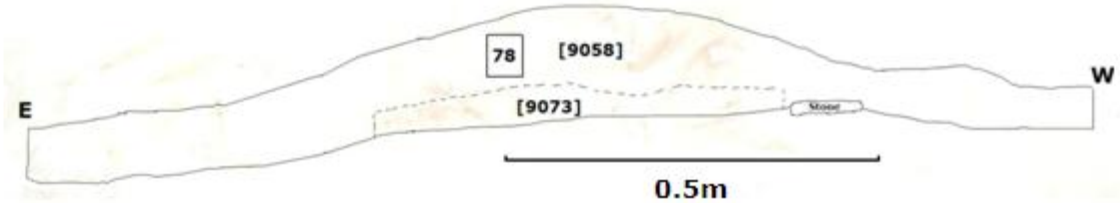


Figure 3.35: North facing section through field boundary, showing location of Kubiëna tin sample 78. Original drawing 1:10 scale, courtesy of EASE. Measurement is approximate.

Figure 3.36: Bronze Age field bank undergoing sampling for thin section micromorphology. Kubiëna tins 74 (left) and 82 (right) in situ.

The ground surface associated with this field bank was a patchy spread of pale brown silty sand [9035] overlying a mixed dark brown silty clay containing flecks of white sand [9036] (Moore & Wilson 2010). This in turn overlay the uppermost anthropic sediment [9031] covering Area 5. Disturbance of the profile at [9036] was interpreted as evidence of cultivation and Kubiëna tins 79, 80 & 81 were deployed here to investigate the nature of these deposits (figure 3.37).

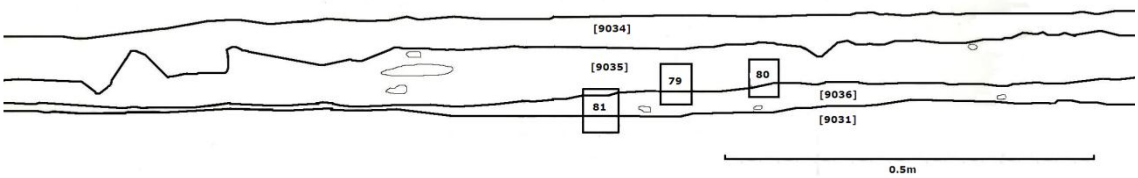


Figure 3.37: South facing section through baulk demonstrating stratigraphic relationships between cultivated old ground surface [9035] and underlying midden [9031] showing locations of Kubiëna tins (Original drawing courtesy of EASE). Measurement is approximate, 1:10 scale drawing.

The construction materials and any anthropic inclusions within the bank [9058] and old ground surface [9035], [9031] & [9072] are of particular interest to this research as they can provide evidence for fuel resource utilisation, environment and land use and management facilitating understandings of the function and organization of the latest surviving prehistoric anthrosols.

3.6.3.8 *Prehistoric cultivation*

Cultivated soils [9420], evidenced by ard marks were uncovered in test trench 22 to a depth of 0.45m, the trench measured 9m by 5m and was hand excavated by archaeologists (Moore & Wilson 2012). A field boundary represented by differences in soil texture and colour and a possible ditch was noted but not explored fully due to excavation time constraints (ibid.). The cultivated soil was sampled for thin section micromorphology alongside archaeological excavation, the locations of the Kubiëna tins 216, 217 & 218 are marked on figure 3.38.

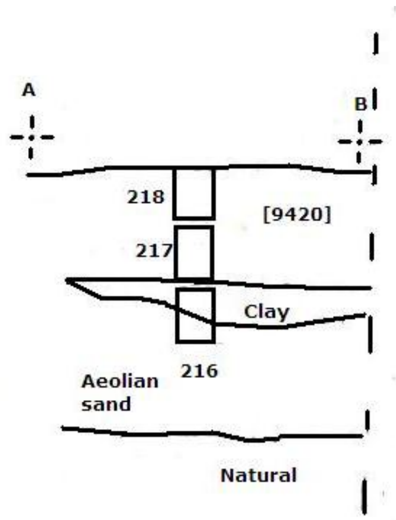


Figure 3.38: South facing section of test trench 22 in PIC area. 1:10 scale (Original drawing courtesy of EASE)

Ard marks were also discovered in a transect cut to the north side of Bronze Age structure 13 (figure 3.39). The transect measured 4.6m by 1m and was excavated to glacial till at a depth of 0.85m. Several layers of sand overlay this, interpreted as sand blow [9586], old ground surface [9585] and cultivation horizons [9564], [9558], [9555]. Ard marks were cut into [9564] and [9558] (figure 3.39) and a further cultivated horizon extended below the outer wall of structure 13 (Moore & Wilson 2012). Contexts [9555] and [9558] contained bone and shell (ibid.) and so are understood to be anthrosols. Kubiëna tin samples 174-177 were deployed by archaeologists for thin section micromorphology.

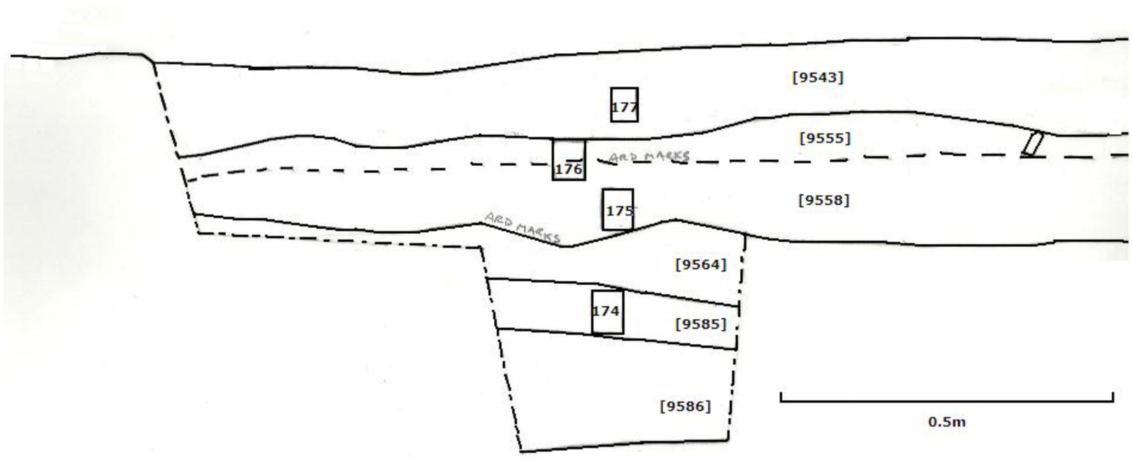


Figure 3.39: North east transect, structure 13 (Original drawing courtesy of EASE). Measurement is approximate, 1:10 scale drawing.

3.6.4 *Sampling IV – Anthropic sediments*

Anthropic sediments were extremely complex, with discrete differences in colouration and inclusions visible in the field, especially in close vicinity to structural remains. Therefore sampling was carried out with regard to the highly sensitive value for archaeological interpretation both in terms of minimizing disturbance and working closely with archaeologists to understand the context for each sediment. Baulks allowed sampling for thin section micromorphology. However, where necessary sampling was also undertaken as excavation proceeded, for example in the case of structure infill. Where sediments were extremely thin, Kubiëna tins were inserted horizontally, loosing formation context but preserving valuable information on inclusions and sediment matrix.

3.6.4.1 *Test pit 2*

As stones were intercepted at auger point 151 and 152 (near to structure 7) and a more complex stratigraphic sequence including a second layer of sand beneath silty sand was encountered at auger point 152, soil test pit 2 (figure 3.41) was opened up to investigate further.

Initially a soil test pit joined up auger points 151 and 152. It measured 5m by 2m and was excavated to a maximum depth of 0.7m where the natural till was reached. A brown organic soil [9103] was revealed, it contained a large, intact cattle horn, charcoal, flint, bone and shell and was interpreted as anthropic sediment. At the south western end of the soil test pit stone work was identified by archaeologists as a possible wall which runs east-west. A further sondage (A) was opened to further investigate sediments associated with this 'wall' which was sealed by a spread of firm orange-brown clay soil thought to be redeposited clay [9102] interpreted as glacial till. Within the 'walling' an accumulation of sand was interpreted as either a windblow accumulating post abandonment or a wall core feature - further investigation would be needed to clarify this. Within the North West of the soil test pit area, a second sondage (B) was dug to identify the depth of the midden and characterise the whole soil profile. Beneath [9103] a layer of grey-black sandy soil [9105] containing charcoal was found to overlie the glacial till.

Kubiëna tin samples 85 to 87 were collected from soil stratigraphy in Sondage B, this area was interpreted as a highly organic exterior occupational deposit, rich in artefacts. Samples 88 to 91 were collected to further investigate the complex stratigraphy found in Sondage A but initial interpretations indicate that these sediments may contain wall core material and sediments lapped up against the exterior of a tumbled section of wall.

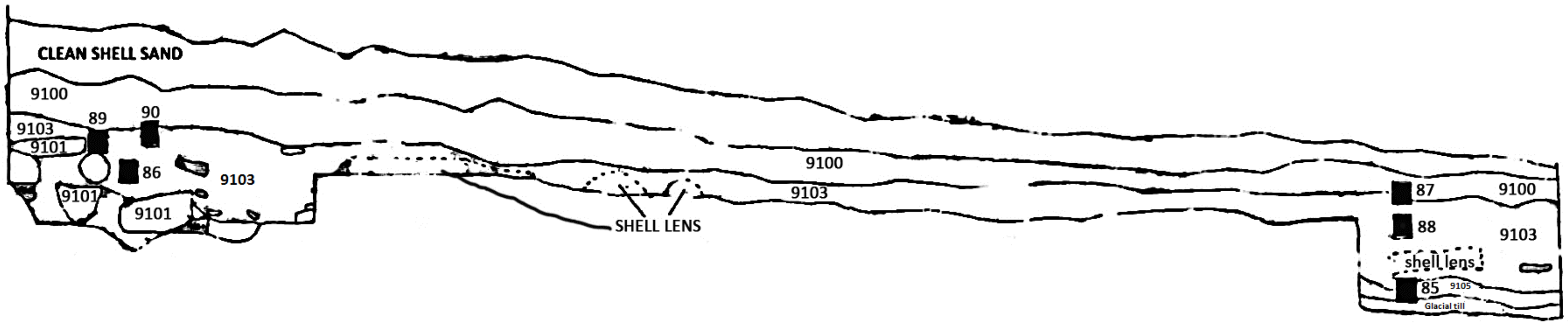


Figure 3.40: Section Drawing Scan – East facing section, soil test pit 2 Links of Noltland 2010

Figure 3.41: Soil test pit 2 during excavation

3.6.4.2 *Area 5*

The sediments across Area 5 proved to be extremely complex attesting to their good preservation. The reconstruction of a chronology for the Area 5 structures is still on-going but a series of radiocarbon dates have allowed an initial consideration which can help elucidate the relationships between anthropic sediments. The earliest date (2890-2660 cal BC) returned by the radiocarbon program was for the infill of a probable kiln, this relates to context [9009] a possible collapsed superstructure. A second radiocarbon date from the 'kiln' (2860-2490 cal BC) was recovered from context [9016] which covers the west wall [9059] these provide a *terminus ante quem* for the use of the structure (Moore & Wilson 2011b). The 'kiln' feature was shown during excavation to have reused paving related to an underlying structure (structure 8). Area 5 has so far been shown to contain at least three additional buildings (figure 3.42). Radiocarbon dates (2840-2480 cal BC and 2580-2460 cal BC) have been returned for cattle skulls placed within the foundations of structure 9, although the period of time between their death and deposition is unknown this does at least provide a *terminus post quem* for the construction of the building. Anthropic sediments or midden deposits are present across Area 5, these fairly homogenous sediments covered structure 8 to the south structure 9 to the north and were recorded at depths in excess of 2.4m to the east and west where accumulation and subsequent cultivation were evidenced. A cow phalange and a sheep vertebra were recovered from the uppermost midden accumulation, present almost everywhere upon removal of windblown sand (ibid.); these produced radiocarbon dates of 2870-2570 cal BC and 2630-2470 cal BC, respectively. This data demonstrates that anthropic sediments overlying much of Area 5 are approximately contemporary with structure 9 (ibid.) and that the kiln feature built over structure 8 fell out of use before this time. This suggests that deeper anthropic sediments and structure 8 are earlier in date. All of the radiocarbon dates returned correspond culturally to the Orcadian Late Neolithic period placing the accumulation of anthropic sediments in Area 5 within this context.

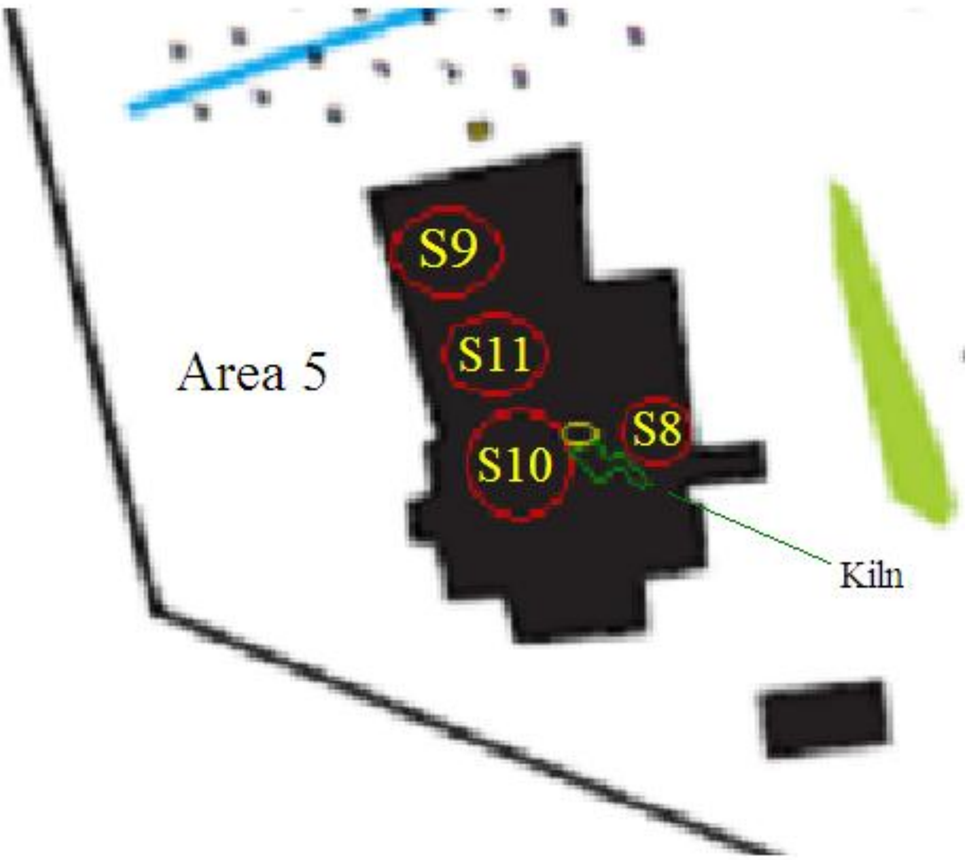


Figure 3.42: Detail of Area 5 adapted from site plan in Moore & Wilson 2011 to show approximate locations of structures.

3.6.4.3 *Building infill*

Two samples (96 & 97) of anthropic sediments infilling structures were collected from silty clay and rubble deposits [9127], [9131], [9132] & [9133] which accumulated within a small alcove-like feature (figure 3.43) just to the west of a paved surface [9083]. This feature is thought to have been used in association with the kiln/oven and was subsequently blocked up with rubble [9141], a short length of rough walling [9130) and silty clay [9029] & [9127] (Moore & Wilson, 2011). Sample 96 was recovered from the upper accumulation [9127] and rubble matrix [9130] and sample 97 from the lower fill stratigraphy [9131], [9132] & [9133] (figures 3.43 & 3.44). Stratigraphically, these are the latest anthropic deposits sampled which have not been subjected to obvious re-working, examination should reveal something of the nature of the sediments which were used to fill in buildings as they fell out of use.

Figure 3.43: Alcove feature, Area 5 structure 8 complex, infilled with anthropic sediments [9131], [9132] & [9133]

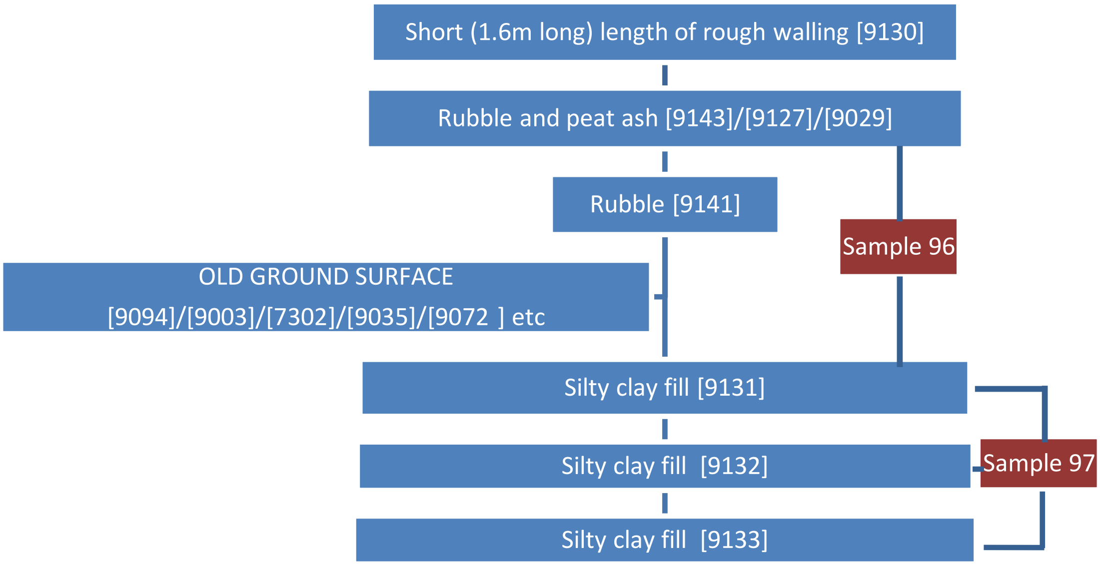


Figure 3.44: Harris matrix for 'cell interior' reproduced from Moore & Wilson (2011) with locations of Kubiëna tin samples added

Bronze Age buildings across the landscape at Links of Noltland were also filled with anthropic material as they fell out of use. Structure 13 was noted to contain interleaving sandy silt, aeolian sand, and clay lenses post-dating occupation (Moore & Wilson 2012). Kubiëna tin samples 178 and 179 were recovered from one of these deposits [9569] by archaeologists. The material infilling Structure 17 was quite different. This structure was filled with rubble and has subsequently been ploughed over (Moore & Wilson 2012). The rubble was set in a matrix of silty sand containing inclusions of charcoal, shell, burned bone and tools. Kubiëna tin sample 198 was recovered from this material.

3.6.4.4 *Exterior occupational deposits*

The stratigraphically earliest anthropic sediment sampled within Area 5 was context [9157]. This was interpreted in the field as laminated accumulations of ashy soil (Moore & Wilson 2011b) which was dumped to the north side of an early paved surface [9161] associated with structure 8. Kubiëna tin sample 106 was recovered from [9157] to test the hypothesis that this material is spent fuel waste, to assist in the interpretation of the kiln feature and elucidate the processes involved in the formation of the context and thus the activities carried out here. Ash is repeatedly described for anthropic deposits within Area 5, suggesting it is an important part of the archaeological record and so characterisation of this and any linked fuel residues will be prioritized. Samples 76 and 77 were collected from laminated deposits [8002] and [8013] which overlay a later paved surface [9083] further up the profile (see figure 3.45) to test the hypothesis that in situ burning occurred here. A further two samples from this area of the site (101 & 100), were recovered from contexts [8016] and [9171] (respectively) to examine structure 8 infill [8016] and sediments associated with possible subsequent re-use [9171].

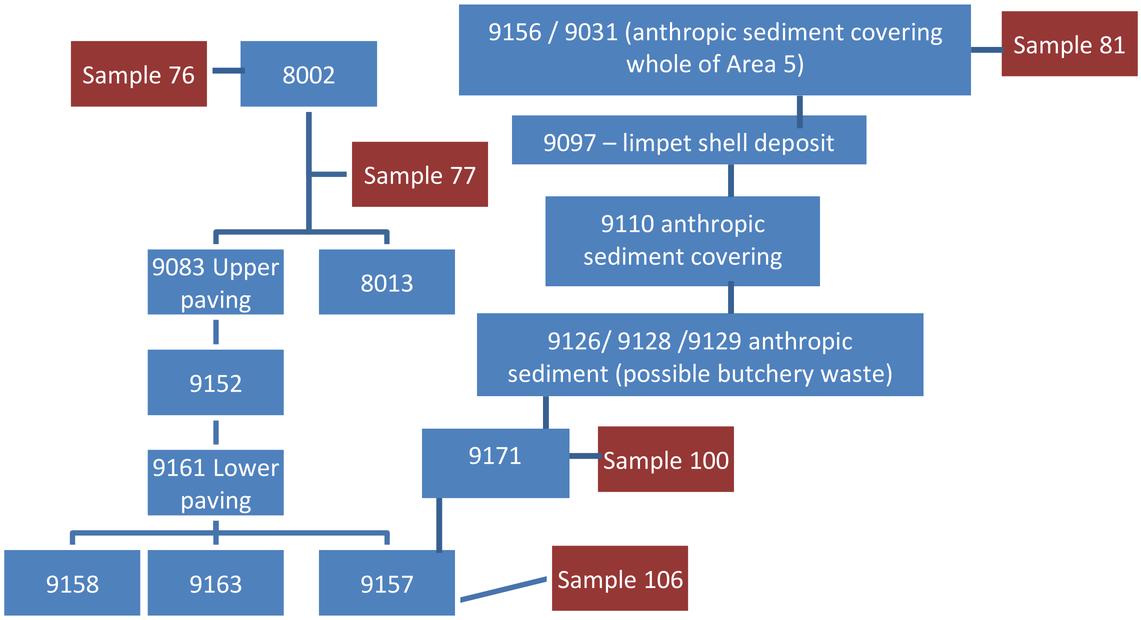


Figure 3.45: Harris matrix simplified from Moore & Wilson (2011) to describe relationships between samples 76, 77 and 106

Bronze Age exterior occupational surfaces at the Links of Noltland manifest as paved areas and old ground surfaces within minimal inclusions. Cultivation, erosion and rabbit burrowing may have also contributed to their disturbance. Therefore, Bronze Age occupational surfaces are not anthropic sediments as defined by this research.

3.6.4.5 *Dumped deposits*

A deep sondage recorded a stratigraphy built up against the exterior wall of structure 8 in Area 5 to a depth of c.1m (figure 3.46) and represented deposits which formed before, during and after occupation. Micromorphological analysis will test the hypotheses that the earlier deposits formed during occupation and that the later deposits represent post-settlement activity and dumping of waste (Moore & Wilson 2011b). The potential survival of a complete stratigraphy representing the lifetime of the settlement is deeply significant. If micromorphological analyses can identify key features such as land surfaces, dumping events/constituents and environmental/climatic indicators then a partial chronological sequence may be proposed. The entire profile was sampled (134, 135, 136, 138 & 188) for thin section micromorphology although rubble and large stones largely dictated the locations of Kubiëna tins.

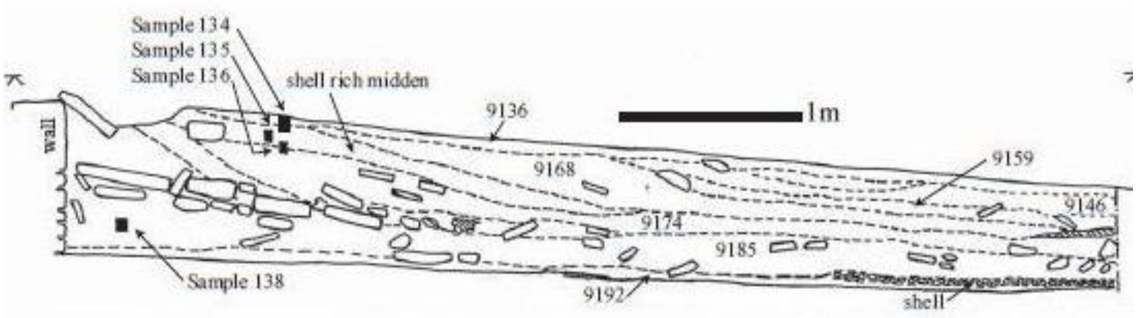


Figure 3.46: South facing section through midden showing locations of Kubiëna tins, sample 188 was recovered later (from Moore & Wilson 2011b)

All structures at the Links of Noltland were associated with dumped materials and twin Bronze Age structures 16 & 17 retained shallow (0.4m deep) 'tips' with at least 12 interleaving layers distinguished in the field (Moore & Wilson 2012). These sediments contained charcoal, small stones, shell and animal bone. Kubiëna tin sample 195 was deployed (figure 3.47) to capture any microstratigraphic sequences not visible in the field including hearth rake-out.

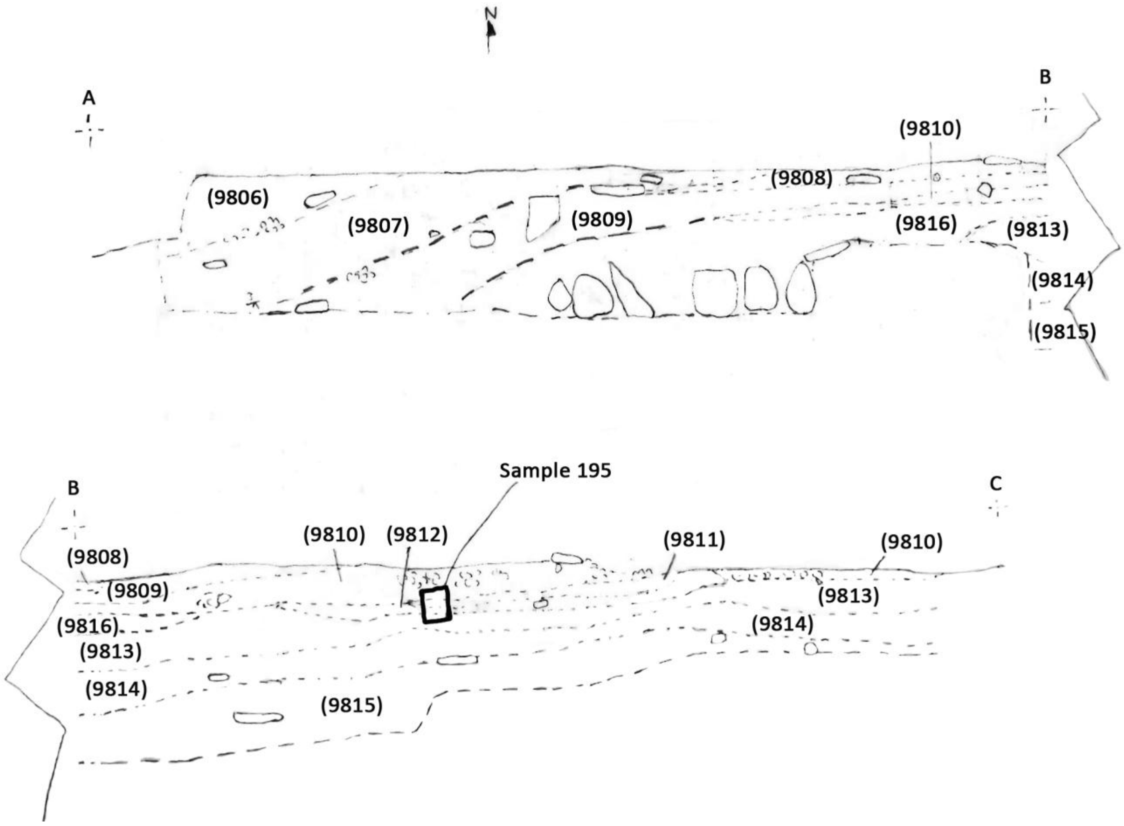


Figure 3.47: Section through Bronze Age anthropic sediment to east of structures 16 and 17 (Digitized from original drawing courtesy of EASE)

3.6.4.6 *Occupational floors*

A series of floor and hearth deposits were recovered from Neolithic structure 9 (109, 110, 125, 126, 127, 128 – see figure 3.48) to identify fuel residues and characterise floor surfaces and sterile clay which was brought in and used as a base within the hearth setting (Moore & Wilson 2011b). The central floor deposits [9173] and [9189] samples (110 and 127) were ashy and contained large fragments of charcoal, burnt bone and peat ash (Moore & Wilson 2011b) whilst the eastern recess floor [9118] (sample 107) was compact and contained ash and articulated bone. The hearth itself contained three distinct fills, a lower ashy deposit contained small bone fragments [9125], an intermediate sterile silt [9124] and an upper ashy silt [9117] containing a large pot base fragment (Moore & Wilson 2011b) samples 125 and 126 provided a complete stratigraphy through these deposits. Sample 128 was recovered horizontally to sample a very thin dark brown/black charcoal rich clay loam forming the floor in a western compartment.

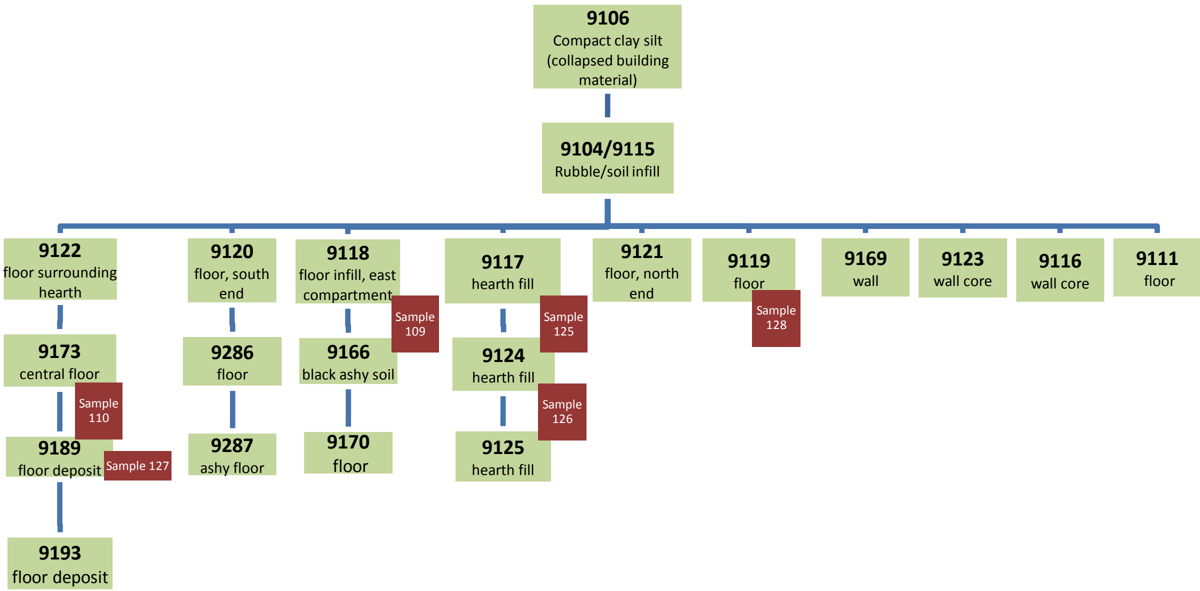


Figure 3.48: Harris matrix for 'structure 9' reproduced from Moore & Wilson (2011) with locations of Kubiëna tin samples added

Bronze Age interior floors survived less well intact but a sample (197) was recovered from an occupational floor deposit [9889] containing bright yellow mottles of silty clay and overlying paving in the south east corner of Bronze Age structure 17. Kubiëna tin samples 178 and 179 already mentioned above were located to intersect the boundary between sediment infill [9569] and an interior floor [9610] within Bronze Age structure 13.

3.6.4.7 *Foundations*

Test trench 14 was opened by archaeologists to investigate the exposed remains of structure 12 (figure 3.9), of probable Bronze Age date (Moore & Wilson 2011b & 2012). A brown sandy old ground surface [9252] was found beneath the structure, representing building foundations. This was sampled for thin section micromorphology (sample 113). Excavation of Neolithic buildings had yet to reach foundational levels at the time of the sampling program.

3.7 Summary

In total, 31 Kubiëna tin samples were recovered from prehistoric anthrosols (table 3.3), 31 from anthropic sediments (table 3.4) and a further two 'controls' from glacial till and aeolian sand (table 3.5). This was achieved through test pitting, targeted opportunistic sampling alongside archaeological excavation and 'cherry picking' the site sample archive. All samples were entered into the site database of 'special samples' using a numerical system allocated by EASE. A before and during digital photograph was taken to accompany most samples, providing an extra record of context, sample number and tin number. All tins were removed to the University of Stirling for slide preparation.

Table 3.3: List of anthrosols sampled for thin section micromorphology. Context descriptions are taken from Data Structure Reports (Moore & Wilson 2008, 2010 & 2011a)

Sample type	Sample Number	Context number	Context description
Field bank	74	9058/9073	Dark red brown silty clay/ dark orange-brown silty clay
	78	9058	Dark red brown silty clay.
	82	9058/9073	Dark red brown silty clay/ dark orange-brown silty clay
	131	9160	Dark red brown silty clay
Old ground/activity surfaces	75	9072	Dark silty clay soil
	79	9035	A patchy spread of pale brown silty sand
	80	9035	A patchy spread of pale brown silty sand
	81	9031	Dark silty clay soil
	83	9099	Loamy clay sand in soil test pit 1
	84	9099	Loamy clay sand in soil test pit 1
	92	9112	Very compact loamy clay. Soil test pit 3
	93	9112	Very compact loamy clay. Soil test pit 3
	94	9108/9112	Mid brown sand, west end of soil test pit 3
	95	9112/natural	Very compact loamy clay/ glacial till. Soil test pit 3
	117	9184	Bank of firm loamy sand. Soil test pit 5
	119	9276	Loamy sand. Soil test pit 5
	120	9277	Dark brown sandy loam. Soil test pit 5.
	121	9179 / natural	Loamy clayey sand/ glacial till. Soil test pit 5
	122	9178/9179	Loose loamy sand/ loamy clayey sand. Soil test pit 5
	123	9178	Loose loamy sand. Soil test pit 5
	124	9178	Loose loamy sand. Soil test pit 5
	133	9274	Loose brown sand with few inclusions.

Sample type	Sample Number	Context number	Context description
Cultivated soils	**216**	**Clay/ aeolian sand**	**Test trench 22**
	217	**9420**	**Light to dark brown sand in test trench 22**
	218	**9420**	**Light to dark brown sand in test trench 22**
	174	**9513/9514**	**Mid orange sandy silt. Loose, occasional stones / dark brown sandy silt. Firm. Occasional stones, cultivated soil Structure 13**
	175	**9585**	**Dark brown sand. Firm. Structure 13, North East transect.**
	176	**9558**	**Pale brown sand. Firm. Occasional to frequent shell, also patches of clean white sand. Structure 13, North East transect.**
	177	**9555**	**Dark brown to black sand. Firm. Contains animal bone, shell and occasional stone. Structure 13, North East transect.**
Disturbed material	**98**	**9135/9138**	**Shell rich soil/ aeolian sand. Test trench 19**
	99	**9139**	**Dark brown sand. Test trench 19**

Table 3.4: List of anthropic sediments sampled for thin section micromorphology. Context descriptions are taken from Data Structure Reports (Moore & Wilson 2008, 2010 & 2011a)

Sample type	Sample Number	Context number	Context description
Foundation	**113**	**9252**	**Brown sand. Test trench 14.**
Interior floor deposits	**109**	**9118/9166**	**Dark red brown silty clay/ dark brown-black ashy soil**
	110	**9189**	**Firm, brown clay loam**
	127	**9173/9189**	**Black - brown silty clay/ firm, brown, clay loam**
	128	**9119**	**Dark brown/black charcoal rich clay loam.**
	178	**9610/9569**	**Pale brown, mixed with darker brown sandy clay. Firm. Occasional lumps of yellowish clay. Structure 13.**
	179	**9610/9569**	**Pale brown, mixed with darker brown sandy clay. Firm. Occasional lumps of yellowish clay. Structure 13.**
Hearth deposits	**125**	**9117/9124**	**Firm silty ash/ sterile silty soil**
	126	**9124/9125**	**Sterile silty soil/compact ashy soil**
Exterior occupational deposits	**76**	**8002**	**A spread of dark grey-black silty clay comprising of finely laminated lenses of dark grey silty clay interspersed with many thin lenses of pale brown clay silt**
	77	**8002**	**As above**
	100	**9171**	**Red brown midden soil**
	106	**9157**	**Grey black silty clay.**

Sample type	Sample Number	Context number	Context description
Exterior occupational deposits (continued)	85	9103/9105/natural	Dark brown organic clay/ grey black sandy soil/ glacial till in soil test pit 2
	86	9100/9103	Sandy mid brown soil/ dark brown organic clay. Soil test pit 2.
	87	9103	Dark brown organic clay. Soil test pit 2.
	88	9103/aeolian sand	Dark brown organic clay. Soil test pit 2.
	89	9103/9102	Dark brown organic clay/ firm orange brown clay-rich deposit. Soil test pit 2.
	90	9100/9102/9103	Sandy mid brown soil/ firm orange brown clay-rich deposit/ dark brown organic clay. Soil test pit 2.
	91	9103/ 9101	Dark brown organic clay. Soil test pit 2.
Dumped deposits	134	9136/ shell rich midden	Dark brown, black silty clay. Soil test pit 2.
	135	Shell rich midden	Shell rich midden
	136	Shell rich midden / 9174	Mid brown silty clay
	138	9185	Mid brown silty clay
	188	9192 (and glacial till)	Mid brown silty clay/ Orange-red boulder clay
	195	9811, 9812	Pale grey sand / reddish brown silty clay
Building infill	96	9127/9130	Red brown silty clay. Fill of cell like feature on west side of paved area [9083]/ walling
	97	9131/9132/ 9133	Firm, mottled pale grey silty clay/dark red brown silty clay/ pale grey silty clay
	101	8016	Mid to light red brown silty clay
	197	9874/9889	Rubble matrix/ greyish brown silty clay mottled with bright yellow silty clay. Structure 17
	198	9874	Rubble matrix, structure 17

Table 3.5: List of control soils sampled for thin section micromorphology. Context descriptions are taken from Data Structure Reports (Moore & Wilson 2008, 2010 & 2011a)

Sample type	Sample Number	Context number	Context description
Control	115	Aeolian sand / glacial till	Calcareous silty sand/ Orange-red boulder clay
	116	Aeolian sand	Calcareous silty sand

Chapter Four

Chapter 4 Detecting resource management in the laboratory: analytical methods and results

4.1 Introduction

In this chapter the methods for semi-quantification of midden composition are described and discussed.

In chapter three thesis objective one, to identify the range and extent of anthrosols and anthropic sediments, their chronologies and relationships to anthropic sediments was met. Anthrosols were identified across the landscape, covering an area of roughly 300m x 200m (although this is patchy) and were stratigraphically related to both Bronze Age and Neolithic structures. Anthrosols related to Bronze Age archaeology were widely preserved, whilst Neolithic anthrosols were spatially interpolated using GSI3D to explore the Area 5 field system. A clayey loamy sand bearing shell, charcoal and bone fragments, which survived in patches beneath loamy sand reminiscent of the Bronze Age old ground surface was related the Neolithic settlement stratigraphies.

Sediments found in association with archaeological structures were interpreted in the field with the aid of experienced professional archaeologists, technicians and specialists (Moore & Wilson 2011b) to provide archaeological context. Each context including cultivated anthrosols and activity surfaces interpreted as anthrosols; these will be examined in detail using soil micromorphology supported by point count data and SEM EDX on-slide chemical analysis where necessary.

This chapter will begin by describing methods employed for laboratory analyses and go on to present results ordered by archaeological contexts described in chapter three and collated below.

4.2 Collation of groups by archaeological and environmental context

Samples collected at the Links of Noltland were grouped into ten categories based upon archaeological context (table 4.1). The contexts are considered as 'system outputs' (chapter two), forming the basis of multiple working hypothesis generation and so the following chapter will describe the results of thin section morphological analysis within these ten categories.

Table 4.1: Contexts identified in the field and used to group samples for discussion

Archaeological contexts	Environmental contexts	Control contexts
Foundations	**Aeolian sand**	**Aeolian sand**
Interior floor deposits	**Glacial till**	**Glacial till**
Hearth deposits		
Dumped deposits		
Occupational deposits		
Building infill		
Cultivated soils		
Field banks		
Old ground/activity surfaces		
Disturbed material		

4.2.1 *Glacial till*

Glacial till was sampled as a control in the southern extent of soil test pit 5 where it lay directly beneath aeolian sand and was interpreted as undisturbed by anthropic activity. It was also intercepted beneath dumped deposits in Area 5 and so was recorded for environmental data.

4.2.2 *Foundations*

A single thin section, recovered from beneath a Bronze Age building (structure 12) identified by archaeologists.

4.2.3 *Interior floor deposits*

Interior floors describe occupational surfaces within buildings which might include deliberately constructed 'floor surfaces' (Courty et al 1989, Macphail & Goldberg 2010) as well as 'living floors' (Gé et al 1993, Matthews et al 1997). Floor interiors were grouped for analysis but differences within this sample group are important too as some were collected from Neolithic structure 9 and others from Bronze Age structure 17. All contexts were identified in the field by archaeologists.

4.2.4 *Hearth deposits*

The hearth in structure 9 was identified and sampled by archaeologists.

4.2.5 *Dumped deposits*

Dumped deposits refer to areas of secondary discard (Needham and Spence 1997, Schiffer 1972) and occur at the edge of structure groups/settlements (such as those identified at Skara Brae). Samples in this group were collected from the edge of the Area 5 settlement, and near to structures 7, 16 and 17. Contexts were identified in the field by archaeologists and sampling was undertaken by the excavators and through geoarchaeological investigation in soil test pit 2.

4.2.6 *Occupational deposits*

Occupational deposits are distinguished from ground surfaces as they occur in close proximity to archaeological structures and have the appearance of anthropic sediments in the field. This includes sediments formed through potential primary and secondary discard episodes which have accumulated around building exteriors and in between buildings. Occupational deposits were identified within Area 5 by archaeologists and within soil test pit 2 through geoarchaeological investigation.

4.2.7 *Building infill*

Building infill was collected from Neolithic structures in Area 5 and Bronze Age structure 17, as with interior floor deposits, comparisons within this group are also expected to be important.

4.2.8 *Cultivated soils*

This sample group consists of anthrosol thin sections recovered from horizons where ard marks or possible ard marks were indentified. Contexts within this group were identified by archaeologists and geoarchaeological investigation in the grid 1 auger survey area.

4.2.9 *Field banks*

This sample group was recovered from field banks identified by archaeologists over Area 5.

4.2.10 *Old ground/activity surfaces*

Old ground surfaces or activity surfaces are stratigraphically related to cultivated horizons, occur across the landscape and exhibit similar textures and colours in the field, where cultivation was not evidenced the sample is considered a ground surface. Two contexts were interpreted in the field by archaeologists and the remainder by geoarchaeological investigation in the grid 1 auger survey area.

4.2.11 *Disturbed material*

Disturbed material from a securely dated Bronze Age context was collected to examine constituents and aid analysis.

4.3 Thin section micromorphology of anthrosols and anthropic sediments

As a method for semi-quantitative analysis of soils and sediments, micromorphology has been convincingly applied to the study of palaeosols (Fedoroff et al 2010), archaeological materials (Macphail & Goldberg 2010) and anthropogenic features (Adderley et al 2010). These three areas encapsulate the natural and cultural processes involved in anthrosol and anthropic sediment formation. As a microscope based investigative technique, micromorphology can provide a detailed consideration of finer discrete stratigraphies representing events such as burning, surface trampling and domestic activities which may not be visible in the field (Matthews et al 1997).

The microscopic features revealed by soil micromorphology reflect post-depositional processes and physical relationships between organic, mineral and anthropogenic components. They can elucidate the formation or manner of entry of archaeological materials and the nature of chemical elements (Davidson and Simpson, 2001, Macphail & Goldberg 2010).

Fossil palaeosols, or soil/sediment processes which have been inhibited by burial (Fedoroff et al 2010), are an important part of this investigation as they reflect the environment in which they were formed (Adderley et al 2010, Cornwall 1958, Jenny 1980, Fedoroff et al 2010, Limbrey 1975). The identification of specific properties and the physical and environmental processes they represent can aid reconstruction of the palaeoenvironment and anthropogenic involvement (Cluett 2007, Fedoroff et al 1990 & 2010). The characterisation of palaeosol elements of anthrosol/anthropic sediments collected from the Links of Noltland will meet an essential component of thesis objective two, to provide an environmental context for anthrosols and anthropic sediments.

To characterise the formation of a specific palaeosol, the relationships between diagenic, chemical and pedogenic processes must be understood (Stoops 2010); in a practical sense, this necessitates the recovery of an undisturbed vertical section of a complete soil profile. At the Links of Noltland this was hindered by truncation or rhexistasic (soil erosion) events in the recent past but it does not have to be prohibitive to palaeosol analysis. Chronologies can be proposed for formation events by disentangling hierarchical relationships between soil and sediment features which may be achieved through recognition of groundmass (the coarse and fine base material) and pedofeatures (discrete units which appear different to groundmass) (Fedoroff et al 2010). Stoops et al state that ‘The aim of [thin section soil] micromorphology is to contribute to the understanding of soils and regoliths, their identification, genesis and relative chronology’ (2010:15). It is acknowledged as the most useful tool for the analysis of least-disturbed diagenic, chemical and pedogenic features overall because the removal and reworking of material necessitated by other analyses (e.g. particle size, bulk chemistry, palynology etc) can influence results (Stoops 2010).

The use of thin section micromorphology as an instrument for uncovering evidence of agricultural activity in anthrosols was affirmed by Courty et al in 1989 who reviewed studies of the manifestations of ploughing, clearing and grazing in the micromorphological properties of buried archaeological soils. Since then agricultural practices have been successfully characterised within a variety of soil types and regions (e.g. French & Whitelaw 1999, Goodman-Elgar 2008, Simpson et al 1998). As yet no absolute method of identifying a cultivated horizon has been proposed without reliance on diagnostic evidence such as the presence of ard marks (e.g., Guttmann et al 2006); however, Lewis (2012) has produced a convincing sample set to describe soil profiles affected by experimental ploughing and Verrill and Tipping (2010) characterised Bronze Age ard marks in thin section.

Soil micromorphology has also been effectively applied to the characterisation of soil amendment. For example, Davidson & Carter (1998) used this technique to determine the sources of organic and mineral manure inputs. In an influential research paper (Woodward et al 2010) Simpson et al (1999) showed that thin section analysis of sediment micromorphology from occupational deposits at Hofstaðir, Iceland can elucidate formation processes not visible in the field, contributing to archaeological interpretation of settlement dynamics. They also successfully identified the origins of materials deposited as waste and advocate the use of this technique for investigating subsistence strategies as it can identify manuring practices and food remains.

Land and resource management and use has been the focus of many recent studies (Guttmann et al 2003, 2005 & 2006 Simpson et al 2003b), this subject particularly attracting research interest due to its implications for understanding ideas of sustainability and resilience. Thin section analysis can be applied in this context to identify what resources were available to a community and whether or not they utilised them. It is implied that understanding the resource utilisation and willingness to modify the environment of past societies can make sense of the complex relationships between cultural behaviour and resilience in the face of changing climates.

The changing concerns of a community toward management of resources can be reflected in the soils and sediments at a site in a range of ways, one example might be the construction of field boundaries for animal husbandry. Turf walls and wall cores have been positively identified through use of thin section analysis where field interpretations were not conclusive (McKenna 2010).

The identification and interpretation of buried anthrosols in thin section has the potential to allow more refined consideration of cultural activities associated with soil formation and archaeological landscapes.

Recently, interest in the complex anthropic sediments inherent to prehistoric settlement sites has led to a successful validation of micromorphology as an instrument for reconstructing socio-economic practices. Coarse resolution methods such as bulk chemical analysis, wet sieving, particle size analysis and loss-on-ignition blurs high resolution data (Shillito & Matthews 2012). Anthropic sediments with complex fine microstratigraphies are like varves (ibid.) and so the fine resolution capability of micromorphological analysis is the most powerful tool to extract this type of information.

Anthropic sediments from archaeological contexts sampled for analysis at the Links of Noltland include building infill, dumped deposits, exterior occupational deposits, interior floors and hearths. In the field it was difficult to recognise any subtle microstratigraphies or micro - components but micromorphological analysis can identify individual events in dumped materials and infill, such as hearth rake-out (Shillito & Matthews 2012) and in situ burning (Courty et al 1989, Shillito & Matthews 2012).

Although most soils and sediments collected will have undergone some degree of reworking in situ (with some exceptions where soils are rapidly buried, beyond the reach of soil fauna), micromorphology contributes a workable snapshot of the anthrosol or anthropic sediment in question allowing hierarchies to be considered. This is especially true where a mostly complete profile was retrieved (e.g. dumped deposits in Area 5 deep sondage but also including intact minor stratigraphies) but also from incomplete profiles where truncation and rhexistasy was identified in the field.

Aspects of palaeosols, anthrosols, anthropic and archaeological sediments have all been successfully analysed by thin section micromorphology (e.g. Canti 1998 & 2003, Davidson et al 1976, Gé et al 1993, Fedoroff et al 2010, Guttmann et al 2003, McCullagh & Tipping 1998, McKenna 2008, McKenna & Simpson 2011, Simpson et al 1998 & 2008) and it is now accepted to be the standard method to attain a detailed, microscope based consideration of the origins, formation and variability of soil and sediment composition in geoarchaeology (Adderley et al 2010, MacPhail & Goldberg 2010 & Stoops 2010).

Investigation of anthropic sediment composition in the thesis study area has demonstrated that the degree of component preservation is suitable for successful reconstruction of past human activities and environments. A better understanding of middle prehistoric land management practices has been gained at Tofts Ness, Northton and Scord of Brouster through the examination of soils and sediments which anthropically introduced debris. Domestic activities such as cooking and heating the home were inferred from dumped deposits at Skara Brae, Northton and Eilean Domhnuill using specialist analytical methods including thin section soil/sediment micromorphology and underwater archaeology. The latter technique relies on preservation conditions which are rarely discovered in the study area, but thin section micromorphology has proven to be an exceptionally successful analytical tool when applied to contexts in the broader North Atlantic region (Simpson et al 2003, Simpson et al 2000, Simpson et al 1996). Thin section analyses of contemporary middens at two Icelandic settlement sites (Hofstaðir and Sveigakot) have resulted in a deeper appreciation of social regulation in Viking Age society (Simpson et al 2003) using fuel residue identification. Whilst the same method applied to fish middens in Norway (Langenesværet) and Scotland (Robert's Haven) has demonstrated that identification of microscopic inclusions within these deposits can further understanding of settlement economies and trade links from the Iron Age to Medieval period (Simpson et al 1996, Simpson et al 2000). Application of thin section micromorphology to floor deposits in Icelandic turf houses at Thverá has helped discern activity areas through detailed analysis of compaction (indicating trampling), artefacts (denoting specific tasks like a broken plate in a kitchen area) and organic residues (animal stabling, food waste etc). Spatial analysis of burnt materials was shown to provide information about the redistribution of hearth materials across a settlement (Milek 2012). Ethnoarchaeology at Thverá highlighted culturally prescribed maintenance tasks manifest in floor formation processes, for example, deliberate ash spreading for hygienic purposes (Milek 2012); an activity which leads to cyclical layer formation and remains detectable by thin section sediment micromorphology.

The accumulated knowledge from soil micromorphological study of anthropogenic sediments and anthrosols and palaeosols provides a base for the identification of natural pre-settlement and anthropogenically influenced soils and sediments (thesis objective three). The rediscovery of past functions of anthrosols and anthropic sediments (thesis objective four) is achievable through the careful consideration of context specific anthropic deposits interpreted by experienced archaeologists and specialist geoarchaeological investigation of anthrosols.

4.3.1 *Manufacture and preparation of slides*

Thin sections were prepared at the thin section micromorphology laboratory, University of Stirling. During this process, all water is removed from the Kubiëna tin samples by acetone exchange. The samples are then impregnated using polyester 'crystic resin type 17449' and the catalyst Q17447 (methyl ketone peroxide, 50% solution in phthalate). The mixture is thinned with acetone and a standard composition of 180 ml resin, 1.8 ml catalyst and 25 ml acetone used for each Kubiëna tin. An accelerator is used and the samples are impregnated under vacuum to ensue complete outgassing of the soil. The impregnated soils are then cured, culminating with a period in a 40˚C oven and removal from the tin encasement. Resin impregnated soils/sediments are then sliced, bonded to a glass slide and precision lapped to 30µm thickness, and polished to complete the manufacture of the thin section. Cover slips were not used to allow SEM EDX analysis.

4.3.2 *Procedures for description and interpretation*

By following procedures laid out in the 'International Handbook for Thin Section Description' (Bullock et al., 1985) and the most recent methods of Stoops (2003), soil properties of manufactured slides were recorded semi-quantitatively on a standard table designed to work alongside research objectives, and adapted specifically for each context (occupational surface, dumped deposit etc). The thin sections were analysed using an Olympus BX-51 petrological microscope at a range of magnifications (x10- x400) and with several different light sources.

Plane polarised light (PPL), crossed polarized light (XPL), oblique incident light (OIL) and an ultraviolet lamp (UV) each allow identification of specific microscopic features, such as, mineral and organic components, pedofeatures, fuel residues and phosphatic material.

Interpretation of the observed features rests on the accumulated evidence of a number of works, notably Courty et al. (1989), Fitzpatrick (1993) and Stoops et al (2010).

4.3.2.1 *Identification of environmental indicators*

Identification of morphological indicators for environmental processes is necessarily site-specific (Adderley et al 2010) but was directed by the accumulated works of Courty et al (1989), Fitzpatrick (1993), Stoops et al (2010) and previous investigation within similar calcareous environments on the Scottish North Atlantic seaboard (McKenna 2008). The most prominent indicator of environmental processes at the Links of Noltland is the aeolian shell sand. This highly calcareous material is composed of sub-rounded fragments of marine shell intermixed with fine quartz grains and other accessory minerals such as feldspar and mica. The principal components of features representing environmental processes at the Links of Noltland are presented in table 4.2 and illustrative micrographs are given in figures 4.1 & 4.2.

Table 4.2: Principal components of features representing environmental processes at work at the Links of Noltland

Feature type	Interpretation	Description
Sediment transport	**Wind events**	**Sub-rounded fragments of marine shell intermixed with fine quartz grains and other accessory minerals. Grey or white (PPL), matt white (OIL), low order birefringence (XPL). Morphology includes intact fusiform, whorled, coeloconoid and pupiform micro-shells and fragments from larger limpet patella etc.**
	Colluviation	**Striated mineral grains oriented in direction of travel suspended in a matrix of fine silt and/or clay.**
	Disturbance	**Pore spaces filled with clay and/or silt and coatings or capping other features and minerals.**
Soil genesis	**C- horizons**	**Formed upon boulder clay. Mineral weathering and rare phytoliths. Amorphous black organic material interpreted as lignified tissues or decomposed plant**
	AB-horizons	**Blocky microstructure structure, organo-mineral with porphyric coarse: fine ratio. No anthropic inclusions or infill pedofeatures.**
	Podzolisation	**Iron depletion hypocoatings (bleached stone rims) of coarse minerals**
Vegetation growth	**Phytoliths**	**Phytogenic silica, transparent (PPL) high negative relief, optically isotropic (XPL). Wavy or smooth outlines, elongate or oval shaped. <1mm in length.**
	Plant material	**Roots, stems, lignified tissue and cellular to amorphous organic matter. Black to yellow (PPL) isotropic (XPL).**
	Rhizosphere	**Channels/chambers overlain on the fine organo- mineral groundmass, intersecting and truncating inclusions including coarse minerals and anthropic material.**
	Phosphatic inclusions	**Autofluorescent pale green or yellow (UV), invisible in PPL, XPL and OIL.**
Faunal activity	**Excremental pedofeatures**	**Coalescent spherical aggregates, brown or orangey brown (PPL) isotropic (XPL).**
Moisture fluctuation and sediment acidification	**Fe/Mn accumulation**	**Matt black/reddish brown amorphous (Fe) or blueish black amorphous (Mn) (PPL) or redish orange (OIL) staining fine material or accumulating as coatings/infill.**
	Fe/Mn depletion	**Grey coloured fine organo-mineral fabric (PPL)**
	Fe/Mn nodules	**Black matt, red or blueish black sub-rounded nodules (PPL) with sharp or diffuse boundaries**
	Pyrite framboids	**Cluster of matt black (PPL) spherical aggregates**
	Shell dissolution	**Re-precipitated calcium carbonate pedofeatures. Grey to white (PPL), randomly aggregated xenotopic crystals. High birefringence (XPL).**
	Bone dissolution (nodules)	**Re-precipitated calcium and phosphates. Phosphatic nodules are sub-rounded yellowish brown (PPL) with anhedral crystallitic fabric. Isotropic matrix with needle-like birefringent inclusions (XPL) Autofluorescent (UV)**
	Apatite replacement of ash (coatings & lenses)	**Yellow (PPL) apatite accumulation, with an equigranular hypidiotopic internal structure (SEM). Isotropic (XPL). Forms as coatings and granostriations.**

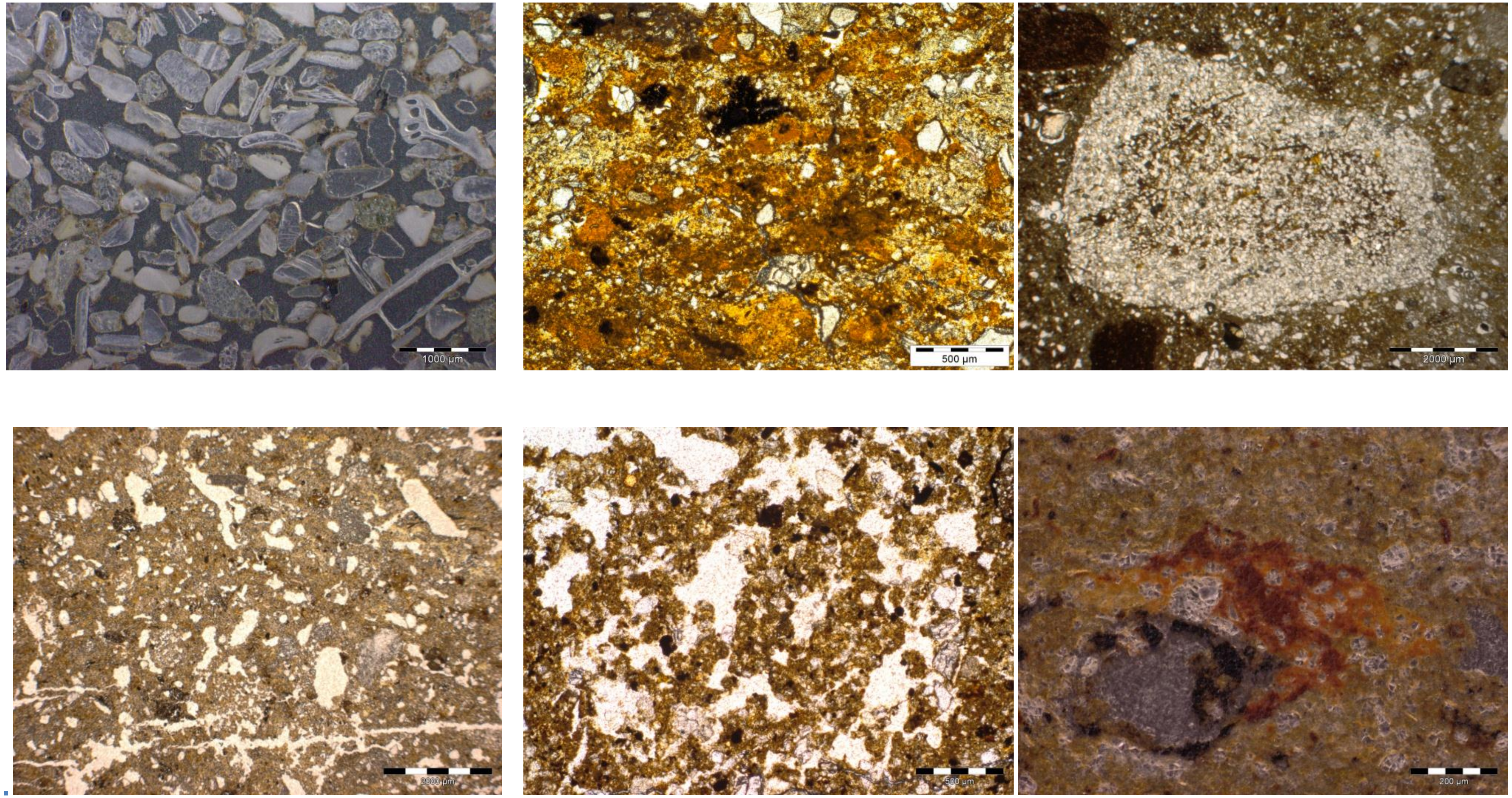


Figure 4.1: Examples of environmental indicators described in Links of Noltland thin sections. TOP (left to right) Aeolian shell fragments (OIL), orange clay infill pedofeatures (PPL), depletion hypocoating (PPL). BOTTOM (left to right) Spongy ground mass composed of a network of channels and chambers (PPL), excremental pedofeatures (PPL), iron accumulation (OIL).

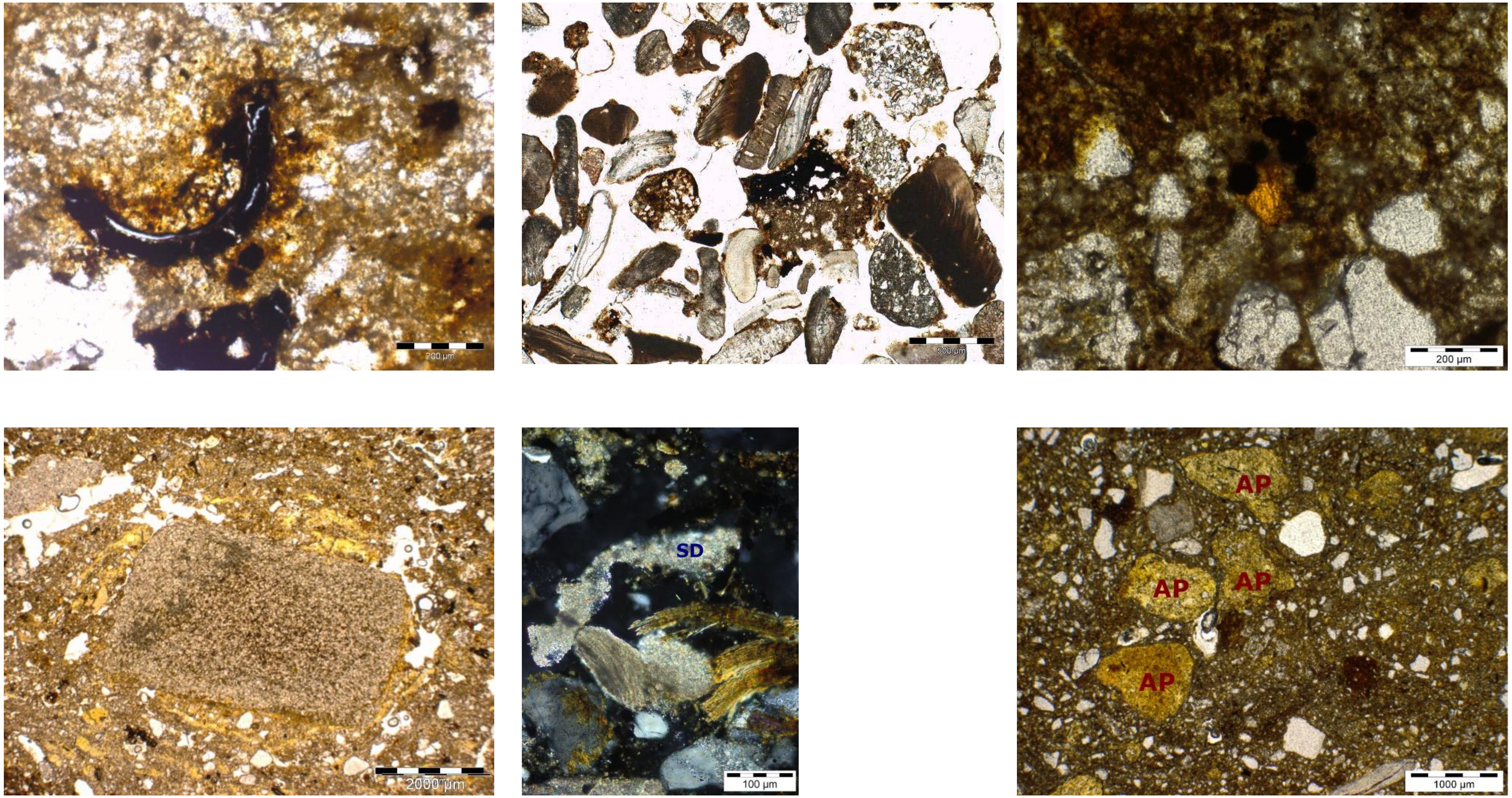


Figure 4.2: Examples of environmental indicators described in Links of Noltland thin sections. TOP (left to right); iron accumulation pedofeatures (PPL) allochthonous Fe impregnated turf fragment (PPL), pyrite framboids (PPL). BOTTOM (left to right); granostriated yellow amorphous organic material around a large mineral fragment (PPL), shell dissolution (SD) pedofeature (XPL), phosphatic nodules (AP) (PPL).

4.3.2.2 *Identification of anthropic inclusions*

In addition to the guidance of Courty et al (1989), Fitzpatrick (1993), Stoops et al (2010) and training provided by University College London, the identification of anthropic inclusions was modulated by recent research carried out on soils and sediments from the Scottish North Atlantic seaboard at the University of Stirling (e.g., Cluett 2007, Guttmann et al 2006 & 2008, McKenna & Simpson 2011, McKenna & Simpson 2010, McKenna 2011, Simpson et al 2006). This included access to reference slides manufactured from experimentally combusted materials at the University of Stirling. These included sheep dung, cattle dung, turf, peat and peat at 400°C and 800°C (Guttmann et al 2001). For detailed interpretation of specific processes or features such as intensity of burning reflected in bone fragments (Hanson & Cain 2007) or charcoal decomposition (Umbanhower & McGrath 1998), referral to supplementary research was made. Key characteristics of anthropic inclusions at the Links of Noltland are given in table 4.3 with illustrative photomicrographs presented in figures 4.3 & 4.4.

Table 4.3: Key characteristics of anthropic inclusions found in Links of Noltland thin sections.

Feature type	Interpretation	Description
Fuel residues	**Woody charcoal**	**Cellular material. Black opaque (PPL & XPL) with sharp boundaries.**
	Burned peat	**Black or dark brown spongy structure (PPL)**
	Cramp	**Greyish white (PPL) containing vesicles. White opaque (OIL) low order interference (XPL)**
	Vesicular char	**Black opaque (PPL) containing vesicles. Incomplete cracks join up vesicles. Reflective black (XPL)**
	Ash aggregate	**Grey (PPL), high interference (XPL), peat ash is bright red or orange in OIL**
	Other char	**Black (PPL) with yellowish admixture. Grass charcoal exhibits a mean length: width ratio of 3.62 and is rectangular elongate. Leaf charcoal is polyhedral with a reflective surface, Umbanhower & McGrath (1998).**
Mineral inclusions	**Unburned bone**	**White to yellow or orange (PPL) with visible osteons, volkman/ haversian canals. Some samples fibrous. Ropey internal structure (XPL) highly fluorescent (UV).**
	Burned bone	**Ranges from dark brown, yellow or pale orange/red (PPL) with minimal carbon accumulations and few cracks to entirely calcinated with high birefringence XPL) and loss of internal structure based upon intensity of burn (Hanson & Cain 2007).**
	Shell	**White matt with made up of fine crystal size, low to high interference colours (XPL)**
	Heated stone	**Red or orange (OIL) high interference (XPL)**
	Pottery	**Dark red/very dark brown (PPL), bright red/orange (OIL), dense internal fabric with mineral inclusions**
Organic inclusions	**Unburned peat**	**Reddish brown organic fibrous material (PPL), spongy structure, no birefringence (XLP) with occasional fine mineral inclusions and diatoms**
	Unburned turf	**Brown organo-mineral fine material (PPL), with occasional fine or coarse mineral inclusions and phytoliths**
	Coprolite	**Yellow or brown matrix (PPL) containing phytoliths, minerals and/or bone fragments. Greenish fluorescence (UV)**

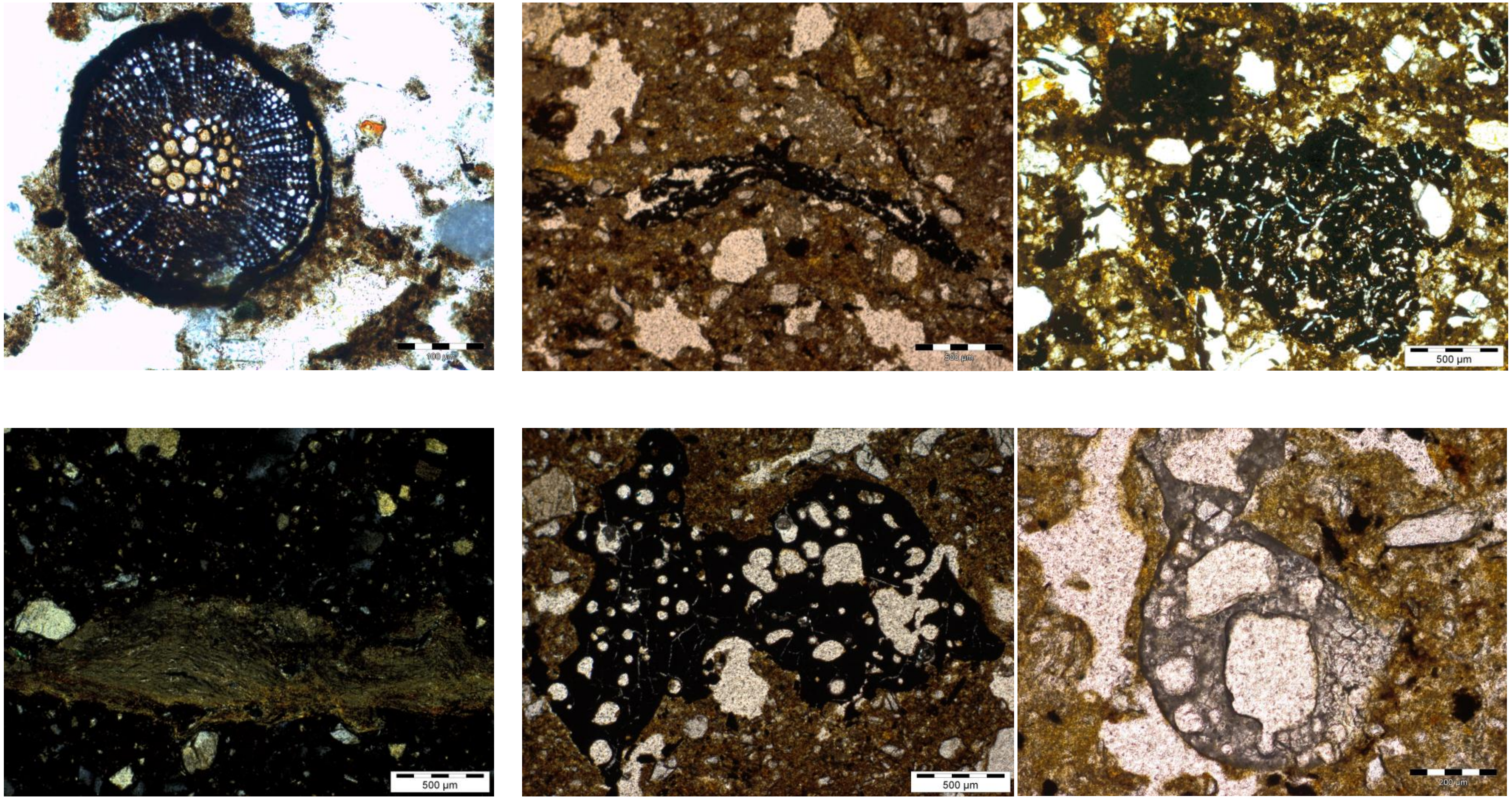


Figure 4.3: Examples of fuel residues described in Links of Noltland thin sections. TOP (left to right): exceptionally well preserved woody charcoal (PPL) more typical charcoal fragment (PPL) Burned peat fragment (PPL), BOTTOM (left to right) ash deposit (XPL), vesicular char (PPL), cramp (PPL).

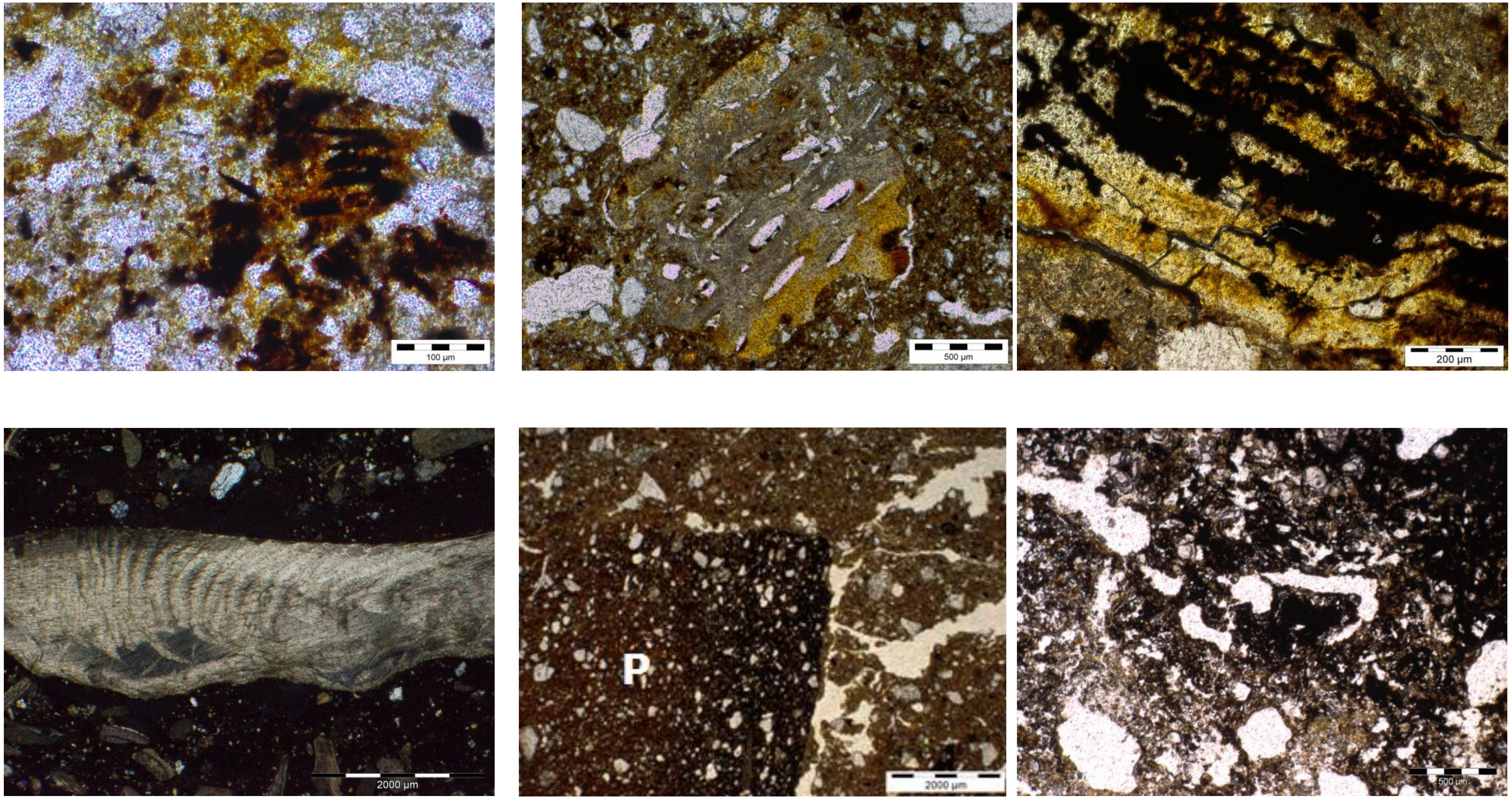


Figure 4.4: Examples of fuel residues described in Links of Noltland thin sections. TOP (left to right): Grass charcoal (PPL), unburned bone fragment (PPL), burned bone fragment (PPL). BOTTOM (left to right) Shell fragment (XPL), pottery fragment (P) in groundmass (PPL), unburned peat fragment (PPL)

4.4 Supporting analyses

Soil and sediment micromorphological description is a semi-quantitative technique which must be validated with supporting analysis (Golding 2008) and so feature abundance was calculated using point counting techniques and feature identification was strengthened using SEM EDX element ID and magnification up to 150x.

4.4.1 *Point counting*

The anthropic sediments at the Links of Noltland were rich in artefacts and so it was anticipated that this would be reflected in similar high amounts of anthropic inclusions present within the slides. To gain a comprehensive understanding of the abundance of these features within each archaeological context, a point counting approach was adopted after the methods of Clarke (1982) and Davidson et al (2004).

Each slide contained approximately a 4015mm^2 thin section of soil or sediment and so 35 x 27 points were recorded at 2mm intervals over a grid (with exceptions made when slides containing a smaller area of soil or sediment) giving a total of c.945 points per slide. Where an on-slide microstratigraphy was observed, this was noted on the form and thus the possibility of interpreting individual micro-horizons was maintained.

Observations were made using an Olympus BX-51 petrological microscope at a fixed 4x magnification with light sources necessary for feature identification. Olympus analySIS image analysis software was used to automatically move the field of view across the slide in 2mm increments from a fixed point on a motorised stage (figure 4.5). The feature present within the on-screen cross-hair was recorded on a specially made form (Appendix I) adapted as new features were discovered. This resulted in the production of abundance measurement for every feature present with each slide including pore space, fine organo-mineral material and those relating to environmental processes, anthropic activity and biological activity.

Figure 4.5: Illustration of point counting pathway, 28 measurements were taken along each horizontal line

4.4.2 *Scanning Electron Microscopy*

Thin sections can be observed at higher magnifications using a Scanning Electron Microscope (SEM). This is useful when higher resolutions are required to identify discrete inclusions in soil and sediment fabrics (Pike & Kemp 1996). Scanning electron microscopes work by generating a beam of incident electrons which are fired at a sample specimen (in this case, a soil/sediment thin section – see figure 4.6). These electrons enter the specimen and react in a number of different ways. Some of the incident electrons collide with free electrons in atoms near the surface of the specimen with enough energy to allow them to escape into the vacuum. These are known as secondary electrons. Freed secondary electrons move through the specimen chamber and are picked up by a detector and converted into images which represent the topography of the specimen's surface (Hitachi 2009). This has proven useful in palaeoenvironmental reconstruction as demonstrated both by Stickley et al (2005) and Maddison et al (2006) who used Secondary Electron Imagery (SEI) to identify diatom species, assisting their interpretations of seasonal climate differentiation. Edwards et al (2012) used SEI to identify fossil bacteria assisting interpretations of palaeoenvironmental sediment forming and diagenic processes.

Back Scattered Electrons (BSE) are another reaction to the incident electrons beam. Formed as incident electrons are reflected deeper within the specimen, they are picked up by a back scattered electrons detector (Hitachi 2009). The image produced records the number of backscattered electrons generated which are directly related to the atomic number of elements within the specimen. Higher atomic numbers (gold, copper etc) generate brighter spots on the image, whilst lower atomic numbers (organic matter, carbon etc) produce darker spots. This allows visual characterisation of thin sedimentation laminae/microstratigraphy, fabric and porosity (Pike & Kemp 1996).

When fitted with an Energy Dispersive X-ray spectroscope (EDS) the SEM can also perform on-slide soil chemistry analysis Prakongkep et al (2010) used this to characterise sand grains in paddy soils and deduce sedimentation events from diverse rock types. Traditionally, soil chemistry for geoarchaeology has focused upon specific elements (e.g., enhanced phosphorous) partly due to the time-consuming nature of broader analyses. However, as Middleton (2004) points out, single elements cannot individually reveal the interplay between sediment formation factors indicative of human activity. Phosphorous is an extremely good indicator of human activity but the detection of other elements present alongside it is necessary to determine more specific human activities (Middleton 2004). On-slide soil chemistry as conducted by the SEM EDS can quickly identify the full range of elements present allowing characterisation of the full suite of elements and traces left by human and natural factors. This technique eliminates the necessity of sampling unknown features in the field prior to identification of archaeological sediment horizons as the same slide can be used for micromorphological identification of archaeological contexts and their elemental analysis (Middleton 2004).

Middleton & Price (1996) examined the viability of multi-elemental analysis of soil in archaeology and found that 'archaeological features are chemically distinct from natural soils, and that features such as floors and hearths can be distinguished from each other and from the natural prehistoric ground surface'. They discovered that although certain elements can serve as indicators of specific anthropogenic activities (food preparation, burning etc) these do not always survive millennial time-scales but that phosphates and potassium are stable indicators of anthropic involvement.

Middleton has used ethnoarchaeological data on elemental residues of human activity to define archaeological contexts, however, Wilson et al (2009) caution that multi-element concentrations are very site specific after performing a comparative study between two sites with very similar geological, geographical functional and temporal variables. They demonstrate that modelling human activity through elemental analysis benefits from the use of a broad comparative data set.

Entwistle et al (2007) have also addressed archaeological research questions through elemental analysis of soils in an attempt to identify and differentiate spatially, specific activities at medieval settlement and farm sites in the Hebridean islands. Through the elemental characterisation of the human impact on soil they were able to identify different types of manure sources and advocated the use of multi-elemental analysis and control sampling to understand phosphate enrichment.

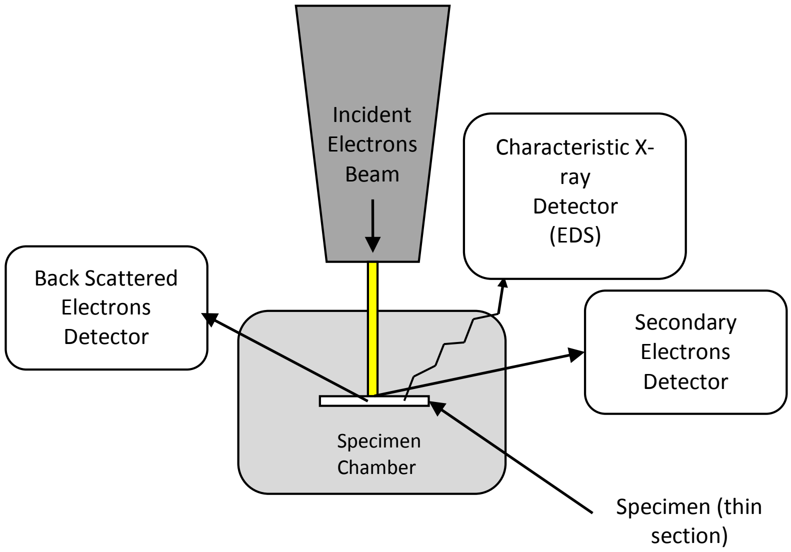


Figure 4.6: Simplified diagram of Scanning electron microscope fitted with EDS and BSE detectors (after Hitachi 2009)

More recently, Golding et al (*in press*) have utilised SEM EDS analysis in the study of anthrosols and anthropic sediments at a Norse archaeological site in Greenland. The elemental loading contributing soil nutrients were quantified and comparisons made between cultivated 'homefields' and 'midden' anthropic sediments. A 'recipe' effect was identified through these comparisons, demonstrating compositing and deliberate application of wastes from settlement to homefield. The implications of these findings demonstrate that the use of SEM EDX after this method can contribute to a greater understanding of the form and function of anthrosols and anthropic sediments (thesis objective 4). Furthermore SEM EDX allows powerful magnification and quantification of elemental composition of individual features supporting and validating micromorphological interpretations.

4.4.2.1 *Procedures for SEM EDX analysis*

Anomalous features and elemental loadings of thin section samples were analysed using a Zeiss EVO-MA15 SEM fitted with an Oxford Instruments InCA Max 80 mm EDS. Samples were loaded into the chamber using a stage designed specifically for thin section analysis at the University of Stirling. Chamber pressure was pumped to low vacuum conditions (60 Pa) to minimise charging upon the surface of the thin section. Protocols were set at 20.01kv accelerating voltage, 2.471A filament current, 69 µA beam current and iprobe 6.9nA. This allowed an x-ray acquisition rate of 11kcps. Sample Z height was set at 21mm, the working distance was kept at a range between 9mm and 8mm. For feature ID this was accepted but for analysis of elemental loadings magnification was set at x75 maintained to standardise analyses.

Each time a new sample was loaded into the chamber polished samples of dolomite and spinel were analysed to control accuracy. A polished Co standard was analysed every two hours to adjust for beam current drift.

Stage initialisation and scanned thin sections were used to assist sample navigation. The xy co-ordinates of slide edges remained consistent and the location of features was assisted by marking the adjacent area with a slither of Cu tape.

For anomalous feature identification, the feature was viewed at a range of magnifications to identify internal structures. Then field of view was set to be entirely taken up by the feature in question. Element data was collected using INCA point and ID feature with three spectra acquired across the area of the feature.

For the characterisation of elemental loadings across contexts, five sites of interest were selected within each micro-stratigraphic horizon with care taken to avoid targeting any patterns with the horizon. At each site of interest, seven spectra were acquired, resulting in spectra data from 35 points for each micro-horizon (method adapted from Golding et al *in press*).

To compensate for resin impregnation, O and C were removed from the data set and the remainder normalized to % weight, therefore results are presented as ratios.

4.4.2.2 *Statistical testing*

Visual inspection of the distribution of each element confirmed that data sets exhibit positive skews (figure 4.7). As the data violate the normality assumptions of parametric tests such as Analysis of Variance (ANOVA), a non-parametric Kruskal-Wallis rank sum test was selected to assess any differences in the distribution of elements between treatments. This tested the null hypothesis that the proportions of each element did not vary across treatments. Where this returned a significant result, this indicated that the proportions of the given element differed significantly between at least two treatments. In this case, planned follow-up (*post hoc*) multiple comparisons between element loadings were carried out to establish where these differences lay.

This combination of analyses was most successfully carried out using SPSS (version19) using the independent-samples non-parametric tests function with customized Kruskal-Wallis 1-way ANOVA (k samples) selected with a multiple pairwise comparisons of *k* samples requested.

4.5 Summary

To achieve objectives laid out in chapter three, thin section micromorphological analysis with supporting SEM EDX and point count data is identified as the optimum method to asses the constituents of midden material and its formation pathways. Statistical testing will be used to help quantify data where possible.

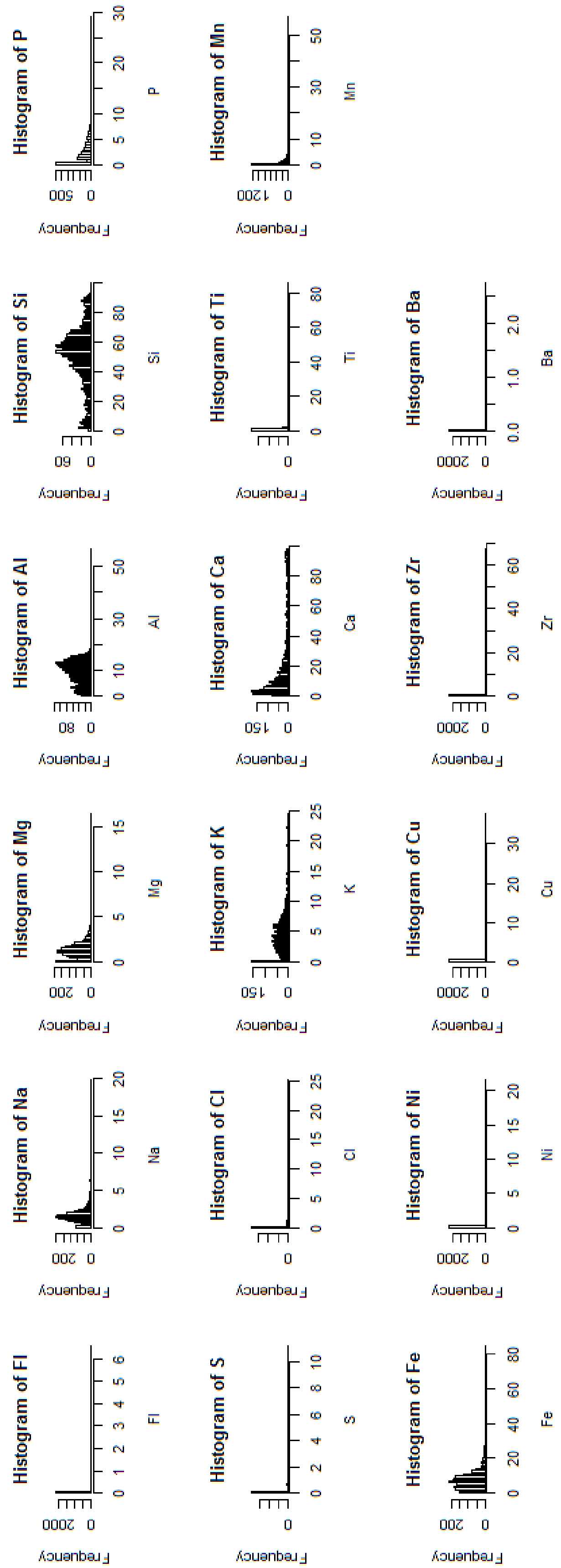


Figure 4.7: Histograms of distribution of each element detected using SEM EDX analysis.

Chapter Five: Results and discussion

Chapter 5: Thin section micromorphological description and chemical composition of anthropic sediments and anthrosols from the Links of Noltland, Orkney

5.1 Introduction

In this chapter, soil/sediment samples recovered from Links of Noltland are presented for thin section soil micromorphological analysis. Soil/sediment formation processes are described and the complex relationship between occupational sediments is interpreted following research objectives and questions laid out in chapters two and three. In addition, soil chemistry is measured using SEM EDX analysis and individual exceptional features such as vesicular char, phosphatic nodules and yellow amorphous material are investigated. The chapter begins with results of point count analysis and statistical testing of these.

5.2 Results of point count analysis

Point count analysis successfully identified trace amounts of materials which would otherwise have been missed by micromorphological observation. However, the resolution at which the study was carried out and the relatively small ratios of cultural material observed meant that point count analysis missed some cultural inclusions. Therefore, point count analysis at this resolution is considered mutually supportive with micromorphology, providing a semi-quantitative assessment of coarse to fine distribution ratios across context groups which allows informed comparison.

A presence/absence chart is presented to assist in understanding where anthropic inclusions occur (Figure 5.1) across the Links of Noltland sample set. The descriptive results of point count analysis are given in Appendix II, with raw data available on request.

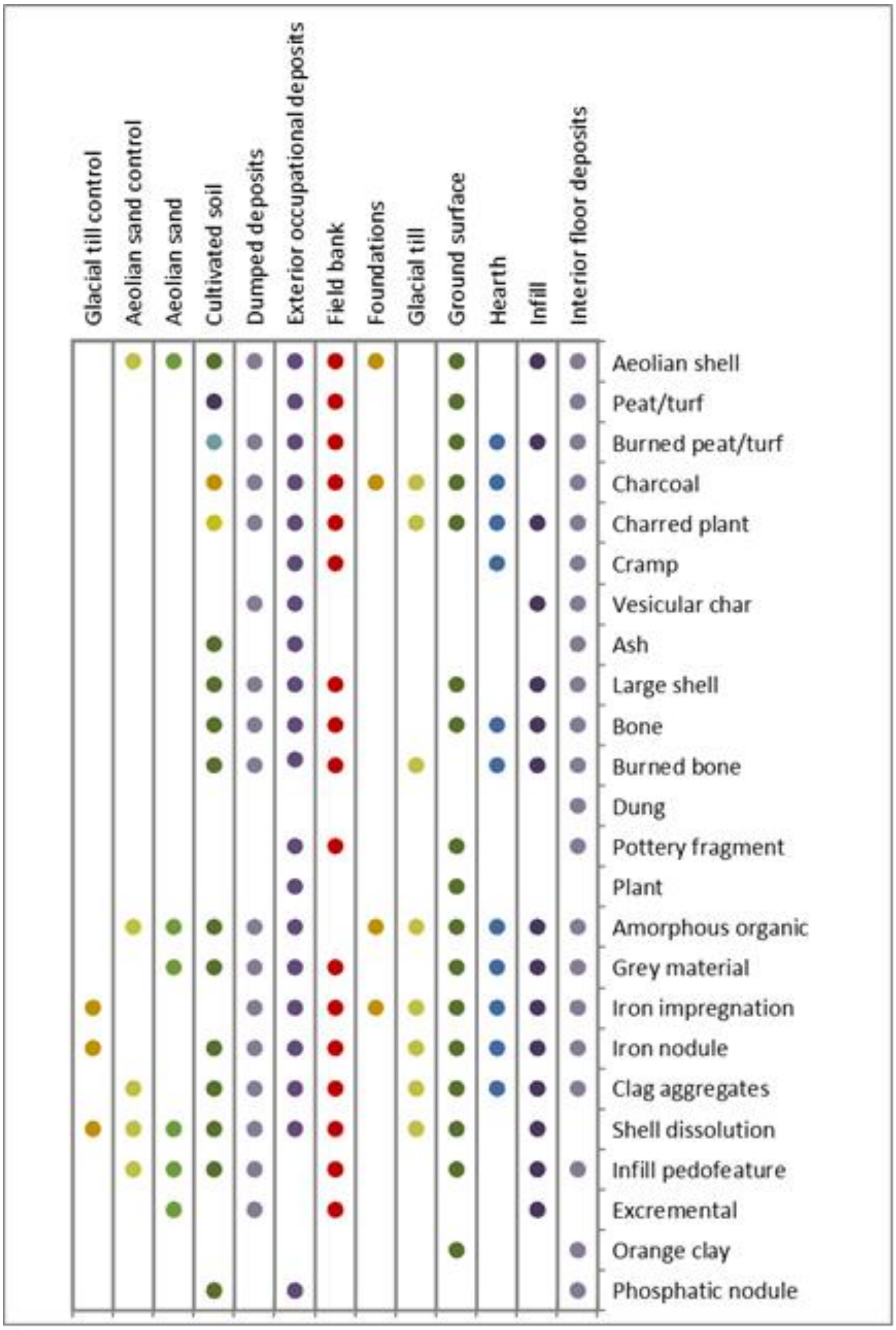


Figure 5.1: Presence/absence chart for anthropic inclusions by context at the Links of Noltland

5.2.1 *Statistical Analysis of point count data*

Slides were grouped into the archaeological contexts defined in chapter three and glacial till/ aeolian sand controls. Aeolian sand and glacial till affected by anthropic activity were given separate groups. Where only part of the slide contained the context of interest, counts were limited to that context (table 5.1).

Table 5.1: Number of slides or part slides analysed through point counting and total number of data points collected for each context

Context	Number of slides analysed	Points counted
Sand Control	1	910
Glacial till Control	1	593
Aeolian sand	2	881
Cultivated soil	4	3341
Dumped deposits	8	5866
Exterior occupational deposits	9	6626
Field bank	2	1773
Ground surface	8	6501
Hearth	2	2074
Infill	3	2613
Interior floor deposits	7	6650
Glacial till	1	326
Foundations	1	996

Observed features were expressed as a percentage ratio where only one sample was available and mean ratio with standard deviation (σ) where more than one sample was available.

Normality tests were conducted using the explore function in SPSS (version 19) which confirmed that data was not normally distributed and so a non-parametric Kruskal-Wallis rank sum test was applied to assess whether differences in percentage ratios of observed features were able to be confirmed statistically between contexts (treatments). This tested the null hypothesis that the distribution of each feature is the same across all categories of treatment, a significance of $p = <0.08$ was accepted as samples sizes were low.

This work established that a statistical difference can be confirmed between context groups based upon fine material, aeolian shell sand, charred plant and large shell fragments and so point count data must be treated as semi-quantitative.

SPSS allows pairwise comparison between k-independent samples where the null hypothesis is rejected. Results are presented below (table 5.2).

Table 5.2: Results of Kruskal-Wallis test on point count data; the null hypothesis was that the distribution of each feature is the same across all categories of treatment (contexts).

Feature	Kruskal-Wallis test result	Decision	Pairwise comparison
Fine material	P = 0.064	**Reject** null hypothesis	**Aeolian sand –Fieldbank** **Cultivated soil - Fieldbank**
Void	P = 0.292	Retain null hypothesis	
Mineral	P = 0.765	Retain null hypothesis	
Aeolian shell	P = 0.008	**Reject** null hypothesis	**Dumped deposits – Ground surface** **Dumped deposits – Cultivated soil** **Hearth – Ground surface**
Peat/turf fragment	P = 0.601	Retain null hypothesis	
Burned peat/turf	P = 0.217	Retain null hypothesis	
Charcoal	P = 0.156	Retain null hypothesis	
Charred plant	P = 0.077	**Reject** null hypothesis	**Aeolian sand- dumped deposits**
Cramp	P = 0.527	Retain null hypothesis	
Vesicular char	P = 0.602	Retain null hypothesis	
Ash	P = 0.926	Retain null hypothesis	
Large shell fragment	P = 0.042	**Reject** null hypothesis	**Ground surface – Dumped deposits** **Infill – Dumped deposits** **Exterior occupational deposits – Dumped deposits** **Hearth – Dumped deposits** **Aeolian sand – Dumped deposits**
Bone	P = 0.751	Retain null hypothesis	
Burned bone	P = 0.170	Retain null hypothesis	
Dung	P = 0.846	Retain null hypothesis	
Pottery fragment	P = 0.543	Retain null hypothesis	
Plant material	P = 0.920	Retain null hypothesis	
Amorphous organic	P = 0.258	Retain null hypothesis	
Grey material	P = 0.524	Retain null hypothesis	
Iron accumulation	P = 0.124	Retain null hypothesis	
Iron nodule	P = 0.337	Retain null hypothesis	
Clay aggregate	P = 0.267	Retain null hypothesis	
Shell dissolution	P = 0.266	Retain null hypothesis	
Infill pedofeature	P = 0.680	Retain null hypothesis	
Excremental pedofeatures	P = 0.188	Retain null hypothesis	
Orange clay	P = 0.947	Retain null hypothesis	
Phosphatic nodule	P = 0.761	Retain null hypothesis	

5.3 Controls

Control samples were collected from boulder clay and aeolian sand. Thin section micromorphological analysis, point count data and elemental loadings are presented below. Thin section description tables are presented in Appendix III.

5.3.1 *Boulder clay*

In thin section boulder clay exhibits a cracked massive microstructure and an open or double spaced porphyric coarse:fine ratio. Coarse minerals are randomly arranged and poorly sorted. The coarse mineral component is composed of quartz (15-30%), quartzite (1-5%), mica (<1%), garnet (<1%) and rock fragments of siltstone mineralogy (5-15%). Coarse minerals are encased in a light brown/greyish (PPL) organo-mineral fabric which is yellowish brown in OIL. The birefringent fabric is speckled micro crystallitic in XPL and reflects weathering of coarse minerals and clay formation. There are sandy infill pedofeatures, sand grains are composed of quartz. Iron movement is evidenced by impregnation, depletion and nodule formation. That this horizon was lightly vegetated is evidenced by trace amounts of lignified plant tissue (<1%, figure 5.2a) and yellow amorphous organic material (figure 5.2b) and pigment (<1% each). Glacial till has undergone compaction caused by dune sand. The boundary between glacial till and overlying aeolian shell sand horizon is diffuse, with discrete microstratigraphic unit (B) containing vughs and channels forming a relict root bed. Mixing of sub-rounded shell fragments into this horizon demonstrates that this horizon was buried gradually. Iron movement is also evidenced in this horizon, indicating seasonal wetting and drying.

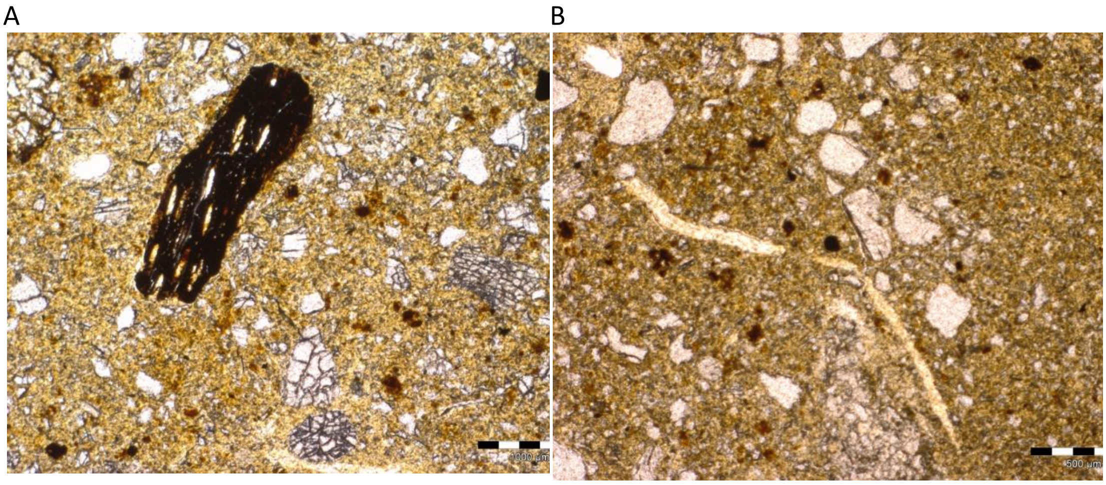


Figure 5.2: Sample 115, unit A. (A) Lignified tissue (PPL). (B) Amorphous yellow organic material, possible root fragment (PPL).

Point count results reflect the high ratio of fine material (65%) and coarse minerals (together, 28%) to pore space (<4%) with iron impregnation pedofeatures contributing 2% and traces of amorphous organic material and iron nodules (<1%) in the remainder.

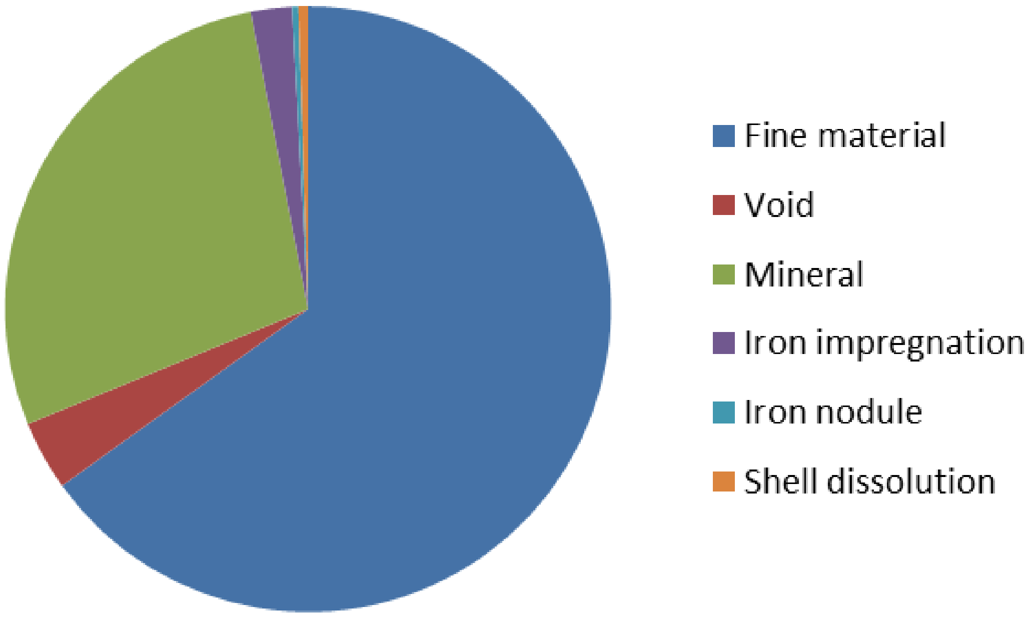


Figure 5.3: Point count results for glacial till control. Extents are expressed as percent ratio

The chemical elements present in the glacial till control were split into macro- (figure 5.4) and micro- (figure 5.5) components and are consistent with known geochemical composition for parent materials present in Orkney (Duncan & Hamilton, 1988, Thornton & Howarth, 1986). Nutrients essential for crop growth (Mg, P, S, K and Ca) are available within the boulder clay parent material but the soil structure and concentrated state of nutrients are not conducive to plant succession.

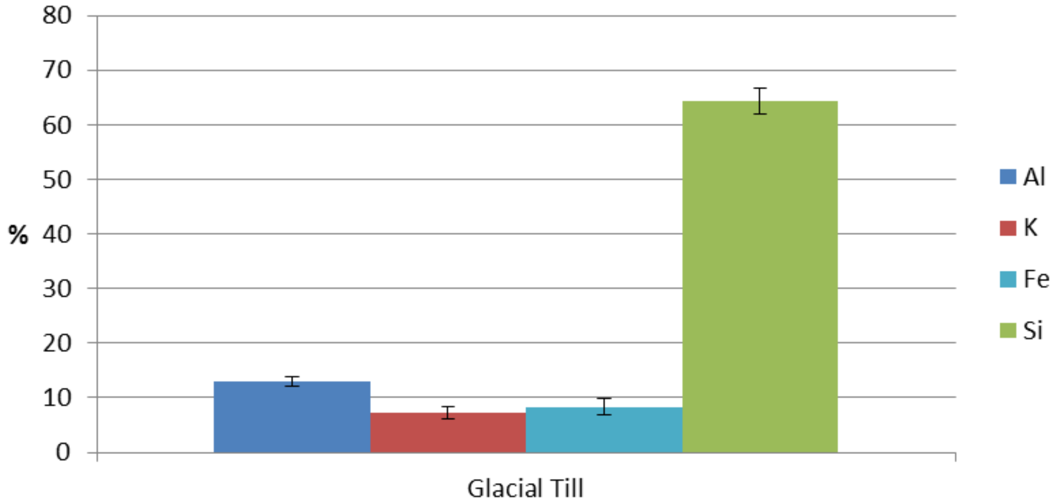


Figure 5.4: Major elements detected in glacial till control. Results expressed as mean percent ratio, error bars = σ

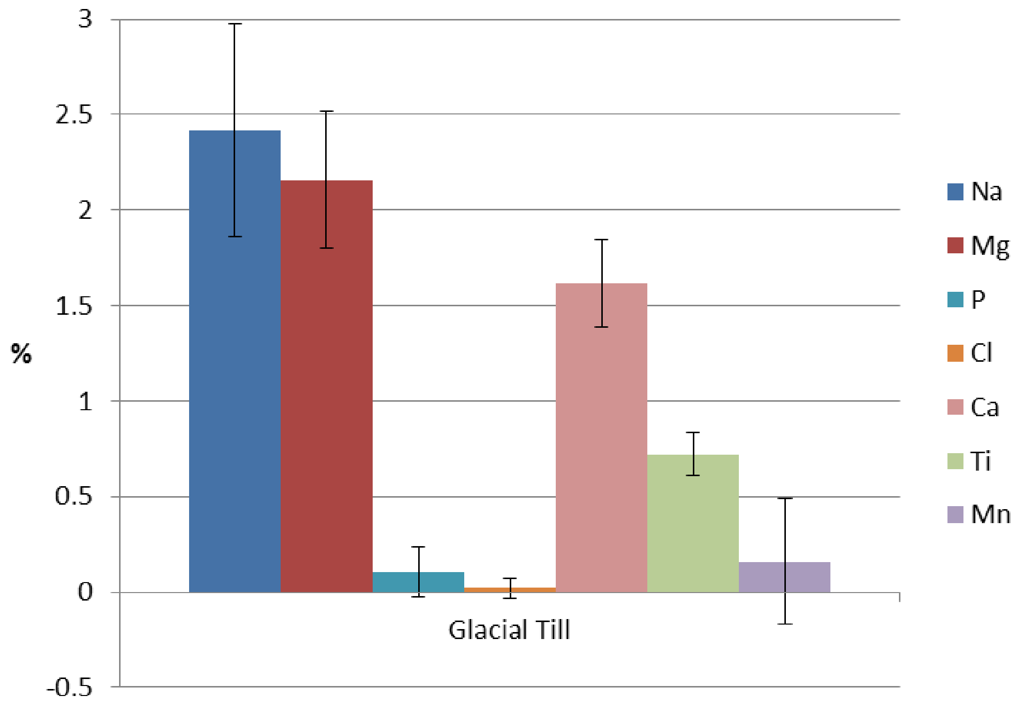


Figure 5.5: Minor elements detected in glacial till control. Results expressed as mean percent ratio, error bars = σ

5.3.2 *Aeolian sand control*

Aeolian sand exhibits a microstratigraphy in thin section, representing differential wind strength or pedogenesis. The microstructure is single grain with pellicular coatings or bridged by micro-aggregates. Coarse fine related distributions are monic or concave gefuric and coarse minerals are random but well sorted. Sub-rounded marine shell fragments or intact shell bodies contribute between 30 and 70% of the slide with quartz grains adding 1-5%, accessory minerals <1% to 5% and coarse to very coarse sand sized siltstone rock fragments between 15-30%. Fine material is light brown dotted organo-mineral (PPL) which is yellowish brown in OIL. b-fabrics are stipple speckled or grano/porostriated micro crystallitic reflecting weathering and the many (5->10%) dusty clay coatings. Punctuations, amorphous reddish brown and black fine organic material are each present in trace amounts (<1%) and one horizon contained a trace (<1%) of charred plant material. Indicators of iron movement are minimal, as would be expected in a calcareous situation. Fe/Mn impregnation (<1%) and nodules (<1%) are likely to have blown into the profile from elsewhere.

The aeolian sand control was free from anthropic inclusions and was semi-quantified using point count analysis (figure 5.6). The results show that sub-rounded shell fragments contribute 46 percent as a ratio of the sample and quartz, quartzite and accessory minerals 11%. Pore space was 19% and fine material contributed 23%. Trace features (>1%) were amorphous organic matter, clay aggregates, shell dissolution and infill pedofeatures.

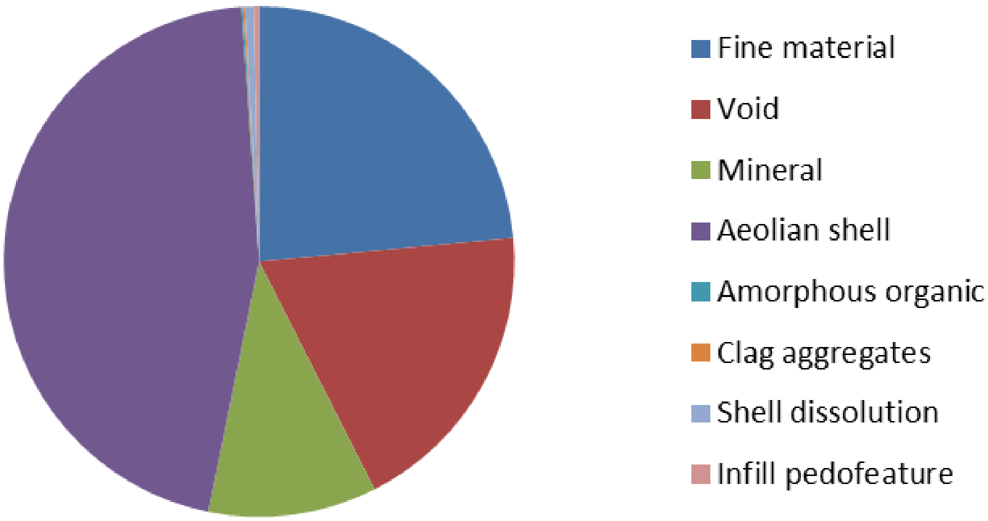


Figure 5.6: Point count results for aeolian sand control. Extents are expressed as percent ratio

The chemical elements present in the aeolian sand control were split into macro (figure 5.7) and micro (figure 5.8) components and are consistent with known geochemical composition for parent materials present in Orkney (Duncan & Hamilton, 1988, Thornton & Howarth, 1986). Nutrients essential for crop growth (P, K, Mg & Ca) are available within the aeolian sand parent material, but the structure indicates a lack of adhesion which makes it prone to further aeolian movement and thus less suitable for plant growth without management.

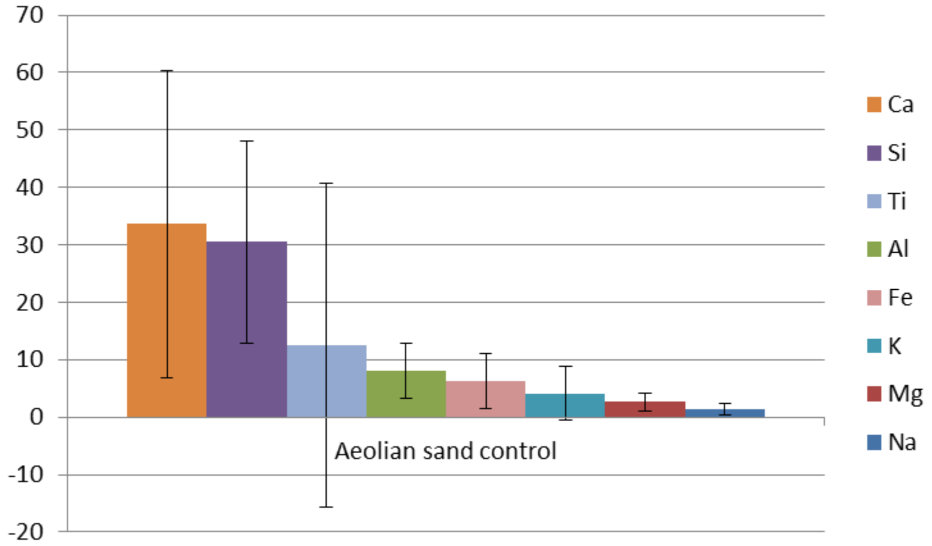


Figure 5.7: Major elements detected in aeolian sand control. Results expressed as mean percent ratio, error bars = σ

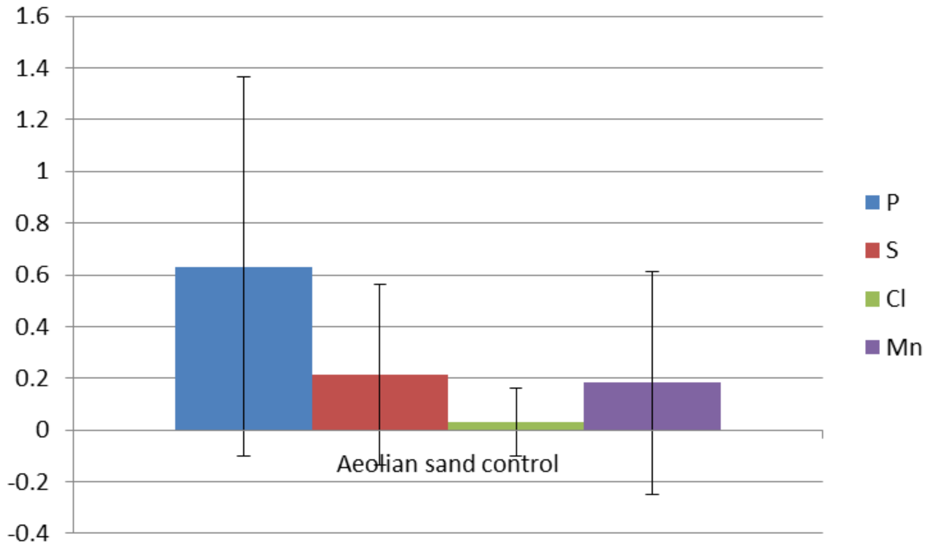


Figure 5.8: Minor elements detected in aeolian sand control. Results expressed as mean percent ratio, error bars = σ

5.4 Exceptional features

During micromorphological analysis several exceptional features were observed. These having no obvious parallel in the body of literature on the subject or through discussion with other micromorphologists (International workshop on archaeological soil micromorphology 2013 in Basel, Switzerland) were investigated in detail to establish their nature. The results are presented below.

5.4.1 *Vesicular char*

The occurrence of vesicular char was investigated further as it does not exhibit typical morphology of known wood cellular structures. The 'walls' are too thick in proportion to the (irregularly rounded) 'lumina' of wood (Dr Allan Hall, University of York, *pers comms*). SEM

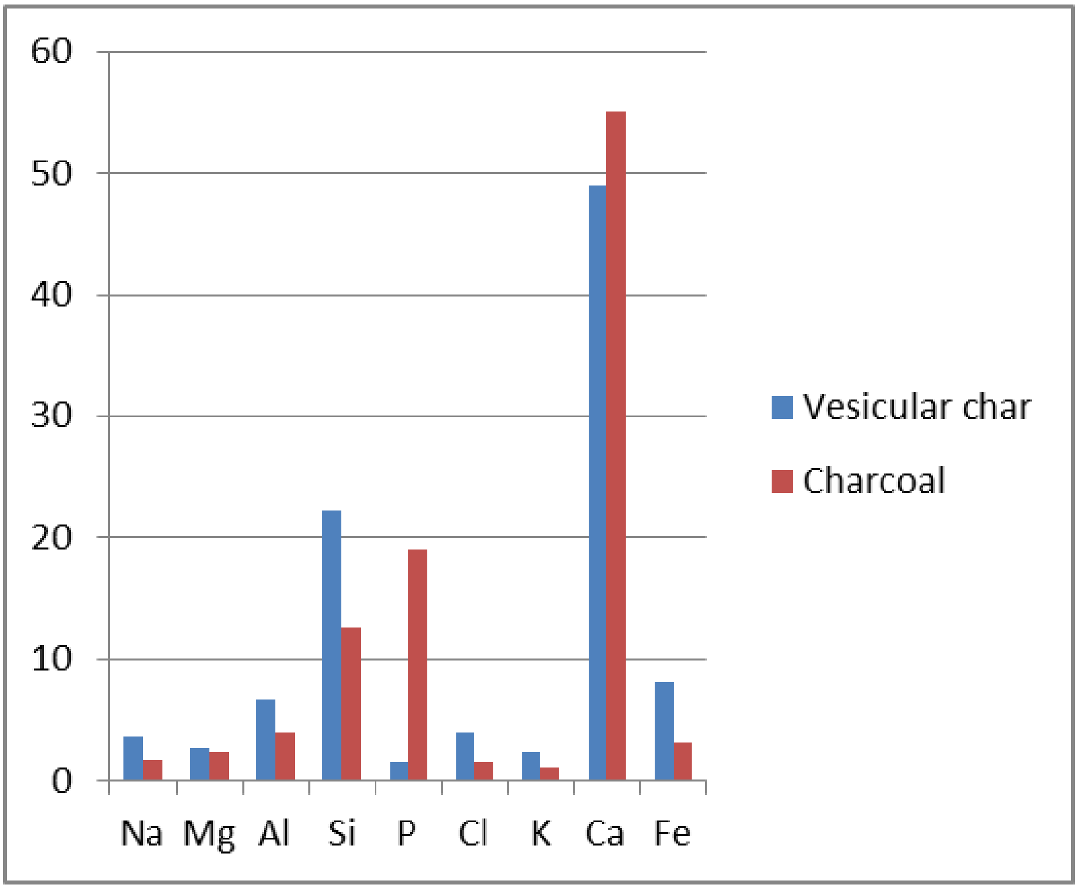


Figure 5.9: SEM EDX results for examination of vesicular char and charcoal in sample 109, context [9166], eastern recess structure 9.

EDX analysis was carried out targeting vesicular char from the eastern recess (sample 109, context [9124]). Two spectra were required from vesicular char and three from charcoal fragments for comparison. Chemically the two appear quite similar with high concentrations of Ca consistent with wood or peat ash (Braadbaart et al 2012), although the vesicular char contained greater proportions of Na, Mg, Al, Si, Cl, K and Fe than charcoal and less P and Ca. (figure 5.9). Statistically this can only be confirmed with P=0.83 but the sample size is very low and so that element loadings between two materials are different seems likely.

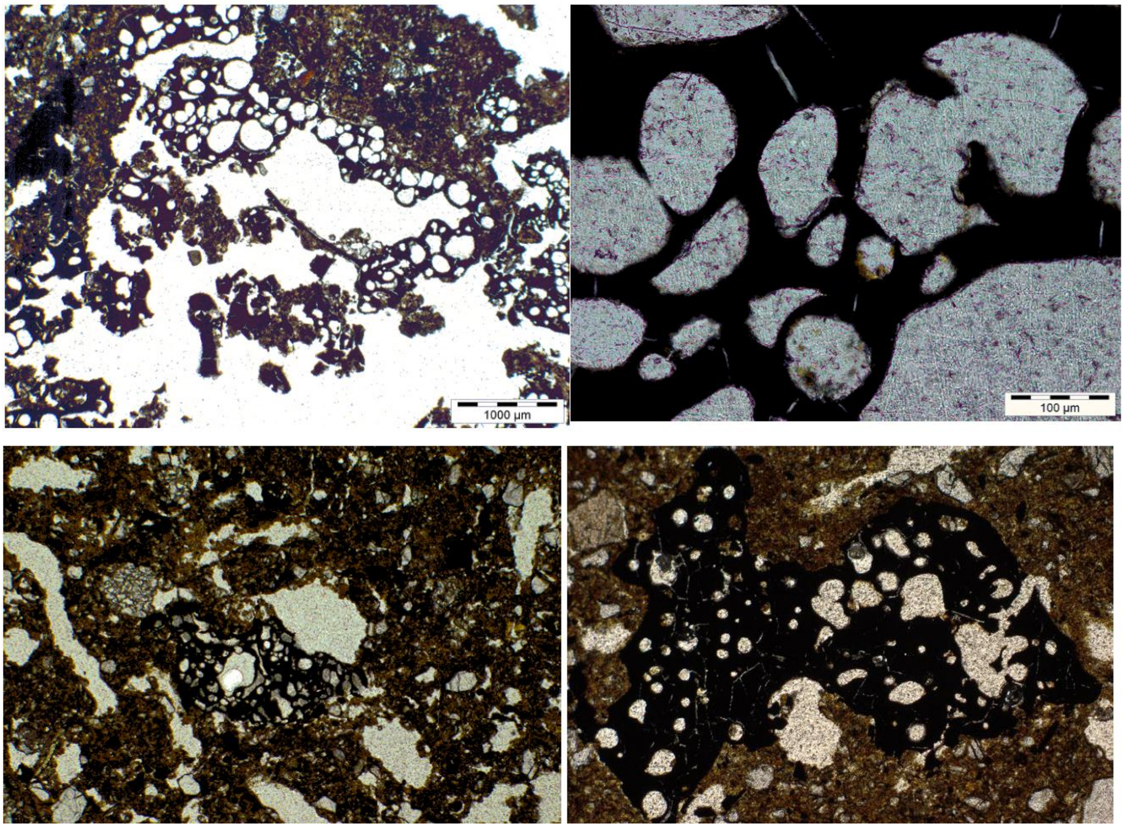


Figure 5.10: Vesicular char found at the Links of Noltland. Top left= sample 82, field bank. Top right = sample 86, pccupational sirface deposit. Bottom left = sample 109, interior floor, eastern recess, structure 9. Bottom right = detail 109. All images PPL.

The size and shape of the vesicles together with the colour and appearance of charr (figure 5.10) resembles burned bread discovered within the Roman temple at Kempraten, Central Switzerland (Pümpin et al 2013). This interpretation was also suggested by Dr Hall (University of York, *pers comms*) and so an experimental sample was manufactured from bread produced following hypothesized Neolithic methods (Haaland 2007). Beremeal from barley grown on mainland Orkney was combined with bacon fat and spring water and baked until it had turned black. This was then processed by the thin section laboratory at the University of Stirling and viewed in thin section under the microscope.

In thin section the burned bread sample exhibited a crack microstructure and was very dark brown to orangey brown (PPL) (figure 5.11). This is inconsistent with archaeological vesicular char and so an alternative explanation is sought. Material described as 'vitrified charcoal' has been recovered from archaeological sites across Europe from Roman and Medieval contexts (McParland et al 2010). The published descriptions are similar to the Links of Noltland samples but also exhibit charcoal morphology. To this extent it is hypothesised that the published descriptions may represent the partial formation of vesicular char structures. Up to date research indicates that these features are not formed through high temperature burning, re-charring, fungal degradation prior to burning, presence of resins, silica or compression (McParland et al 2010).

Instead a complex formation pathway is anticipated but poorly understood. One possible explanation is 'jetification' of wood (ibid.). This process involves 'mummification' or burial of wood, alteration and re-exposure (Kool et al 2009, McParland et al 2010). This is perhaps compatible with the changes incurred within wood cellular structures at sea before burning driftwood, futher experimentation would be needed to support this interpretation, but it seems a likely explaination given the composition of seawater and location of the site.

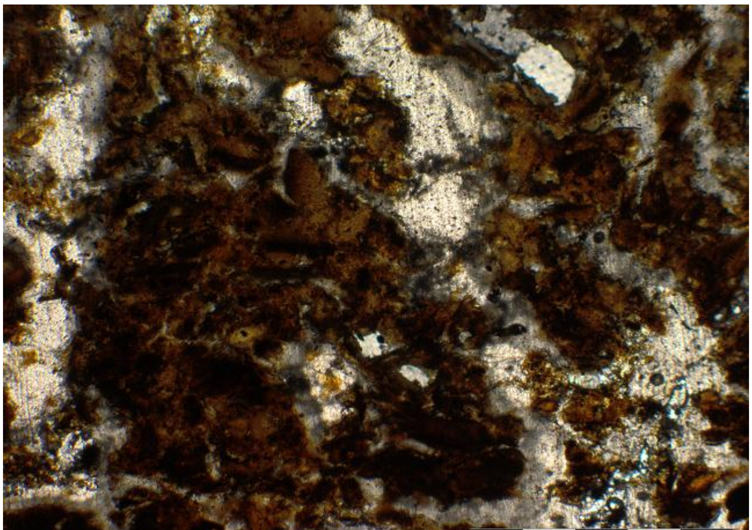


Figure 5.11: Burned bread experimental sample (PPL).

5.4.2 *Cramp*

'Cramp' from sample 106 and 77 (exterior floor deposits) were subject to SEM EDX analysis as they are atypical and are poorly understood features in geoarchaeology. Often described in relation to the Orcadian Neolithic, 'cramp' is a vitreous slag-like material found predominately at cremation sites (Photos-Jones 2007) but also in non-funerary contexts (Ritchie 1976). At the Links of Noltland, cramp was also specifically described in relation to burials and cremations (Moore & Wilson 2011b, 2012). However, within the thin section samples, lumps of vitreous glassy material containing vesicles measuring >1cm in diameter (figure 5.13) were observed structure 9, dumped deposits near to structure 7 (85 & 86), exterior occupational deposits in Area 5 (106), field bank (131) and hearth deposit (126) in structure 9 (figure 5.21). To test the hypothesis that this material is the substance known as 'cramp' found elsewhere in Orkney, SEM EDX characterisation was compared with published findings from funerary sites (Photos-Jones 2007). The major chemical elements of 'cramp' are thought to be dictated by mineral grains trapped in the matrix (Fleet 1976) but broadly SEM-EDX shows cramp glass is composed of Si, Al, K and Na with a small amount of Fe and P (Photos-Jones et al 2007). Findings from SEM EDX analysis of cramp from samples 109 and 77 concurred with this (figure 5.12) with Mg, Cl, Ti and Mn also present which is consistent with the chemistry described in the boulder clay control sample.

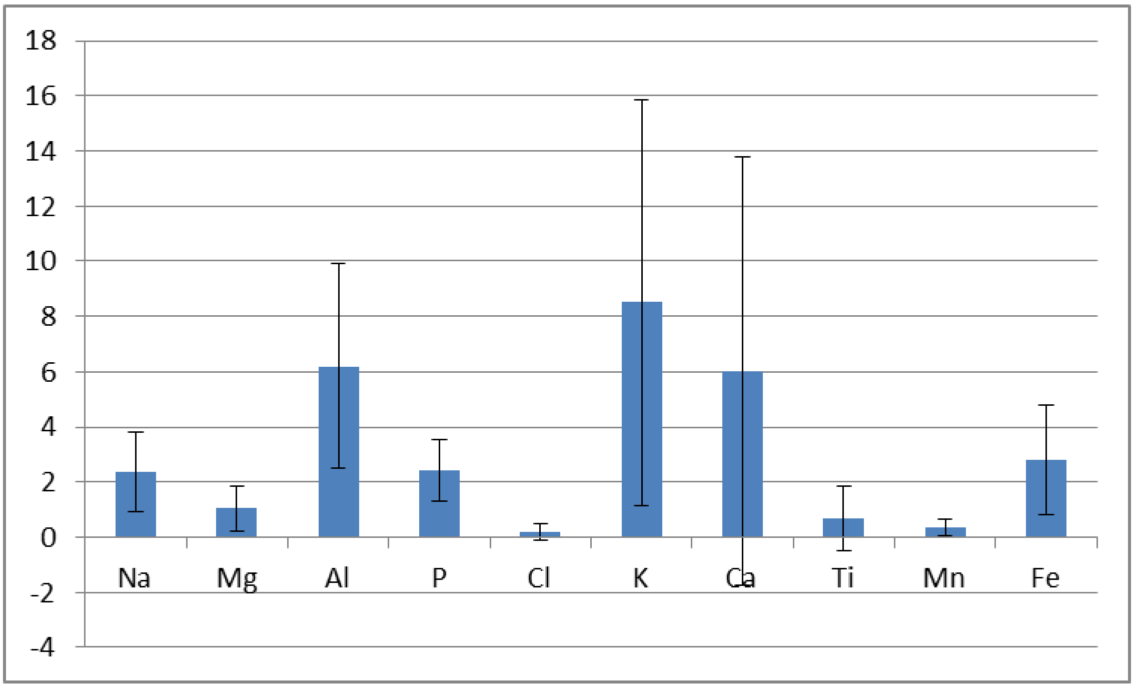


Figure 5.12: Results of SEM EDX analysis of cramp found in samples 109 and 77. Results in mean percent ratio, error bars = σ. Si is the main component contrib#uting 69.41 ± 15.82 (this is omitted from the graph to allow micro elements to be discerned)

The formation processes of 'cramp' are still poorly understood, but vitreous non-metal slag like material has been described at a Norse Farmstead at Bornais, South Uist (Milek 2005), a Saxon settlement at Flixborough, England (Canti 2003) and Frisa, Italy (Huisman et al 2013). Such materials are commonly thought to be produced by melting phytoliths associated with grass, cereals and dung (Macphail & Goldberg 2010).

Phytolith silica melts at temperatures in excess of 1500°C but this can be reduced with the use of alkaline flux (Canti 2003) such as could be manufactured from marine shell to create powdered $CaCO_3$. Huisman et al suggest that burning herbivore dung 'combines high silica-phytolith contents with high concentrations of alkalis and earth-alkalis' which creates the conditions to melt silica in domestic fires (Huisman et al 2013). They recorded high levels of Na and Mg in molten silica blocks. Photos-Jones et al (2007) found that burning sea-weed from Orkney also provided the necessary flux for melting silica derived from soil, silt and sand but makes a distinction between vitrified fuel ash slag and cramp; the former being a waste product and the latter a potentially intentionally manufactured material which necessarily incorporates cremated bone.

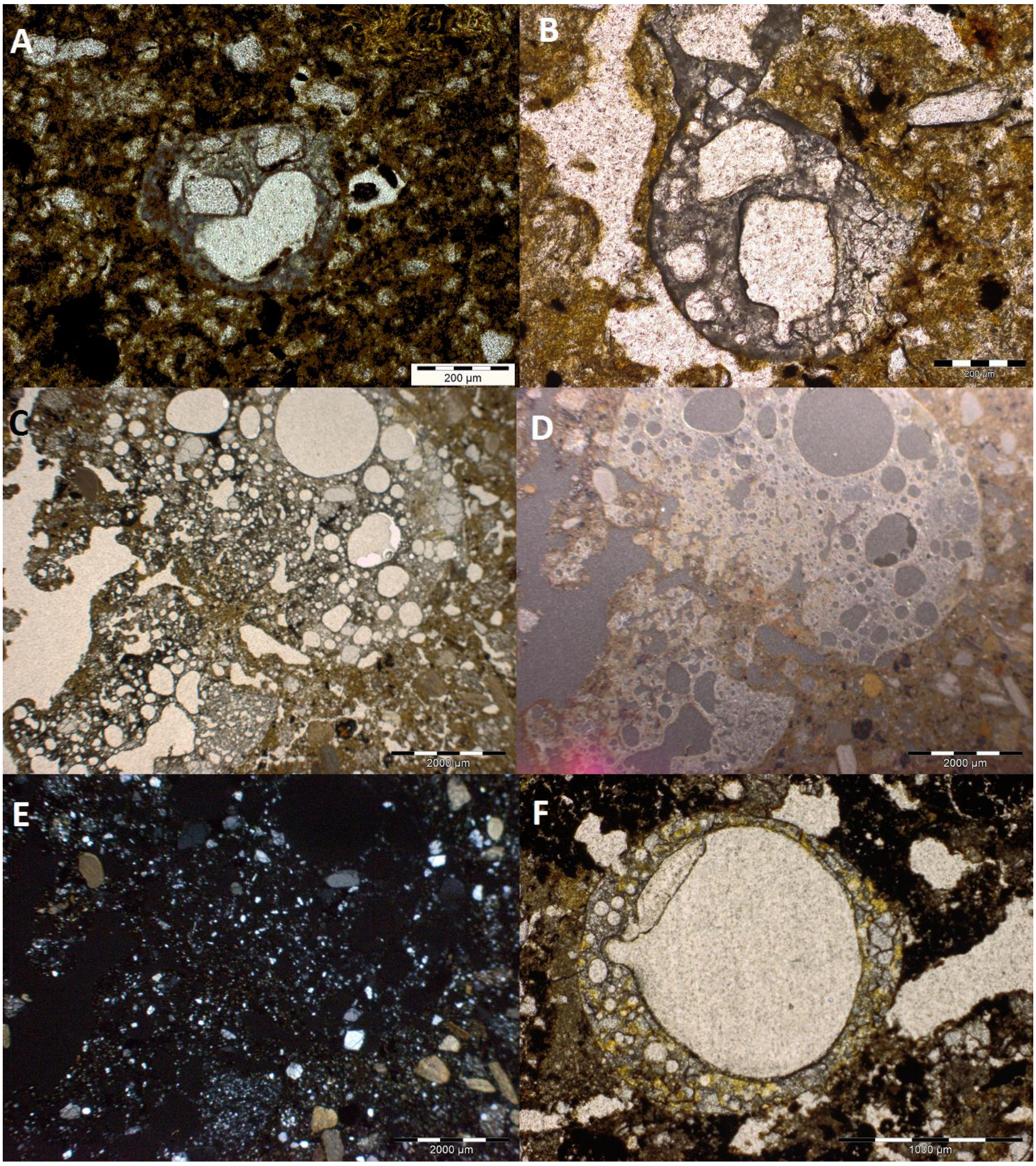


Figure 5.13: Cramp features in thin section. A) Sample 131, context [9058], 'field bank' (PPL). B) Sample 136, context [9174], 'dumped deposit' in Area 5 (PPL). C) Sample 85, context [9103/9105] 'dumped deposit' near structure 7 (PPL). D) As C, OIL. E) As C, XPL. F) Sample 77, context [8002], 'exterior occupational deposit' in Area 5 (PPL).

The features examined in thin sections 106 and 77 do not contain any discernible bone fragments but, viewed with the SEM, exhibit similar morphologies (figure 5.14). Additionally, a Pearson's correlation in SPSS demonstrated that a strong positive relationship exists between P and Ca (correlation is significant at the P=0.01 level) which is taken as evidence for the presence of bone in cramp (Photos-Jones 2007). Therefore, it would seem that the occurrence of cramp incorporated into the floor of structure 9 is surprising and atypical within a domestic context. It may have been incorporated into the floor through trampling. Cramp incorporated into dumped deposits may indicate that this material was mobile around the site. Incorporation of cramp into field boundaries might indicate the opportunistic re-use of waste material available in the immediate vicinity in construction or perhaps deliberate use of important ingredients.

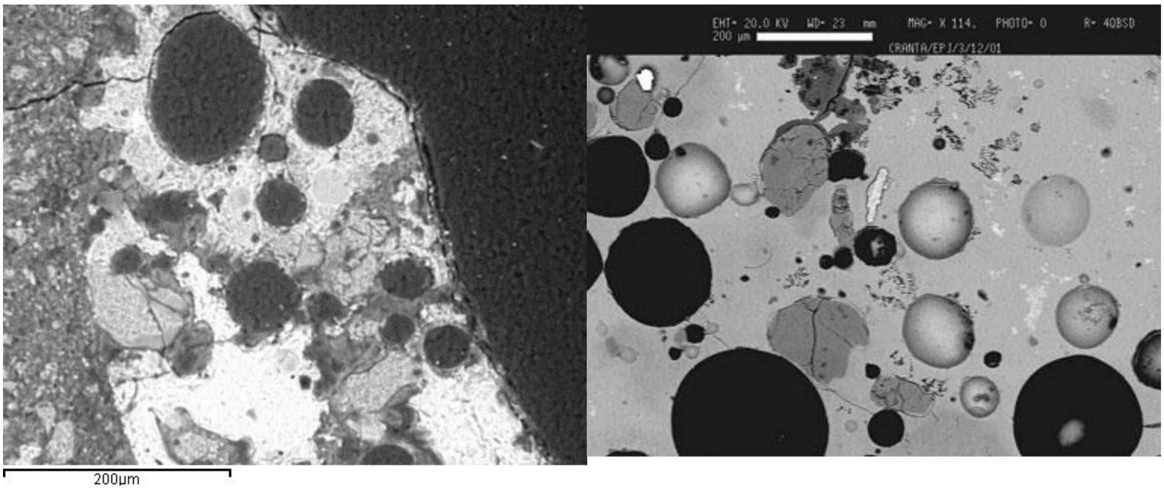


Figure 5.14: Left= SEM BS micrograph of cramp from sample 77, Links of Noltland. Right = SEM BS micrograph of cramp from Crantit cist (reproduced from Photos-Jones et al 2007).

5.4.3 *Clay aggregates*

Burnt, rounded clay aggregates were described in detail within structure 9 hearth but were also recorded in interior floor deposits, exterior occupational deposits, dumped deposits, ground surfaces, field bank and cultivated soil groups. Similar features have been described in colluvial settings as products of transportation (Fedoroff et al 2010) and also in cultivated soils (Lewis 2012). Both formation pathways involve high-energy dragging and mixing of clay-rich soils and so the widespread occurrence of these features across the site seems unusual. Their distinct rubification in OIL indicates these features have been subjected to heating and so are perhaps comparable to sub-rounded burned clay aggregates found in association with fuel residues and burned bone in Late Neolithic midden at Ḉatalhöyük, Turkey and interpreted as hearth ‘rake-out’ (Shillito et al 2011, Shillito & Matthews 2012). Certainly, they represent some form of mechanical scraping of burned sandy clay material which is consistent with hearth or oven rake-out. A subset of clay aggregate type material is also recorded in the sand and glacial till controls. These are well rounded and appear related to aeolian transportation (sand) and glacial action (glacial till).

5.4.4 *Phosphatic features*

Phosphatic features were identified as yellow mammillate nodules (figure 5.15) set within an orange clay matrix. The nodules exhibited an undifferentiated b-fabric and an amorphous or cryptocrystalline internal fabric which has trapped clay particles (figure 5.16). Exposure to UV light revealed many of them were autofluorescent (Karkanas & Goldberg 2010). Further examination using SEM EDX confirmed the elemental fabric of these nodules to be composed of Al, Si and Fe macro-components (figure 5.17) and Na, Mg, P, S, Cl K, Ca and Ti micro-components (figure 5.18). Phosphate nodules are consistent with the presence of anthropic activities (Karkanas & Goldberg 2010), often forming through alteration of bone, ash and human waste (ibid.). In alkaline soils, such as the calcareous environment at the Links of Noltland, Phosphorous (P) is expected to bind with calcium ions to produce Ca-phosphates (Holliday 2004). However, a simple Pearson correlation in SPSS on SEM EDX data demonstrated a positive and significant (P=0.013) relationship between P and Al, but not between P and Ca. Al-phosphates can replace Ca-Al phosphates with increasing apatite diagenesis (Karkanas & Goldberg 2010) and so it seems likely that the phosphatic nodules are the result of prolonged chemical alteration. It is not possible to say how long this process took, but the morphology and chemical composition of these features is close to those described in severely altered Palaeolithic cave sediments (Karkanas & Kyparissi-Apostolika 1999) and phosphatic nodules can form in calcareous environments (Carreira et al 2006). The orange clay in which the nodules have formed is fragmented and surrounded by aeolian shell sand. The formation materials can be described as Fe-rich clay and phosphate-rich anthropic inclusions, probably bone derived. Therefore this may represent omnivore coprolite material.

Dog coprolites have been reported in a similar context at Cladh Hallan where they were gathered up and dumped into disused buildings (Parker-Pearson et al 2001). Both pigs and dogs are evidenced at the Links of Noltland (Fraser 2011).

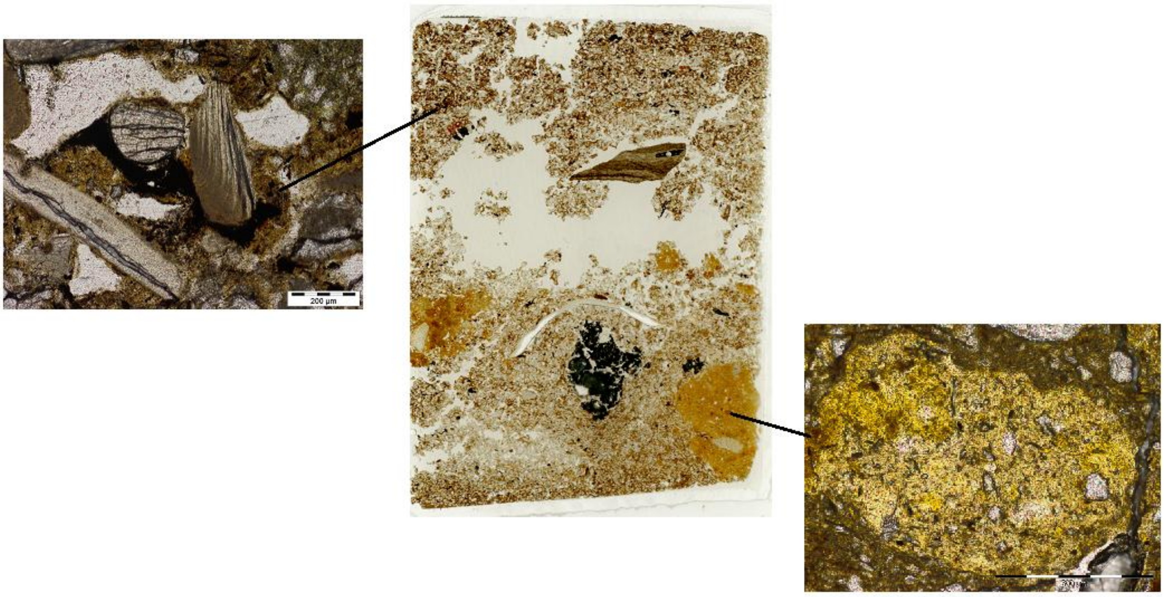


Figure 5.15: Thin section scan of slide 197. Left= black amorphous pendant coating of aeolian shell fragments (PPL). Right = Phosphatic nodule (PPL).

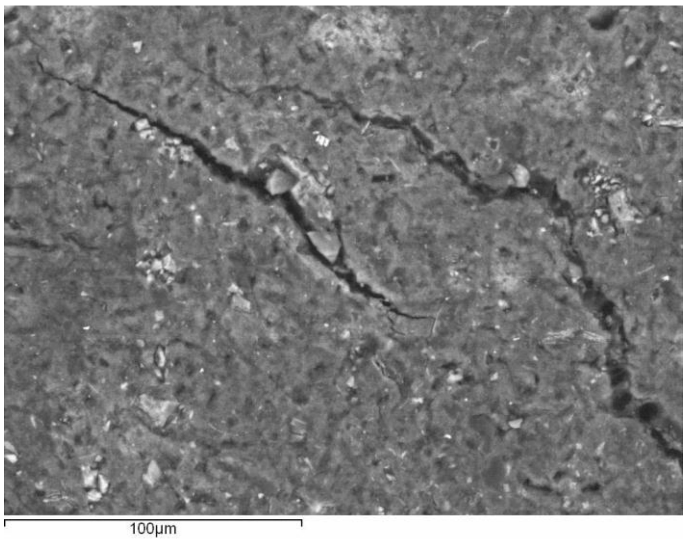


Figure 5.16: SEM micrograph of phosphatic nodule fabric containing mineral grains.

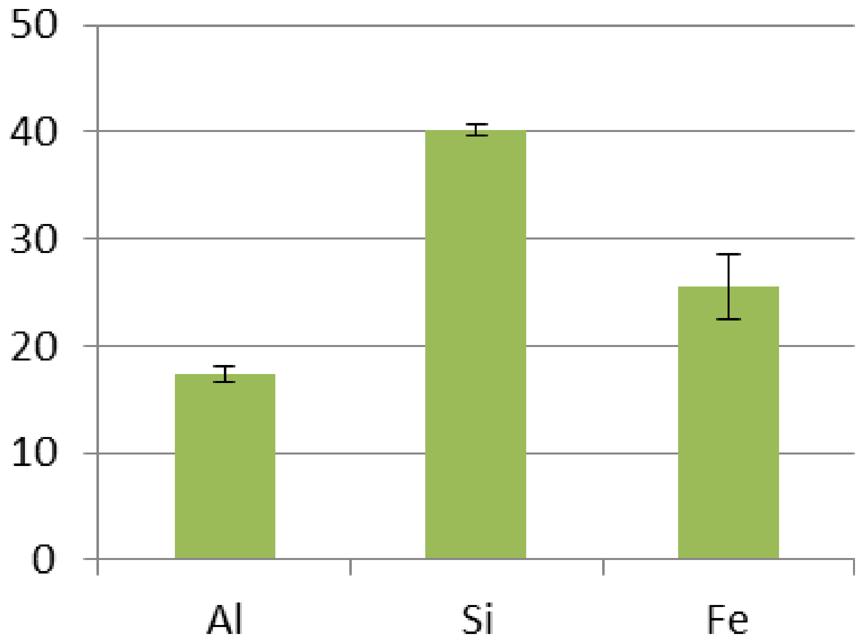


Figure 5.17: Macro elements present in phosphatic nodules in sample 197. (SEM EDX results, average % ratio, error bars = σ of the sample, n=10 spectra)

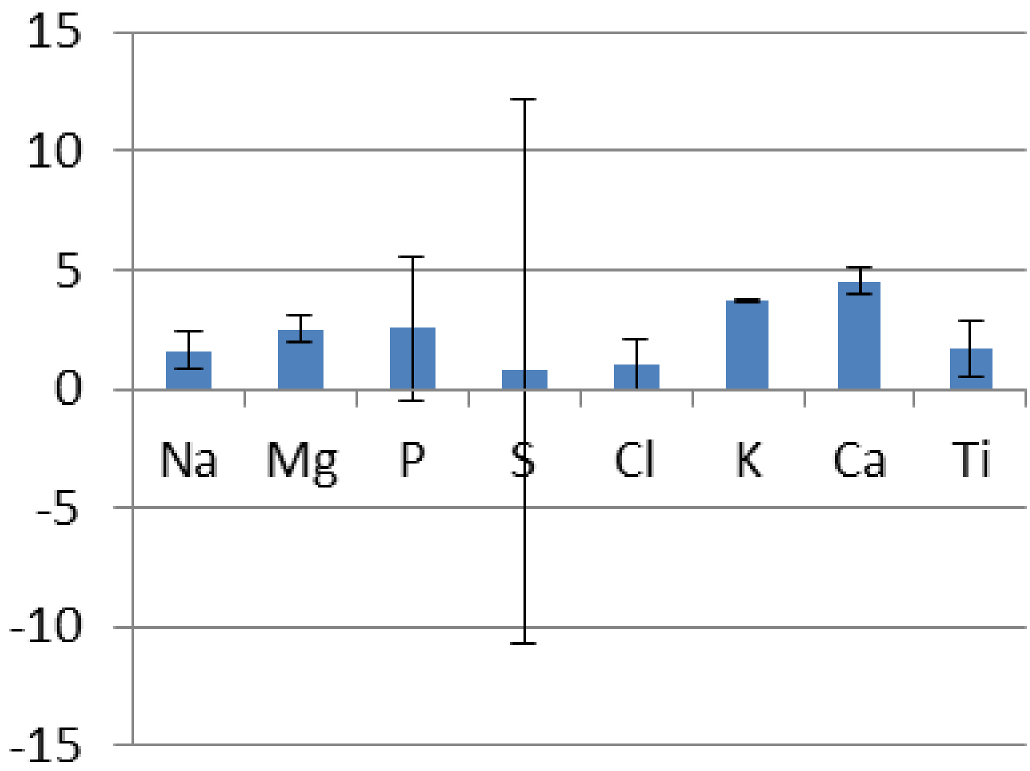


Figure 5.18: Micro elements present in phosphatic nodules in sample 197. (SEM EDX results, average % ratio, error bars = σ of the sample, n=10 spectra)

5.5 Anthropic sediments at the Links of Noltland

Thin section description tables are presented in Appendix III.

5.5.1 *Foundations*

This thin section was manufactured from Kubiëna tin sample 113 collected from material beneath structure 12. In the field the context was described as brown sand forming an old ground surface. In thin section Aeolian shell sand is dominant (c.50%, figure 5.19) with heavily weathered quartz grains contributing a further c.40% ratio of the slide area.

Fine material is brown organo-mineral (PPL), light yellowish brown in OIL but contributes to <7% of the slide. The microstructure is therefore described as bridged grain enaulic with random, well sorted coarse grains.

The birefringent fabric is crystallitic, reflecting weathering of quartz minerals. Charcoal was picked out during point count analysis and contributes <1% of the slide, but is not compelling evidence for an anthropic sediment. Amorphous black organic material also contributes <1% of the slide which is a similar level to the Aeolian sand control. The foundations for structure 12 appear to be composed of unstable, blown sand with little evidence of a land surface or succession of vegetation.

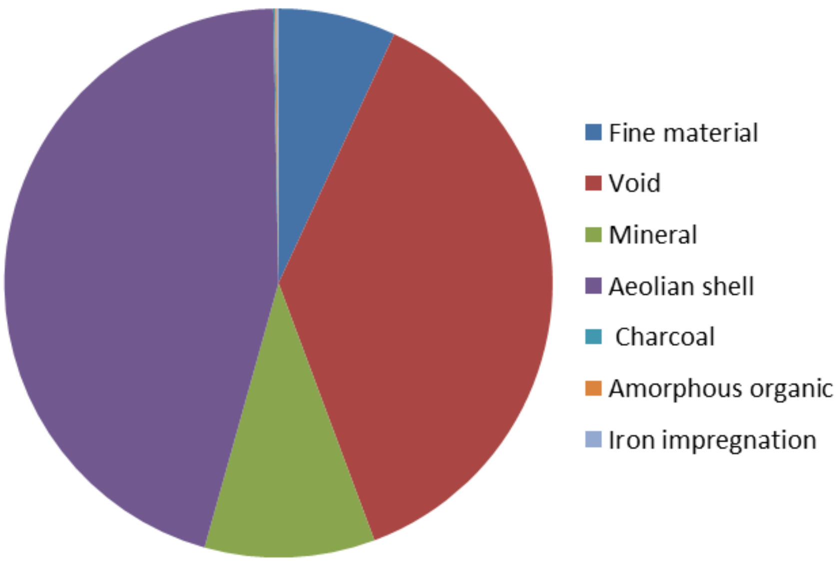


Figure 5.19: Point count results for foundations sample.

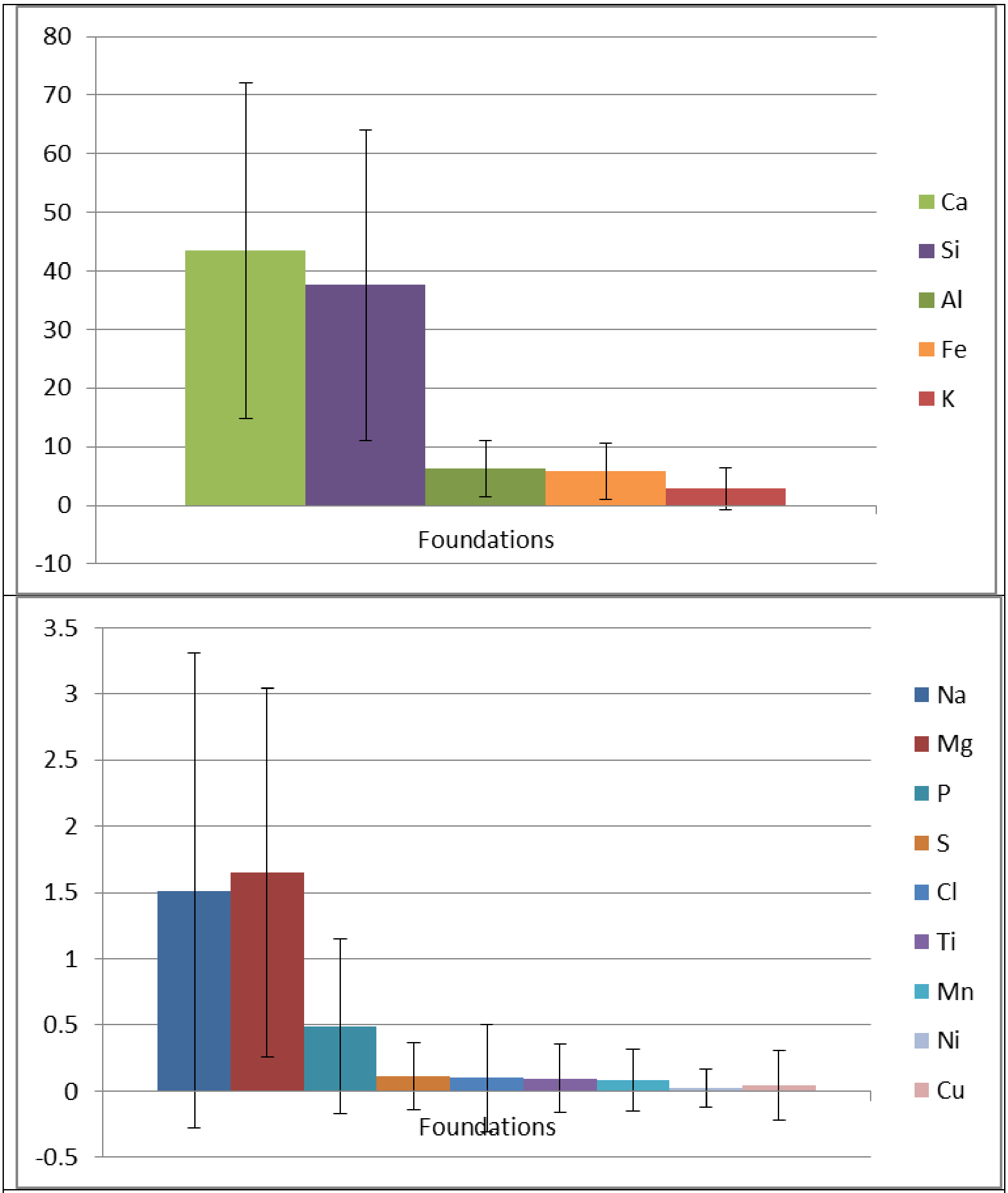


Figure 5.20: SEM EDX results for foundation deposits in structure 9. Top = Macro elements, Bottom = Micro elements. Results expressed in mean percent ratio, error bars = σ.

5.5.2 *Interior floor deposits*

Samples were collected from interior floors within structure 9 (101,109, 110, 127 and 128) and structure 13 (178 and 179)

The two interiors were described very differently in the field and this is reflected in the micromorphological observations.

Structure 9

Samples from structure 9 were collected from the eastern and western recesses and the central floor (figure 5.21). The sediments in the Eastern recess were described in the field as dark red brown silty clay [9118] (top) and dark brown-black ashy soil [9166] (bottom), sample 109 intercepted the boundary between these two sediments and it is clearly discernible in thin section as a sharp difference between lighter brown microstratigraphic unit A and darker microstratigraphic unit B (PPL) with a wavy morphology (figure 5.22). Both units share microstructures characterised by channels, chambers and vughs, indicating soil faunal activity. Coarse minerals are consistent with the local geology and are randomly arranged and moderately to poorly sorted within an open porphyric coarse fine related distribution. Both units share a stipple speckled microcrystallitic birefringent fabric related to coarse mineral weathering.

Unburned turf fragments are present within unit B (1-5% of the unit). Anthropic materials are present in greater amounts in microstratigraphic unit B whilst unit A contains more pedofeatures related to Fe/Mn movement. This may imply the development of the active and reactive floor layers described by Gé et al (1993) and Simpson et al (1999). Sandy (<1%) and silty (2-5%) infill pedofeatures occur with greater frequency in unit A and anthropic inclusions of unburned bone (1-5%), burned bone (<1%), vesicular char (<1%), charcoal (<1%), charred plant material (<1%) and burned peat (<1%) are fragmented and appear to have moved down profile from unit A with sandy and silty material to form pedofeatures. This, together with levels of Fe/Mn related pedofeatures which are higher than the control samples is persuasive evidence for a reactive in situ occupational floor.

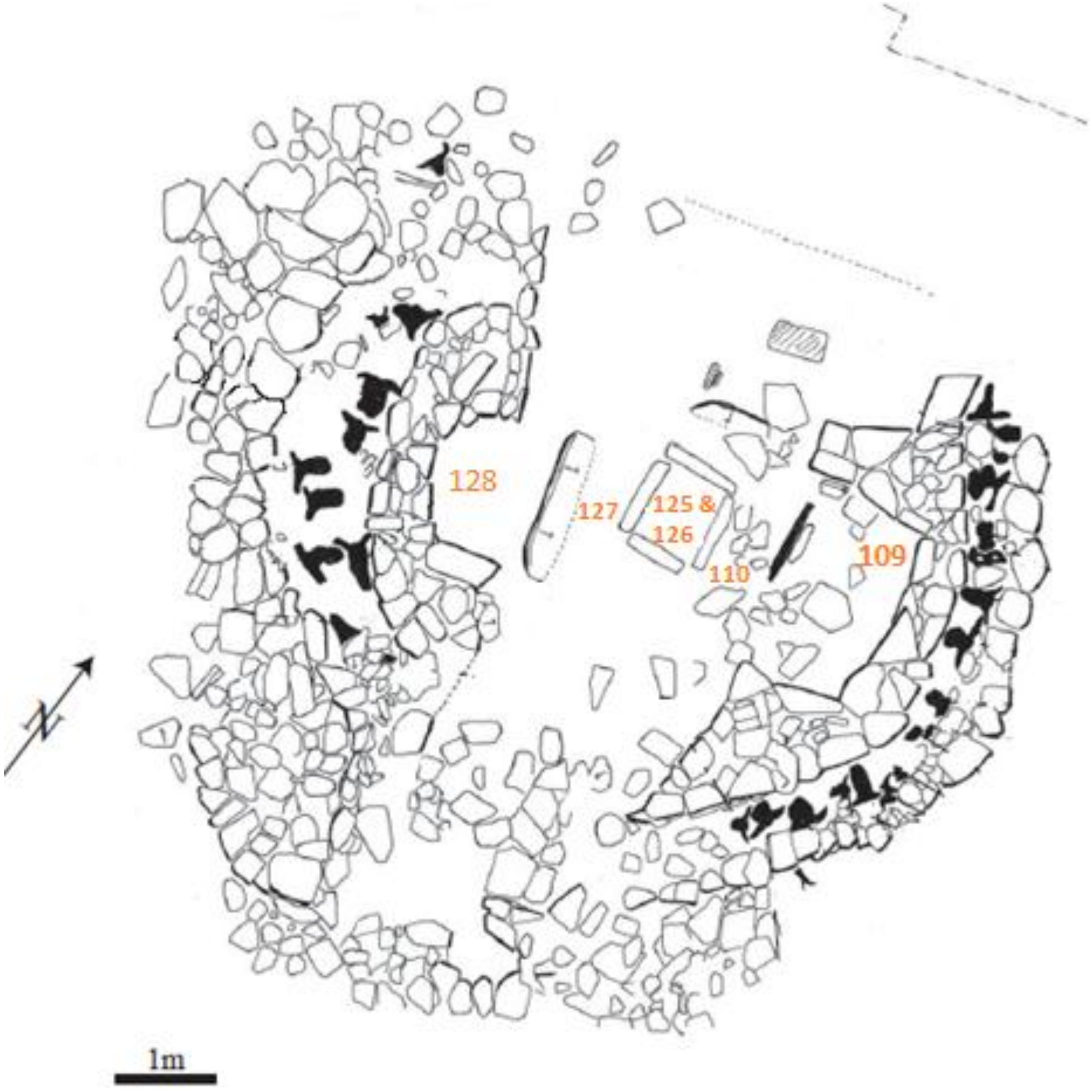


Figure 5.21: Structure 9 interior plan showing approximate locations of samples. Image adapted from Moore & Wilson 2011b

The active zone has collected many more anthropic inclusions. Vesicular char contributes 15-30% whilst charcoal and charred plant each (5-15%), burned peat (<1%), burned turf (1-5&) and unburned bone (<1%) make up the remainder.

There was no micromorphological evidence for ash, although the fine material hues dark orangey brown in OIL which might indicate a peat ash component (Guttmann et al 2005).

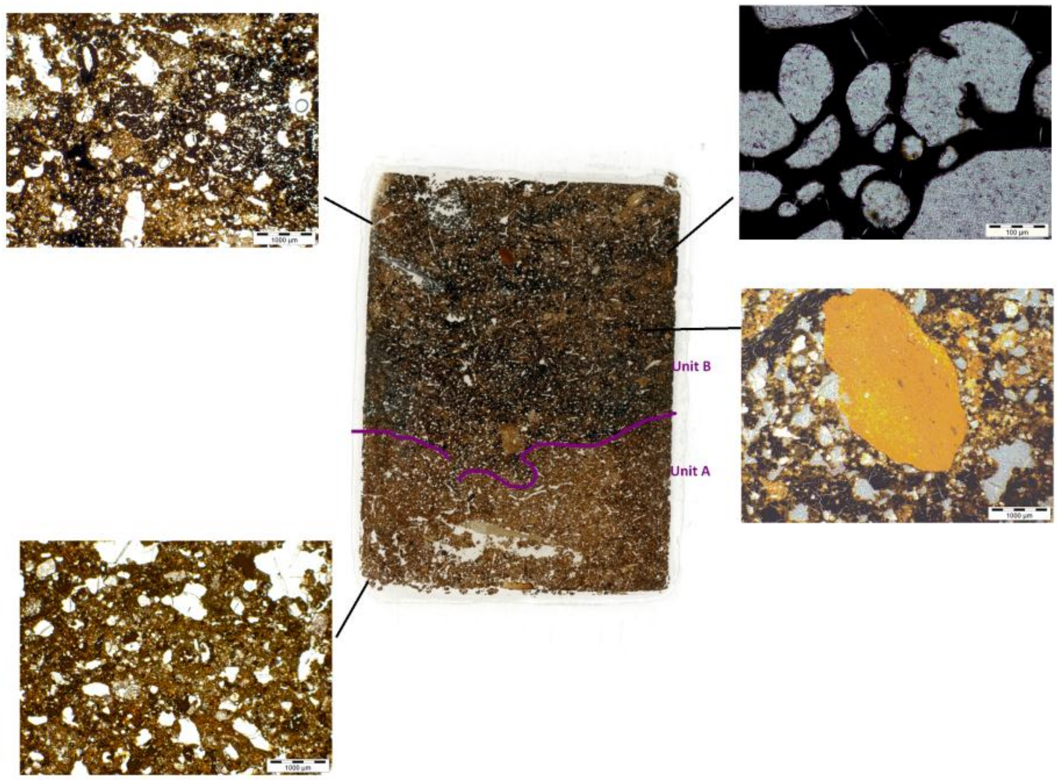


Figure 5.22: Thin section scan, sample 109 demonstrating boundary between microstratigraphic units A and B. Left of slide: bottom = ground mass unit A (PPL), top = ground mass unit B (PPL). Right of slide: bottom = rubified mineral (OIL), top =vesicular char (PPL).

The sediment in the western recess [9119] described as an ashy floor deposit in the field, was very thin and so sample 128 was collected horizontally to identify anthropic inclusions. As sediments exist in three dimensions, it was possible to ascertain that sediments in the eastern and western recesses share a similar microstructure characterised by vughs and channels, sample 128 also contained cracks which are usually taken as evidence for sediment drying (Kovda & Mermut 2010). No evidence for ash preservation was found in thin section. However, the fine material is greyish brown organo-mineral (PPL) (dark yellowish brown in OIL) indicates depletion pedofeatures (2-5%) may be responsible for the ashy texture described in the field.

Anthropic inclusions in the western recess are vesicular char (<1%), woody charcoal (1-5%), charred plant remains (1-2%), burned peat (5-15%) and burned bone (1-5%).

The central floor sediments were described in the field as firm, brown clay loam [9189] to the east of the hearth and black-brown silty clay [9173] overlying firm brown clay loam [9189] to the west of the hearth. Sample 110 was collected from the east sediments and sample 127 from the west (figure 5.23).

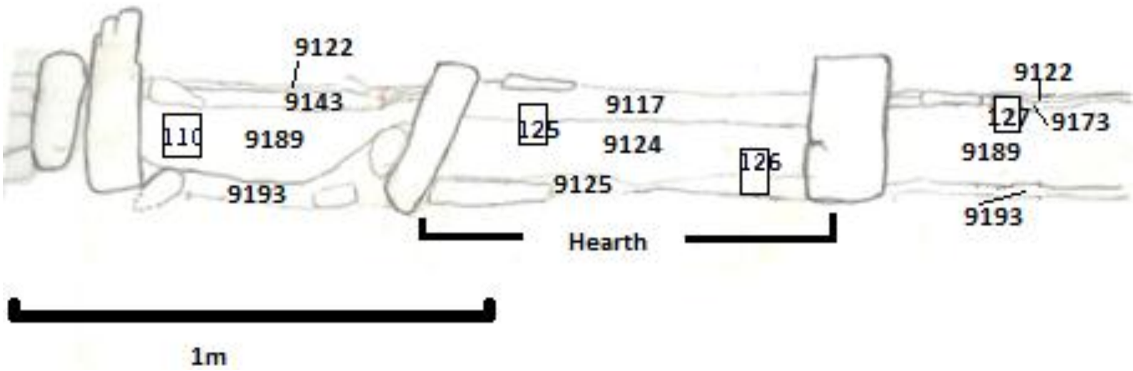


Figure 5.23: East-west section drawing of hearth and central floor sediments in structure 9. Courtesy of EASE.

In thin section, sediments share microstructures characterised by deformed channels and poly concave vughs which indicate soil faunal activity followed by compaction indicating higher levels of activity around the hearth than within the recesses. However, unlike the recess sediments, the central floors contain an element of aeolian marine shell fragments. These occur as traces (<1%) or very few (1-5%) accumulations throughout the area of each slide (point count results indicate this is 0.22% of central floor samples) indicating that the sediment was formed whilst aeolian shell sand was a feature of the landscape but this was kept out of the structure interior.

To the east of the hearth, fuel residues are limited in sediment [9189] contributing <1% of the area of microstratigraphic units A & B compared with 8-30% to the west of the hearth (microstratigraphic unit A). Fuel residues are mixed, comprising peat/turf, charcoal, charred plant (derived from heath-like plants), vesicular char and peat ash. Bone and burned bone fragments are also present in sediment [9189], though in greater quantities in the western sample (127). Burned bone fragments exhibit indicators of medium to high intensity burning

(Hanson & Cain 2007) with partial loss of histology, carbon deposits and calcination observed at edges of fragments.

A phosphatic nodule was observed in sample 110 (figure 5.25), this was verified as autofluorescent using UV exposure.

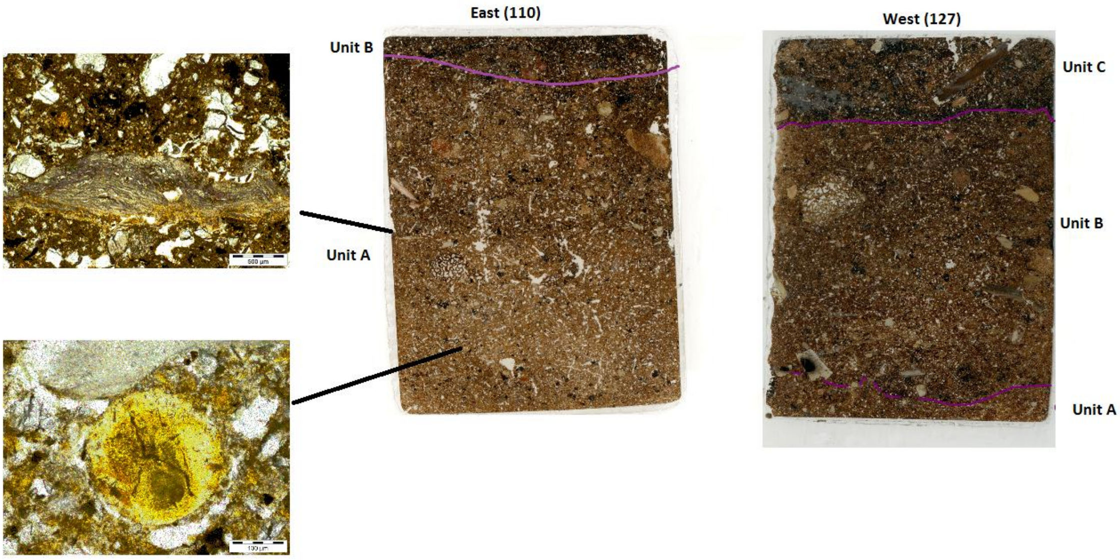


Figure 5.24: Thin section scans of slides 110 and 127. Micrographs: top = fibrous ash (PPL), bottom = phosphatic nodule (PPL).

Silty and limpid clay pedofeatures are present within both samples of sediment [9189] indicating low energy down profile movement of fine material, this has filled pore spaces within the microstructure and within bone and charcoal fragments but is unrelated to cracks. This together with orthic iron nodules indicates that the sample was moist allowing the precipitation of iron and movement of clay particles. The profile later dried out, forming cracks and iron nodules. The moisture in this sediment is unlikely to have accumulated through exposure to rain as aeolian sand particles are rare. This indicates the structure was roofed as the sediment accumulated, but the floor was damp for a period.

The boundary between sediments [9189] and [9173] is visible in both samples and is particularly sharp in sample 127 where a layer of peat fuel residue forms a layer resting upon the surface of [9189]. This indicates that fuel residues were spread over the surface of sediment [9189] before the formation of [9173]. In thin section sediment [9173] is termed

Unit B in sample 110 and Unit C in sample 127. The microstructure continues on from [9189] as compact with compressed channels and poly concave vughs indicating soil faunal activity and subsequent compaction of the unit. The distribution of coarse and fine material is open or close porphyric and fine material is dark brown (PPL) organo-mineral, mottled with orangey/yellowish brown (OIL).

Sediment [9173] is more easily distinguished in sample 127 where anthropic inclusions of vesicular char (<1%), woody charcoal (5-15%), charred plant remains (1-5%), burned peat (15-30%) and burned bone (1-5%) are indicated along with a fragment of possible burned cow dung (<1%). Turf fragments (1-5%) are included in the sediment along with siltstone rock fragments (5-10%) indicating that the formation process active in sediment [9189] continued through to [9173]. This suggests that the floor was an active 'living floor', into which allochthonous debris were incorporated and allowed to remain. Some weak striation of birefringent fabric further supports the interpretation of a 'beaten floor' (Macphail & Goldberg 2010) developed upon a lightly prepared surface of fuel residues.

Amorphous black material (1-5%) and punctuations (1-5%) are also present in the sediment, intermixed with Fe/Mn accumulation (2-5%) and psuedomorphic ferruginous pedofeatures (<1%). Both indicate a reducing environment typical of most compacted sediments (Lindbo et al 2010).

Platy microstructures are normally observed in occupational floor layers (Courty et al 1989, Milek 2012) however, bioturbation by soil faunal activity may have removed this. Soil faunal activity has been observed to begin following exposure to sunlight (Milek 2012) which would suggest that the building became unroofed. However no evidence for collapsed roofing material was noted in thin section. The consistent levels of amorphous organic material and punctuations present within the floor samples may help to explain the high levels of bioturbation. This may also hint at organic floor coverings which have been comminuted.

Floors within structure 9 are predominately composed of organo-mineral derived fine material (47.31 ± 5.20 percent ratio) and coarse minerals (19.26 ± 2.93 percent ratio) with minor anthropic inputs (combined mean of all anthropic materials = c.8.35 ± 11.23 percent ratio).

The observed differences between alcoves and the central floor indicate that the central floor is more compacted. Porosity is 14% east of the hearth and 6% west of the hearth compared with 22% in the eastern alcove and 16% in the western alcove. Also, anthropic inclusions are proportionately higher in the western central floor (20%) than the eastern central floor or either east or west alcoves (4%, 7% and 5% respectively) indicating that floors across the whole interior were kept free from debris with the exception of the western central floor area. SEM EDX analysis indicates that all samples are enriched in P and Ca relative to the glacial till control (figure 5.26). This was shown as statistically significant ($p=0.05$) using a Kruskall-Wallis test with pairwise comparisons. Within the structure, phosphorous enrichment was statistically significant between the east alcove and west alcove and between east central floor and west central floor. Calcium enrichment was statistically significant between the west alcove and the east and west central floor and the east alcove (a [9166] and b [9118]), and between the west central floor and east alcove (b). This is consistent with the distribution of bone material as the west alcove and west central floor contain 3.4% and 3.35% (respectively) unburned bone and 0.10% (both) burned bone compared with the 0.2% (unburned) bone found in the east alcove and none in the east central floor (point count results).

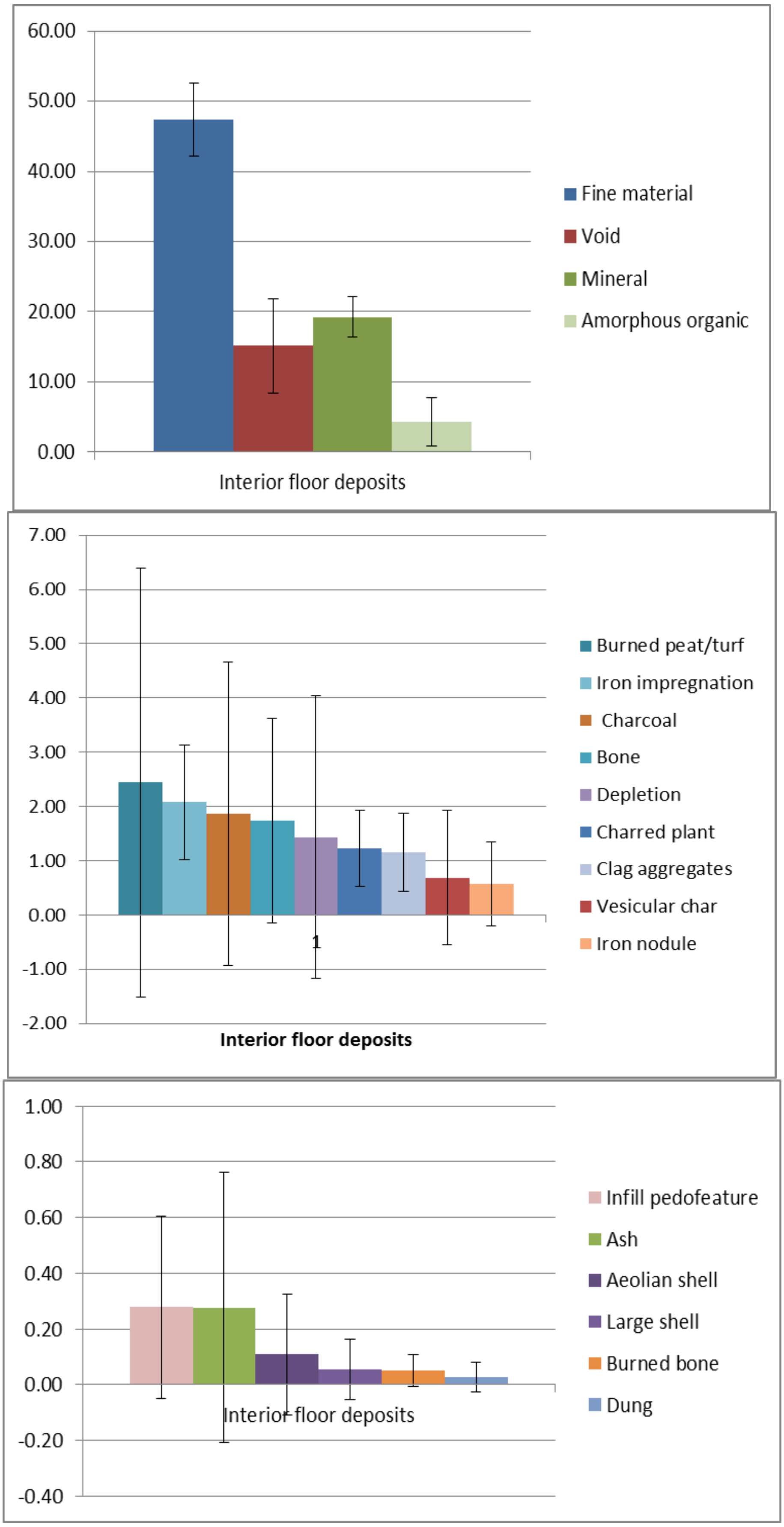


Figure 5.25: Point count results structure 9 'interior floors'. Top, macro-components. Middle, intermediate components. Lowest, micro-components

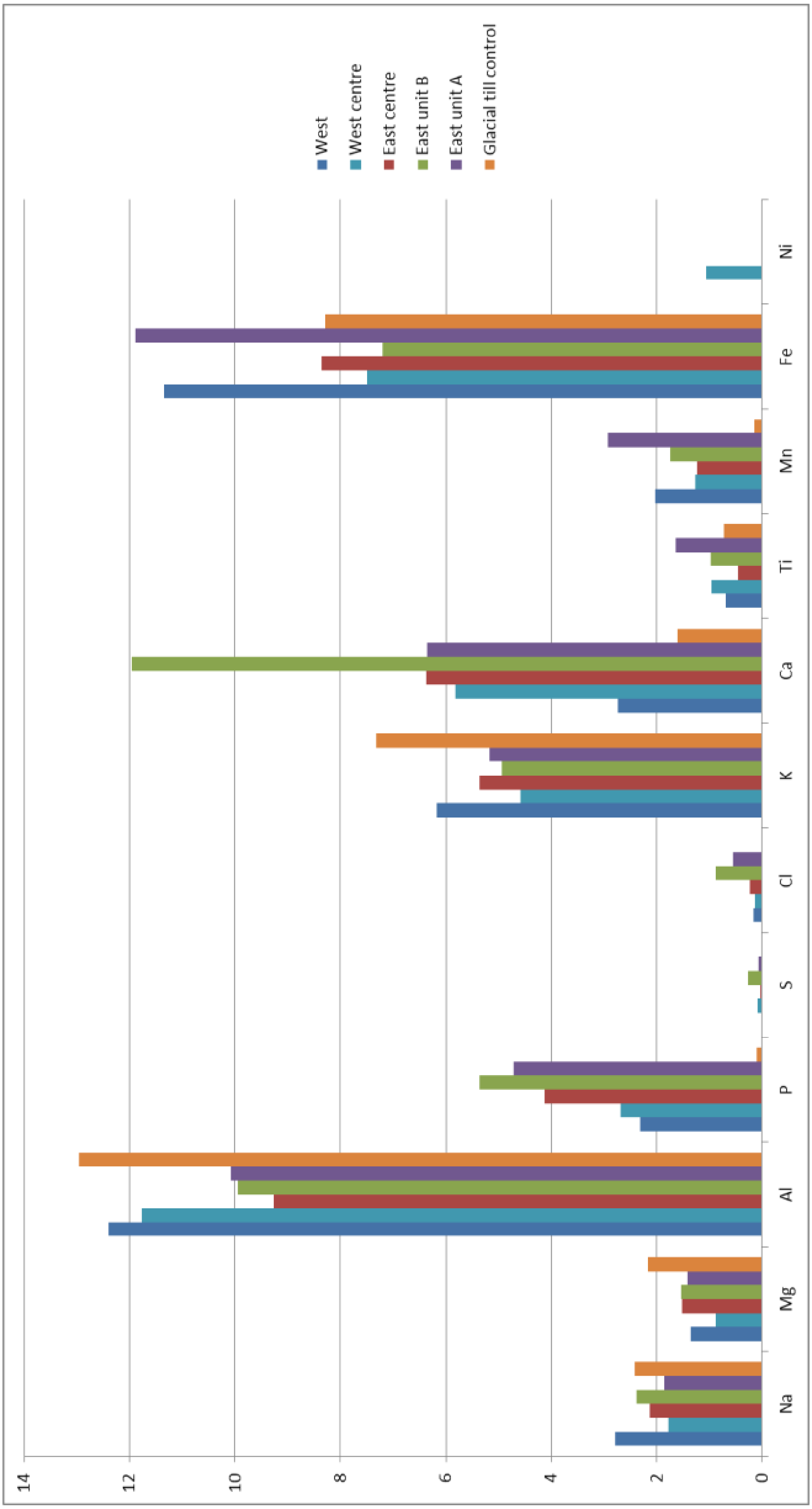


Figure 5.26: SEM EDX results for each sample in structure 9. Si is omitted. Results expressed in mean percent ratio.

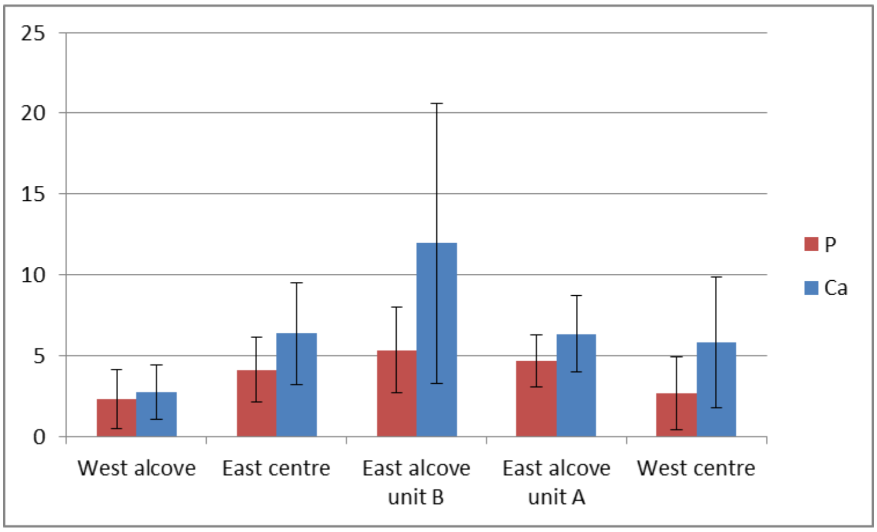


Figure 5.27: Detail of figure 5.26, SEM EDX results for Ca and P in structure 9 interior. Results expressed in mean percent ratio, error bars = σ

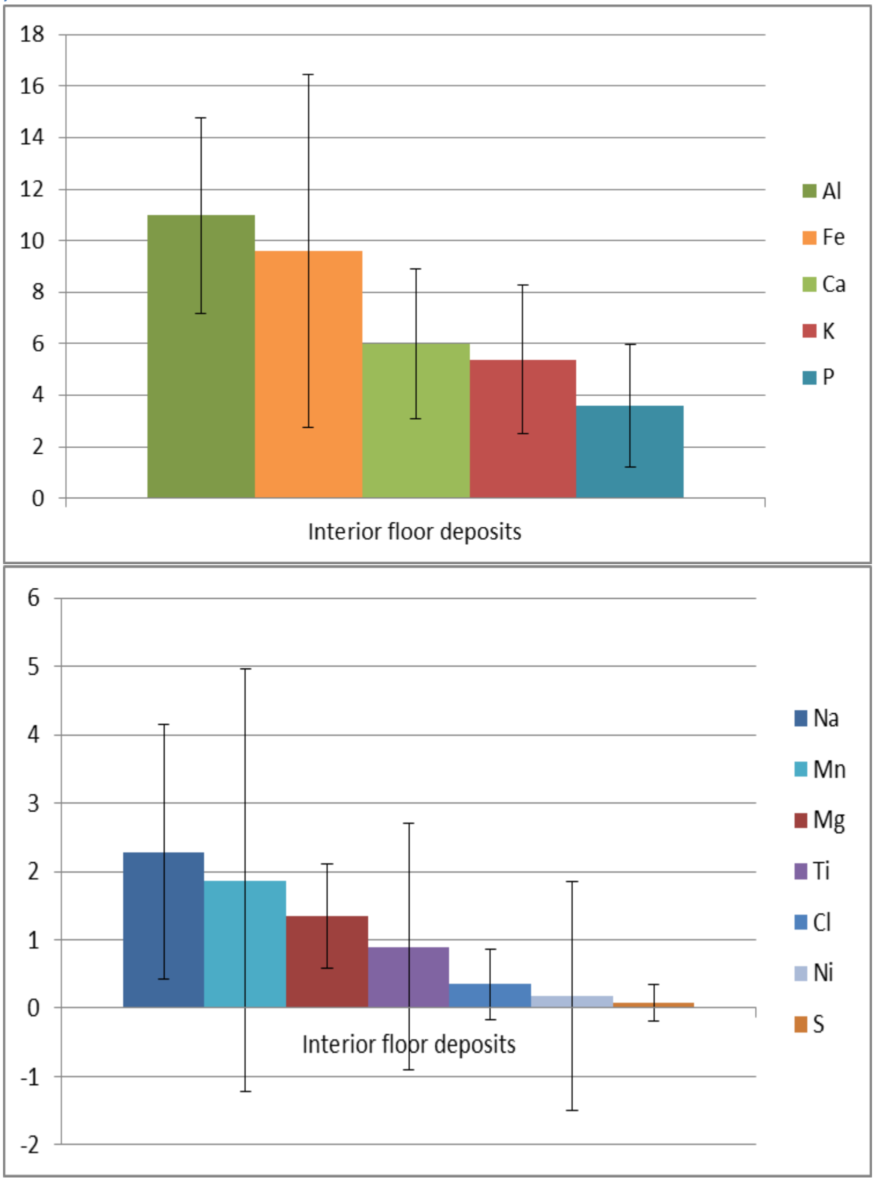


Figure 5.28: SEM EDX results for interior floor deposits in structure 9. Top = Macro elements, Bottom = Micro elements. Results expressed in mean percent ratio, error bars = σ. Si not included, this is the main component at 57.47 ± 14.09 percent ratio.

Structure 13

Samples 178 and 179 were recovered from a firm pale brown sandy clay sediment interpreted as an occupational deposit [9610] which lay directly on paving stones within structure 13 (Moore & Wilson 2013) (figure 5.29).

Figure 5.29: Internal sediments, structure 13. Image adapted from section drawing, courtesy of EASE.

This sediment was just clipped in sample 179 but was well represented in sample 178 (figure 5.29). In thin section, sediment [9610] exhibits a complex microstructure characterised by packing voids, intergrain microaggregates and discrete aggregates of cracked dark brown organo-mineral fine material (PPL), which is brown and orange in OIL indicating peat ash content. This gives an enaulic related distribution with random well sorted coarse minerals. The sediment is composed of marine shell sand (15-30%), quartzite (1-5%), mica (<1%) and large rock fragments (1-5%). Anthropic inclusions comprise charcoal (<1%), charred plant (1-5%), burned peat/turf (<1%), unburned bone (<1%), pottery (<1%), rubified minerals (1-5%) and the clay aggregates interpreted as hearth rake out. This indicates a mixed sediment composed of fuel waste and broken artefacts.

A pebble sized aggregate composed of rubified fine material containing quartz grains and herbivore dung fragments (figure 5.31b) is interpreted as some form of dung and turf mixed fuel residue, though it is not possible to say whether this represents the anthropogenic formation of dung-cake (Fenton 1985) like material.

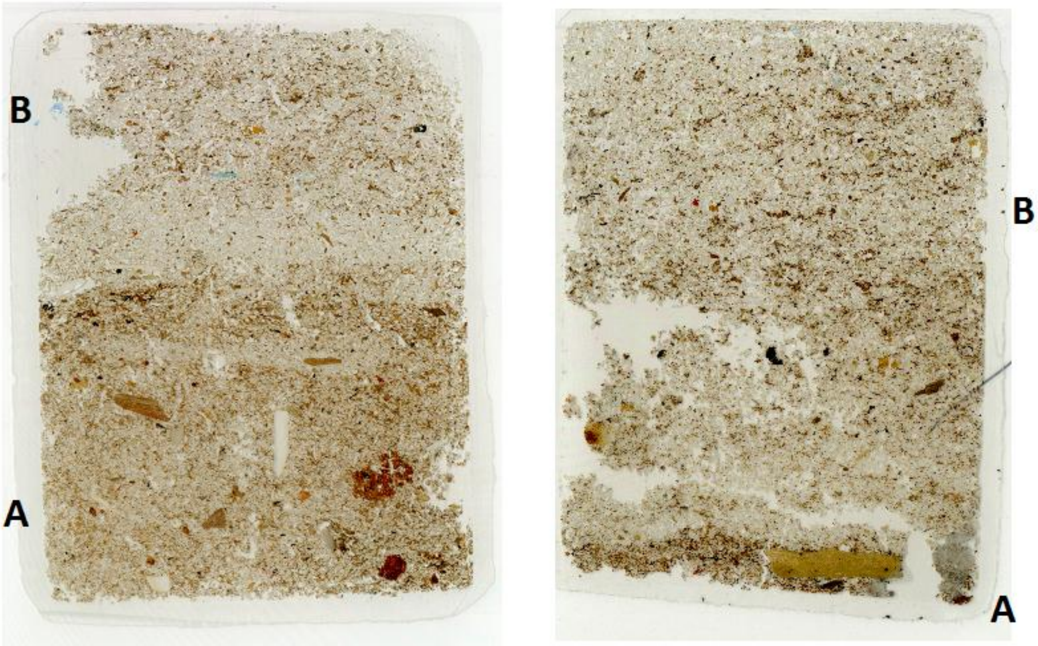
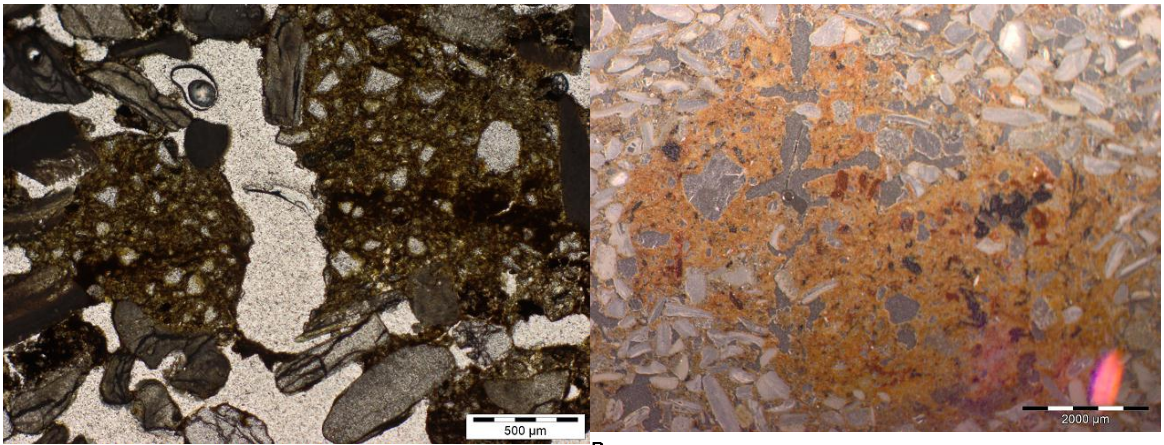


Figure 5.30: Thin section scans, samples 178 (left) and 179 (right), positions of microstratigraphic units are indicated.

Formation processes are distinct from occupational surfaces in structure 9 but there are discrete iron accumulation horizons indicative of trampling present in truncated fine material (figure 5.30a) which indicates this sediment has formed through occupation.



A B

Figure 5.31: A) discrete iron pan in sample 179, unit A; truncated by later soil faunal activity (PPL). B) burned aggregate in unit 178, unit A (OIL).

5.5.3 *Hearth deposits*

Hearth deposits [9125], [9124] and [9117] in structure 9 were examined. Sample 126 was taken from the basal deposit (figure 5.23), described in the field as a compact ashy soil [9125]. Sample 126 intersected the boundary between [9125] and the overlying 'sterile silty soil'

[9124] interpreted as a new base within the existing hearth setting (Moore & Wilson 2011b). In thin section this boundary is diffuse and distinct with a dark layer (microstratigraphic unit B) observed inbetween (figure 5.32).

Figure 5.32: Thin section scans, sample 125 (left) and 126 (right)

Microstratigraphic unit A corresponds to context [9125]. In thin section this exhibits a microstructure characterised by channels and vughs. At the very base, a trace (<1%) of aeolian shell fragments is observed, hinting at the aeolian environmental aspect. Over all the mineral component is randomly oriented and poorly sorted with large siltstone rock fragments contributing 1-5% of the unit, other minerals are consistent with the local geology. The dark brown organo-mineral fine material is orangey brown in OIL which indicates high iron content. The birefringent fabric is stipple-speckled microcrystallitic and consistent with mineral weathering. Fuel residues identified are. Wood charcoal (1-5%, burned peat/turf (5-15%) and charred plant (<1%). Other anthropic inclusions are burned (5-

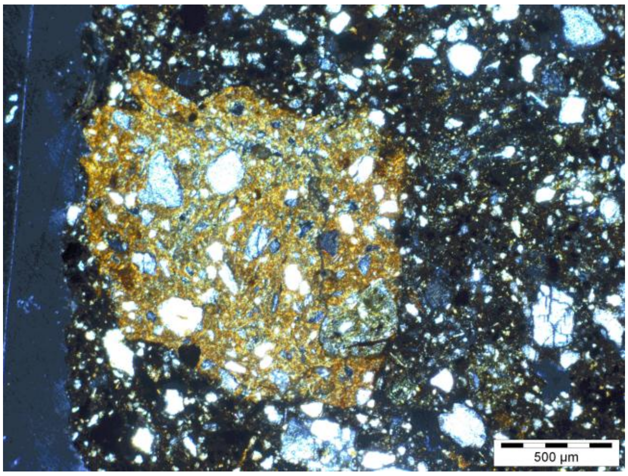


Figure 5.33: Clay aggregate, sample 126, microstratigraphic unit A (XPL).

15%) and unburned (<1%) bone fragments. Bone fragments exhibit morphologies of various intensities of burning. Heat altered clay (<1%) and clay aggregates (1-5%) are also present. Clay aggregates are recognised by their strong interference colours in XPL which are distinctive in comparison with the organo-mineral groundmass (figure 5.33). Morphologically these aggregates are smooth, mammilate and contain coarse mineral fragments and in OIL they appear reddish yellow against a light olive brown matrix (figure 5.34).

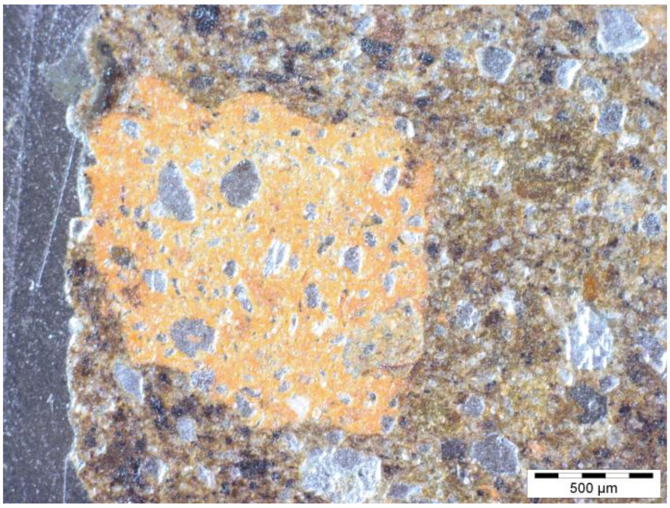


Figure 5.34: Clay aggregate, sample 126, microstratigraphic unit A (OIL).

Post-depositional features include Fe/Mn accumulation (5-10%), orthic Fe/Mn nodules (2-5%) and silty clay infill pedofeatures (1-2%). Excremental pedofeatures are also present (<1%), supporting the interpretation of channel and vugh microstructures as related to soil faunal activity.

The dark layer visible on the macro-scale and termed 'unit B' is composed of dark reddish brown fine material (PPL) which hues dark orangey brown/black in OIL. The microstructure is characterised by channels and vughs but also by cracks. Fuel residues are discernible, woody charcoal contributes 1-5% of the unit as do charred plant remains. However, burnt peat contributes 30-50%. Burned bone indicating medium intensity heating is incorporated into this material (1-5%). Post depositional Fe/Mn movement is limited in this unit (<1% accumulation, 1-2% nodules). Silty infill pedofeatures contribute a further 5-10% of the unit along with limpid clay (1-2%). The former may have infiltrated from unit C as a result of burrowing activity and the initial deposition of silty soil sediment [9124].

The boundary between microstratigraphic units B and C is sharp and clear, indicating rapid deposition. Unit c represents sediment [9124] and is characterised by a channel and vugh microstructure and an open porphyric related distribution. Coarse minerals are randomly oriented and moderately sorted. The fine material is light-mid brown organo-mineral (PPL) with no evidence of rubification in OIL. The 'sterile' nature of this sediment (with regard to anthropic inclusions) is confirmed in thin section with inclusions limited to charred plant and unburned bone (<1% each). Fe/Mn nodules (5-10%) which have not formed in situ demonstrate that the sediment was taken from a stone-free sandy silt subject to redoximorphic wetting and drying. Where this sediment is recorded in sample 125, there is also a trace (<1%) of aeolian sand particles incorporated into the matrix.

Overlying this sediment was a deposit [9117], described in the field as 'firm silty ash soil' (Moore & Wilson 2011b). The boundary between the two was intercepted in sample 125, and is observed in thin section as a clear, sharp colouration difference (figure 5.35) although particle size difference is faint. Sediment [9117] corresponds with microstratigraphic unit B in sample 125 which is characterised by a vughy microstructure with a compact open porphyric distribution. The organo-mineral fine material is dark brown (PPL) with a stripple speckled microcrystallitic b-fabric. Anthropic inclusions are woody charcoal (1-5%), <1% pottery and burned bone fragments (1-5%).

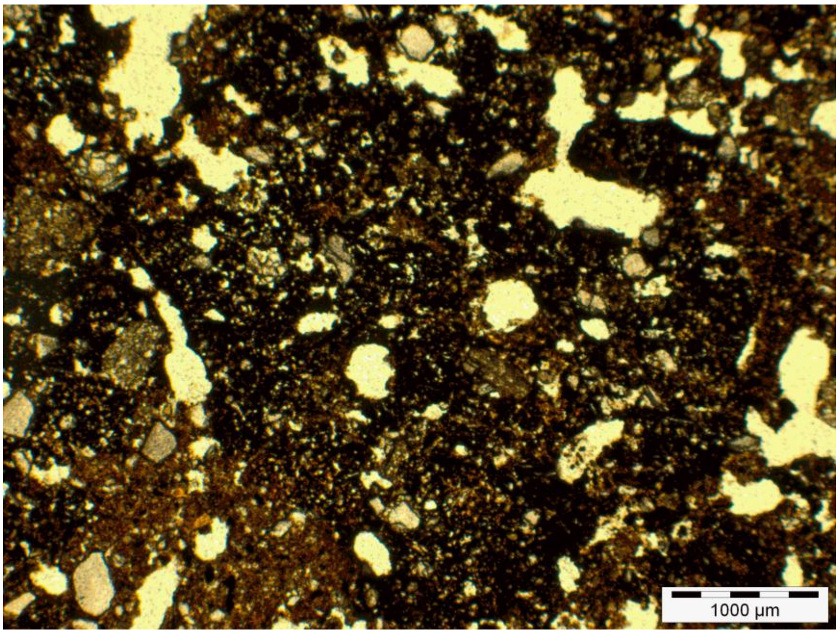


Figure 5.35: Groundmass, unit B, sample 126 (PPL).

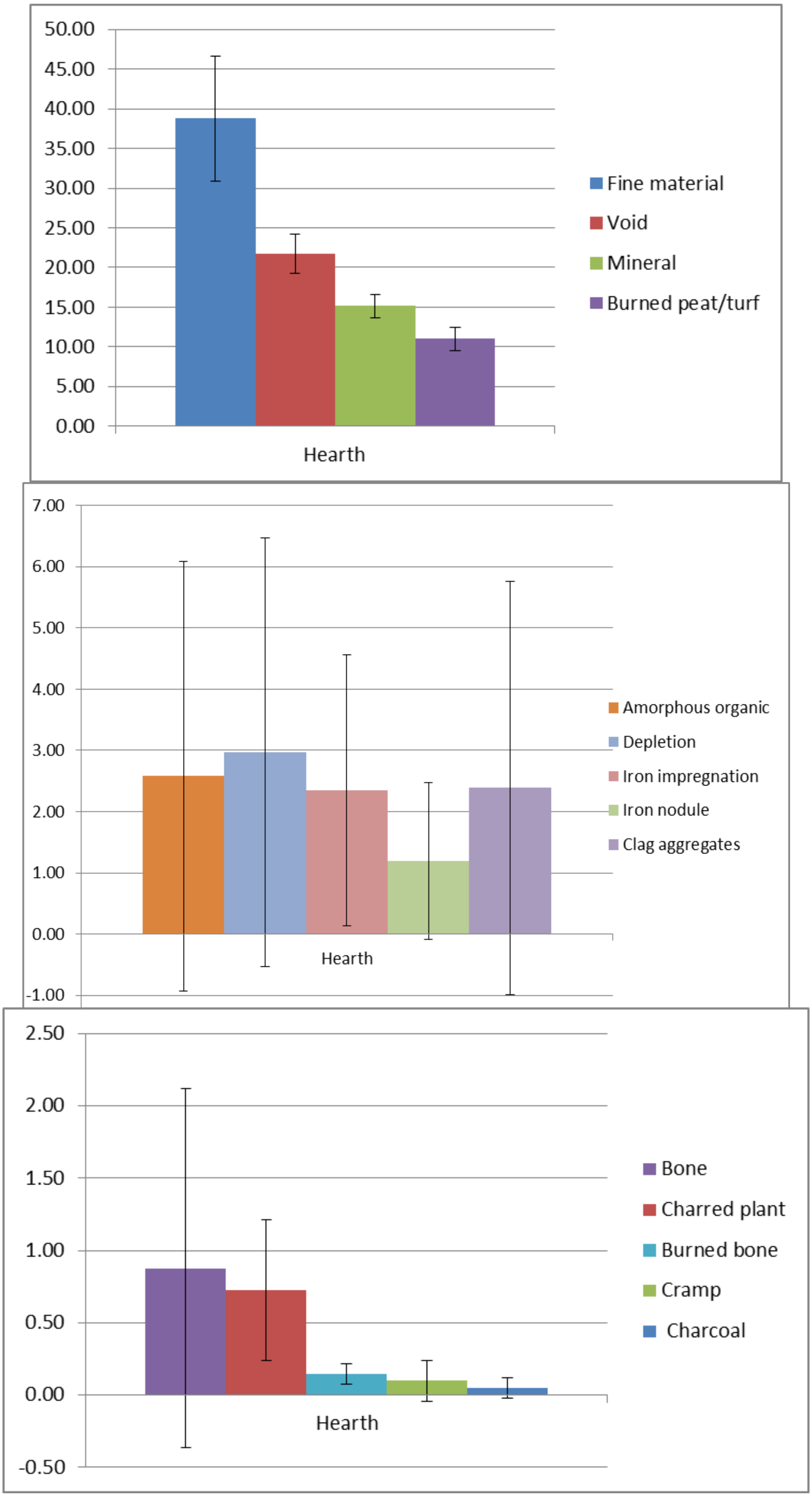


Figure 5.36: Point count results structure 9 'hearth'. Top, macro-components. Middle, intermediate components. Bottom, micro-components

The hearth samples are indicative of a typical in situ burning layers (Courty et al 1989) which have been reworked and subject to weathering. The material is not laminated indicating that some level of maintenance was applied. Any ash was removed and silty sand was deposited within the hearth feature. Point count results from the hearth sediments indicate the main constituents are fine organo-mineral material (38.75 ± 7.83, mean percent ratio) followed by coarse minerals (15.15 ± 1.45 mean percent ratio) and burned peat (11.01 ±1.43) (see figure 5.36).

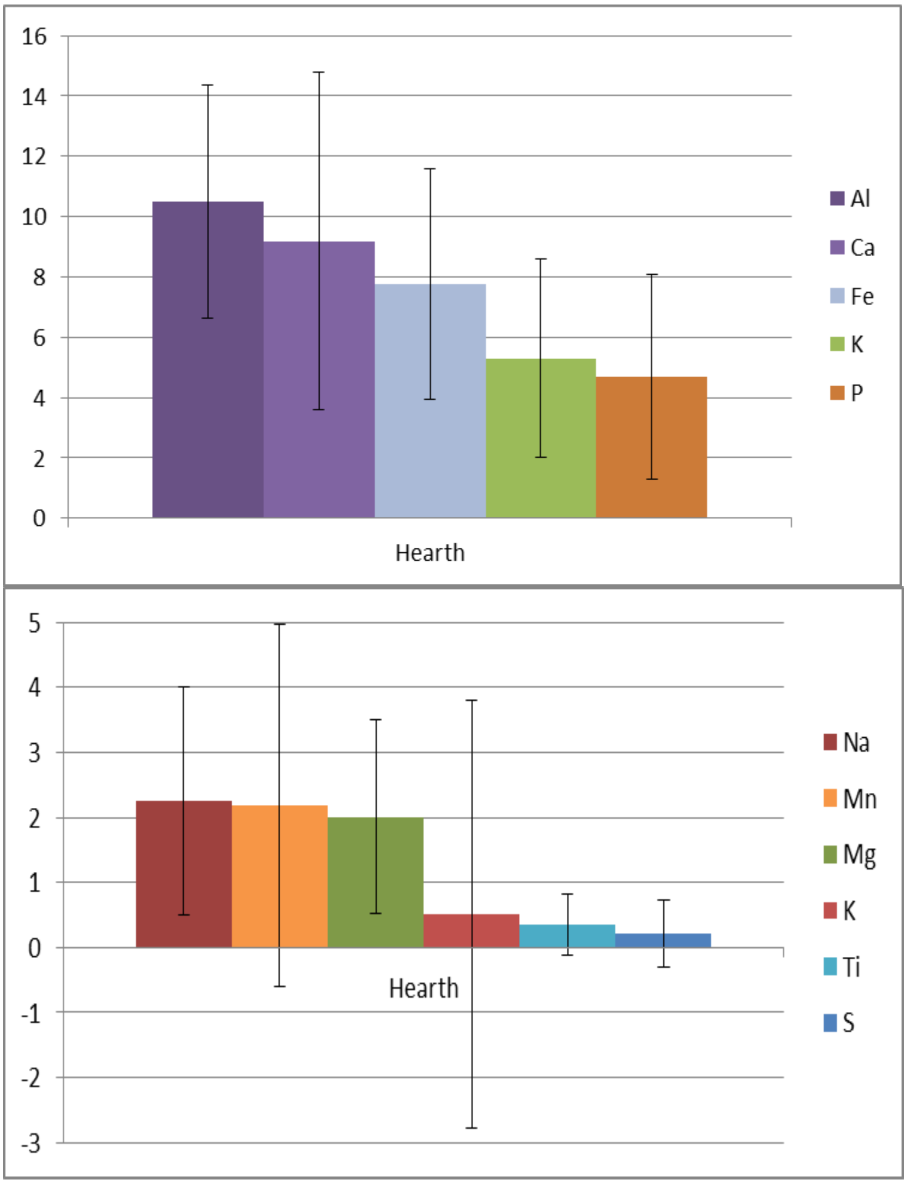


Figure 5.37: SEM EDX results for hearth deposits. Top = Macro elements, Bottom = Micro elements. Results expressed in mean percent ratio, error bars = σ. Si not included, this is the main component at 55.19 ± 13.70 percent ratio.

Burned peat is intimately related to fine material (figure 5.35) and at least some of the estimated percentage fine material will inevitably be misidentified. However, this does indicate that peat fuel residues have been mixed with the silty sand deposit. Whether this represents anthropogenic activity or post-depositional reworking by soil fauna is difficult to ascertain.

5.5.4 *Exterior occupational sediments*

Ten samples were collected from exterior occupational deposits found in several locations. Samples 76, 77 and 106 were recovered from surfaces overlying paving in Area 5, sample 100 from deposits covering the ruins of structure 8 and samples 86-91 were recovered from the soil in test pit 2.

Paved area, structure 8 complex

The sediments overlying paving in Area 5 were described in the field as a series of finely laminated ashy deposits [8002] and dumps [9157]. In thin section the samples are characterised by distinctive lenses distinguished by colouration and inclusions (figure 5.38).

Figure 5.38: Thin section scans of samples 76, 77 and 106 (left to right).

These three samples exhibited signs of bioturbation with microstructures characterised by channels and vughs. A weak blocky structure has developed superimposed upon this, formed as the sediment dried out. Coarse and fine related distributions were open porphyric indicating a dense sample. Point count results estimate pore space at 24.15 percent ratio (± 5.73).

Samples 76 and 77 can be described as a sequence of light and dark deposits. The lighter material is composed of a mixed light brown and grey organo-mineral fine material (PPL) containing poorly or well sorted, randomly arranged coarse quartz grains and rock fragments. The limited variation in coarse mineral type is notable in these samples as it is not consistent with that found elsewhere across the site. Where parent material is geologically complex, quartz is the last mineral to weather, as softer less resistant minerals (including feldspars) are worn away or dissolved. Therefore, a deposit which only contains quartz should be considered to be heavily weathered. This might indicate anthro-weathering of materials (Pope & Rubenstein 1999) as individual quartz grains exhibited cracks and softer minerals such as mica were not observed although the b-fabric is stipple speckled microcrystallitic. In OIL, the fine organo-mineral material is mixed light grey and yellowish brown. Fine material usually appears grey due to a lack of staining substances such as Fe or organic matter (Stoops 2003) which points to depletion or calcitic ash. Therefore, an initial interpretation of 'weathered ash' was applied, although this was a tentative term as there is no observable calcitic ash morphology (Canti 2003) and peat ash usually hues red in OIL. Further analysis with SEM EDX indicated a lower ratio of Ca in the lighter horizons. As Ca is the primary component of wood ash (Canti 2003, Deymeyer et al 2001, Misra et al 199), this would be expected to be more concentrated in an ash deposit compared to dark units elsewhere in the sequence and glacial till controls, but this is not the case (figure 5.39).

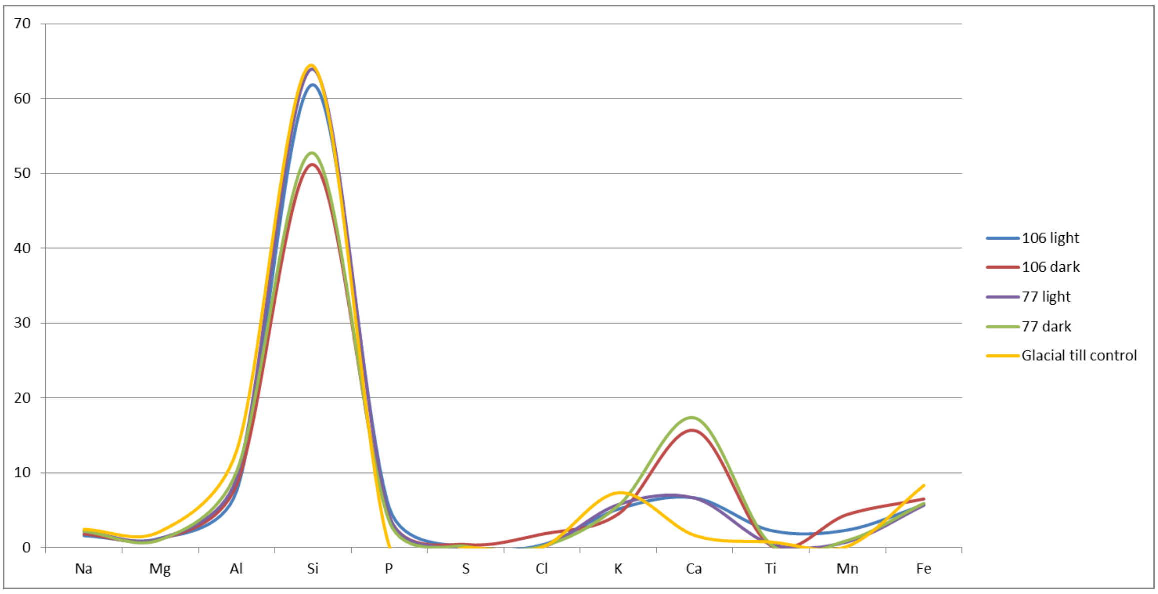


Figure 5.39: SEM EDX results for samples 76 and 77 compared to glacial till control. Results expressed as mean percent ratios.

Likewise, P, Mg and K are major elements of wood ash (Demeyer et al 2001) and do not show any significant enrichment within the light units. Instead, a closer parallel may be drawn between sheep dung burned at 400°C and cow dung burned at 800°C from reference samples available at the University of Stirling and published elemental data for cow dung (Braadbaart et al 2012). Reference samples for micromorphology were grey under OIL and heightened Si and slightly lower Ca is reported for experimentally burned cow dung compared with wood or peat fuel. However, no phytoliths or plant residues were noted in samples 76 or 77 which indicates that any ash content has undergone fragmentation, perhaps caused by secondary deposition or post-depositional reworking. It may be of note that the light horizons in samples 76 and 106 are comparable with the structure 9 hearth 'sterile' sediment [9124], which share micromorphological properties and chemistry (figure 5.40).

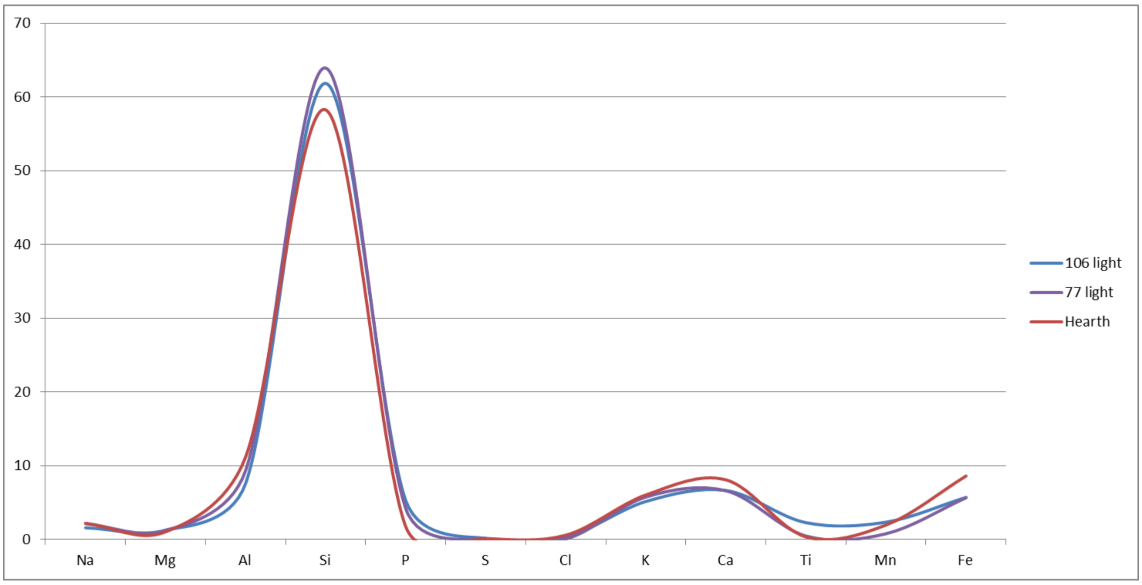


Figure 5.40 SEM EDX results for light coloured micro-horizons in sample 77 compared with sediment [9124]. Results expressed as mean percent ratios.

The dark layers in the sequence are composed of mixed black and very dark brown organo-mineral fine material (PPL) which exhibits a black or yellowish brown colouration in OIL. The micro-structure, distribution and arrangements are the same throughout the slides, indicating post-deposition formation related to compaction and bioturbation. A horizontal crack in sample 76 is consistent with vertical pressure which can lead to a platy microstructure (Adderley et al 2010, Milek 2012) but this is not strongly developed. Fissures and cracks were observed in the dark layers, but not the light layers (figure 5.41) which indicates a difference in composition and relative moisture levels – fissures and cracks form upon rapid drying and so the black layers have dried out more rapidly than the light layers.

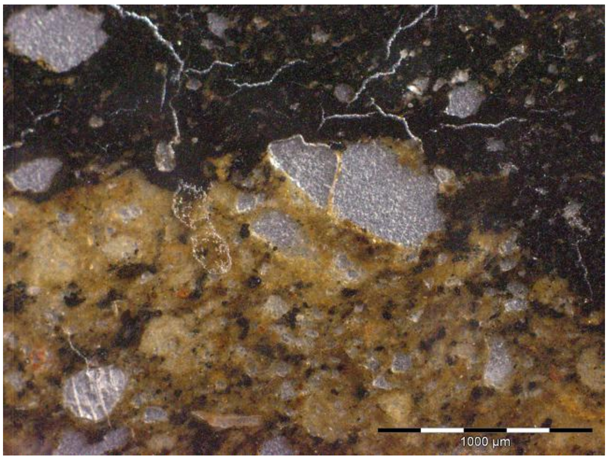


Figure 5.41: Boundary between microstratigraphic units A and B, sample 77 (OIL).

Fuel residues observed in the dark layers are woody charcoal and charred plant material. However, the high levels of amorphous black fine material (up to >70%) present within these layers indicates either strongly humified or charred organic material consistent with peat or herbivore dung.

The sequence repeats several times within each section and each unit is very clearly constructed, exhibiting sharp, straight boundaries even at higher magnifications (figure 5.41).

Silty or dusty clay infill pedofeatures occur throughout the samples, contributing up to 10% of each unit. These show weak laminations in place indicating several elluviation/illuviation events of fine materials through disturbance higher up the profile.

The sequence bears a strong resemblance to 'layer cake' deposits from Eneolithic and Bronze Age layers in Grotta Cotariova, Italy where periodical burning of dried and trampled dung deposits formed alternating black and white layers (Mlekuž 2009). Each combination of black and white layer is described as a single burning event where light layers are the result of properly burned dung with the black layer comprising the bottom and lateral parts containing charred and partially burned organic matter (Brochier 2002, Mlekuž 2009).

The morphological resemblance combined with chemistry consistent with cow dung provides the implication that this sequence of sedimentation formed through consecutive or periodic animal penning and burning/trampling events, with fine material filtering down profile through compression of each new surface layer forming silty infill pedofeatures (Brochier 2002).

The survival of in situ organic-rich dung deposits is exceptional in the archaeological record and is consistent with a protected environment (e.g. frozen, waterlogged or rapid burial, Shahack-Gross 2011), although carbonisation would aid survival. Another possibility is that the paved area could have been roofed such as in a cave environment (Mlekuž 2009).

A piece of cramp was identified incorporated between the boundary of light and dark layers in sample 77, this is an allochthonous inclusion, seemingly out of place within this context and thus evidencing the mobility of this material around the site.

Formation processes evidenced in sample 106 begin with the sequence described in samples 76 and 77 (microstratigraphic units A and B) then graded into a complex series of truncated lenses (figure 5.38). Units C, D and E are a strongly bioturbated version of the several episodes of the light/dark sequence. At least five black layers are discernible in thin section. Plant structure residues are better preserved, although these have been subject to charring either as additions to or inherent to the black 'animal dung' layers. There are many pedofeatures related to Fe/Mn accumulation and depletion within samples 76, 77 and 106 indicating redoximorphic conditions.

Over ruined structure 8

Sediment [9171] was associated with anthropic deposits with archaeological assemblages suggestive of butchery activities (Moore & Wilson 2011b). In thin section sample 100, three microstratigraphic units are observed, labelled A and B (122). Unit B is a lens of ashy material representing a hiatus in the formation of unit A.

Unit A is characterised by dark brown organo-mineral fine material (PPL) which hues yellowish brown in OIL. Coarse minerals are randomly arranged and unsorted with large sand and siltstone fragments contributing 5-15% of the unit. The coarse mineral material is consistent with local geology and there is a trace (<1%) of aeolian shell sand. Anthropic inclusions are allochthonous turf fragments (<1%), woody charcoal (1-5%), charred plant (1-5%) and burned (<1%) and unburned (<1%) bone. Burned bone morphology indicates medium and high intensity burning episodes.

Figure 5.42: Thin section scan, slide 100.

Unit B is composed of light brown organo-mineral material (PPL) which is grey in OIL. The coarse mineral components are weakly horizontally striated and poorly sorted. The particle size difference between units A and B is notable. Unit B is composed of 1-5% quartz, 1-2% quartzite and <1% mica whilst unit A contains 5-15% quartz, 1-5% quartzite, <1% mica, <1% garnet and 5-15% rock fragments. Anthropic inclusions in unit B are woody charcoal (<1%), burned peat/turf (<1%), burned (1-5%) and unburned bone (<1%) and ash (1-5%). Ash is identified as calcitic with high birefringence (Canti 2003).

5.5.4.1 *Yellow amorphous material*

A major component of unit B is amorphous yellow material (5-15%) which formed lenses and granostriations (figure 5.43) around rock fragments and Fe/Mn nodules. In XPL this was undifferentiated from the groundmass, sharing the same stipple-speckled micro crystallitic b-fabric.

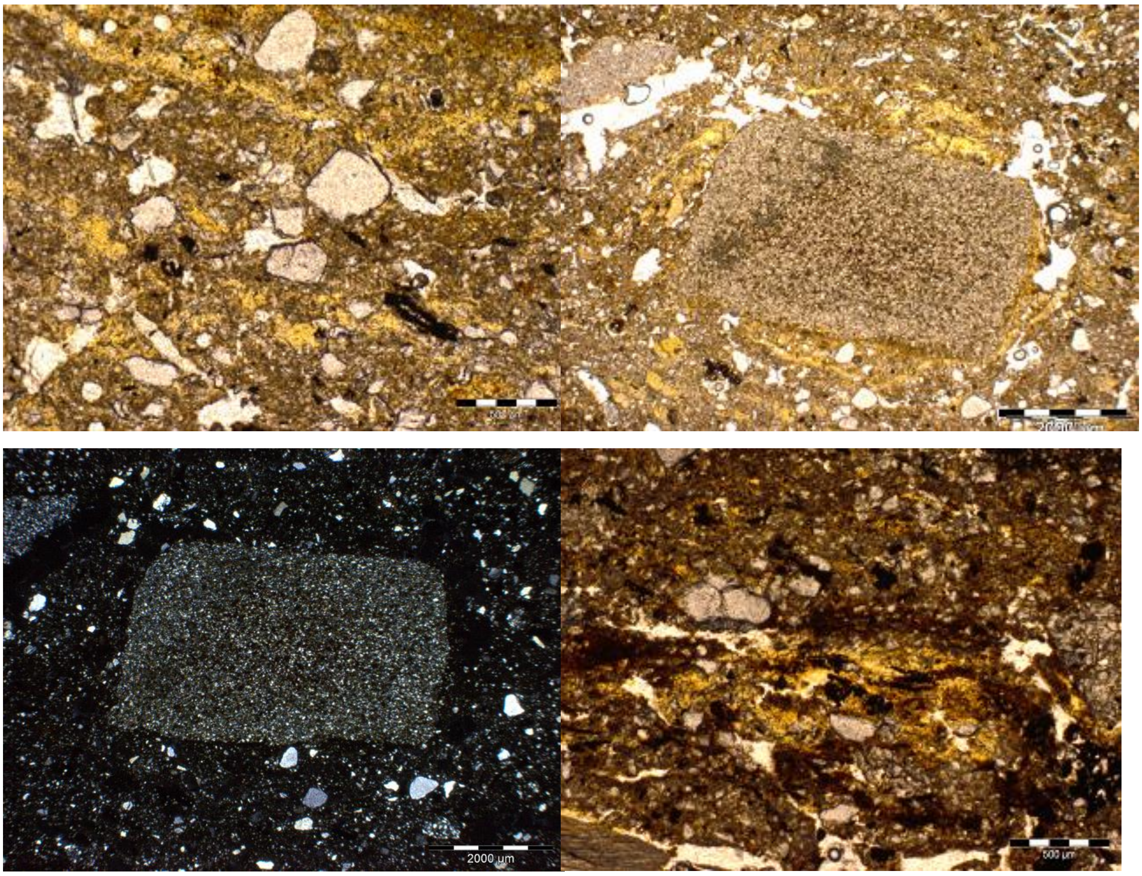


Figure 5.43: Yellow amorphous material in sample 100. Top left = lenses, top right = granostriations (PPL). Bottom Left = same view as top right but XPL. Bottom right = micro-laminated grass ash and charcoal, at the boundary between units B and upper A (PPL).

This material was investigated using SEM EDX analysis to determine its composition which was hypothesized to be either organic matter or, following Mees & Stoops (2010) descriptions, jarosite ($KFe_3(SO_4)_2(OH)_6$). Under higher magnification, euhedral/subhedral crystals are observed within an amorphous to slightly fibrous matrix (figure 5.45). Elemental composition is primarily Si (34 ± 5%), Fe (22 ± 3%) and P (15 ± 3%) with <15% Al, K and Ca and <2.5% Na, Mg and Ti (figure 5.44).

Pearson correlations on spectra data (table 5.3) indicate there are positive relationships between P and Ca, Ca and Fe and between P and Fe. Si and Al are negatively correlated as are Al and P, Al and Ca and Al and Fe. There is a negative correlation between Si and P, Si and Ca and Si and Fe. This indicates that Al is primarily related to mineral content and Fe, Ca and P enrichments are closely associated with each other.

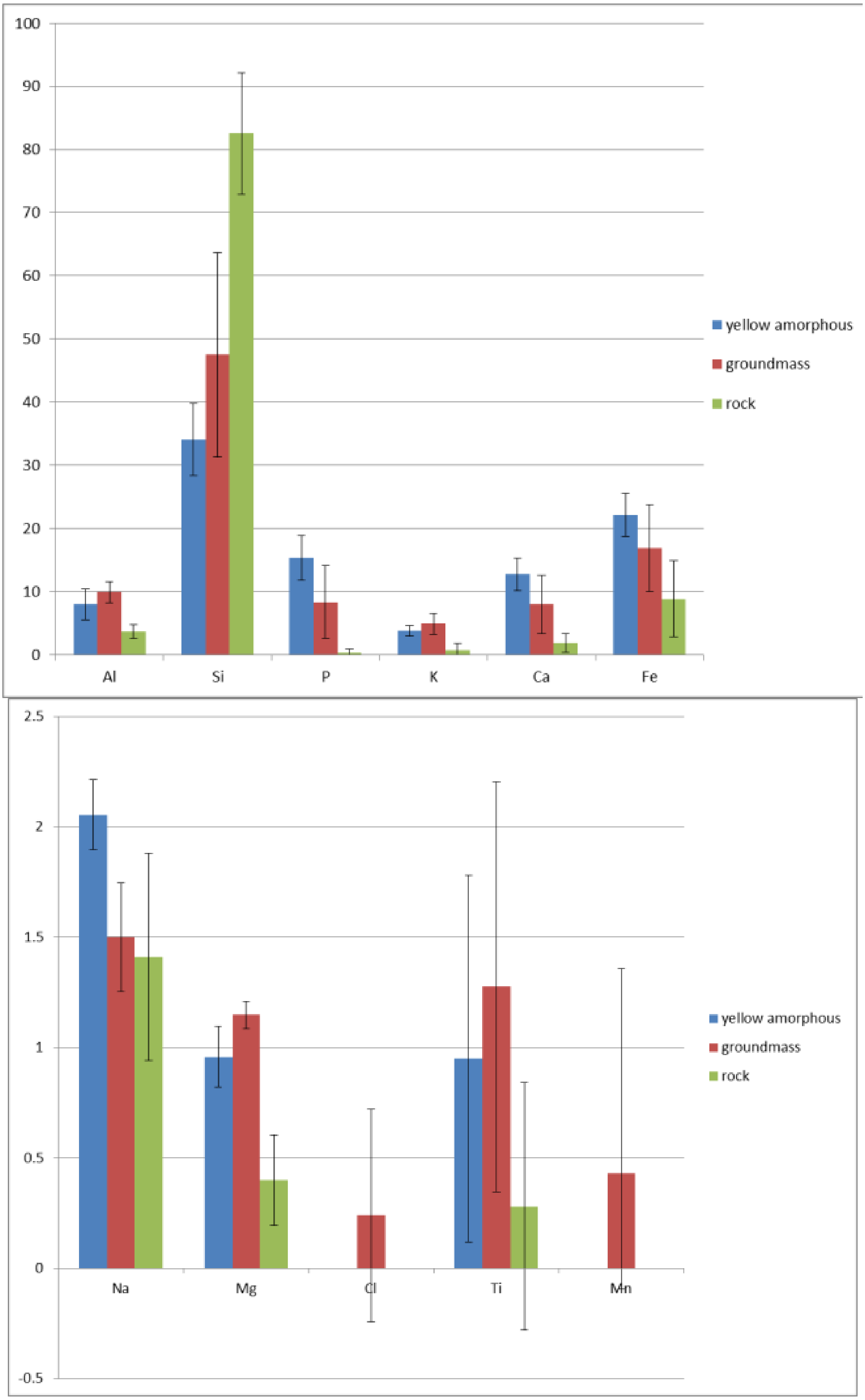


Figure 5.44: SEM EDX results for yellow amorphous material in sample 100. Top = macro elements, bottom = micro elements. Results expressed in mean percent ratios, error bars = σ

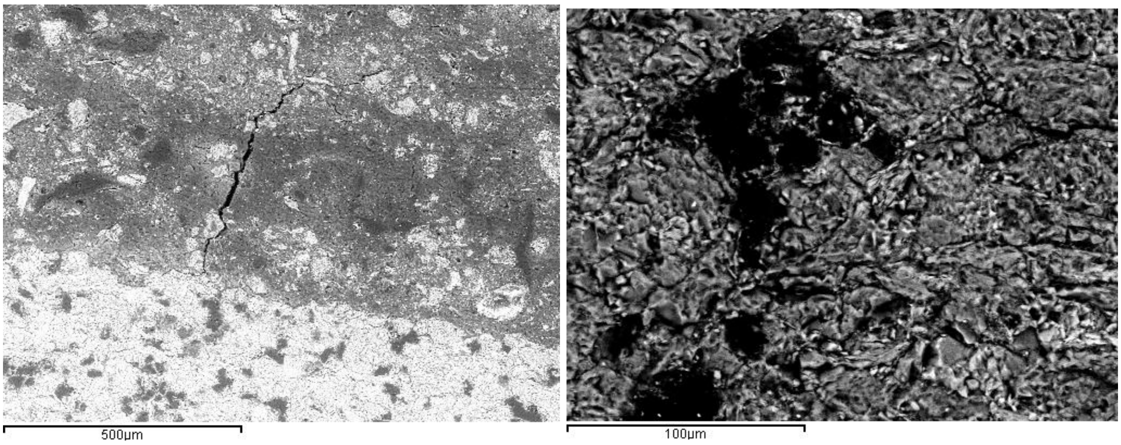


Figure 5.45: SEM BS images of yellow amorphous material granostriated around rock fragment (detail of figure 5.43)

Table 5.3: Pearson correlations for spectra data retrieved from yellow amorphous material in sample 100.

Correlations

		Na	Mg	Al	Si	P	K	Ca	Ti	Fe
Na	Pearson Correlation	1	-.305	.625	.672	-.783	.669	-.756	.919	-.627
	Sig. (2-tailed)		.695	.375	.328	.217	.331	.244	.081	.373
	N	4	4	4	4	4	4	4	4	4
Mg	Pearson Correlation	-.305	1	.338	.205	-.120	.487	-.229	-.290	-.368
	Sig. (2-tailed)	.695		.662	.795	.880	.513	.771	.710	.632
	N	4	4	4	4	4	4	4	4	4
Al	Pearson Correlation	.625	.338	1	.990*	-.970*	.908	-.983*	.352	-.999**
	Sig. (2-tailed)	.375	.662		.010	.030	.092	.017	.648	.001
	N	4	4	4	4	4	4	4	4	4
Si	Pearson Correlation	.672	.205	.990*	1	-.987*	.857	-.982*	.374	-.983*
	Sig. (2-tailed)	.328	.795	.010		.013	.143	.018	.626	.017
	N	4	4	4	4	4	4	4	4	4
P	Pearson Correlation	-.783	-.120	-.970*	-.987*	1	-.875	.993**	-.520	.966*
	Sig. (2-tailed)	.217	.880	.030	.013		.125	.007	.480	.034
	N	4	4	4	4	4	4	4	4	4
K	Pearson Correlation	.669	.487	.908	.857	-.875	1	-.926	.545	-.927
	Sig. (2-tailed)	.331	.513	.092	.143	.125		.074	.455	.073
	N	4	4	4	4	4	4	4	4	4
Ca	Pearson Correlation	-.756	-.229	-.983*	-.982*	.993**	-.926	1	-.515	.984*
	Sig. (2-tailed)	.244	.771	.017	.018	.007	.074		.485	.016
	N	4	4	4	4	4	4	4	4	4
Ti	Pearson Correlation	.919	-.290	.352	.374	-.520	.545	-.515	1	-.368
	Sig. (2-tailed)	.081	.710	.648	.626	.480	.455	.485		.632
	N	4	4	4	4	4	4	4	4	4
Fe	Pearson Correlation	-.627	-.368	-.999**	-.983*	.966*	-.927	.984*	-.368	1
	Sig. (2-tailed)	.373	.632	.001	.017	.034	.073	.016	.632	
	N	4	4	4	4	4	4	4	4	4

***. Correlation is significant at the 0.05 level (2-tailed).**
****. Correlation is significant at the 0.01 level (2-tailed).**
Significant positive correlations coloured blue.
Significant negative correlations coloured red.

The chemistry of the large rock fragment associated with yellow amorphous material was also analysed along with ground mass of unit B for comparison (figure 5.42). The difference observed between calcium, phosphorous and iron ratios in the rock fragment and the yellow amorphous material are statistically significant ($p=0.05$) despite their close proximity indicating that the material is not weathering from the rock fragment. Differences between the yellow amorphous material and the groundmass were not confirmed statistically, but mean ratios of P and Ca are perhaps far enough apart to suggest similarity is brought about by mixing (such as of the lenses of amorphous yellow material, figure 5.23). The chemical elements present within the yellow amorphous material are more consistent with organically derived materials than jarosite but parallels for granostriated organic material were not found reported in published literature although adsorption of organic matter to minerals is suspected. Therefore it is suggested that some form of phosphatic mineral formation is represented. Phosphate-rich solutions derived from decaying organic material can lead to the replacement of plant ash by apatite $Ca_5(PO_4)_3(OH)$ in anthropogenic horizons (Karkanas and Goldberg 2010) and so this seems the most likely explanation given the limited evidence.

The lenses of yellow amorphous material would therefore be interpreted as apatite replacement of micro-laminated ash. Micro-laminated grass ash and charcoal is recognised at the boundary between unit B and upper unit A (figure 5.23) adding strength to this argument. Formation of dahllite (carbonated apatite, $Ca_5(PO_4,CO_3(OH,F))$ has been reported in cave sediments (Schiegl 1996). Typical conditions for this type of formation process are wet with high amounts of available soluble acidic phosphates from bone or guano sources coming into contact with alkaline calcitic ash (Albert et al 2012, Karkanas et al 2000, Schiegl 1996). Therefore is it proposed that unit B represents a dump of mixed fuel residues but mainly calcitic ash which were rapidly buried by phosphate rich sediment in a very wet environment, creating a locally alkaline lens in an acidic anthropic sediment.

The whole slide exhibits a vugh and channel microstructure consistent with soil faunal activity, this is confirmed by excremental pedofeatures (<1%). Channels also split woody charcoal fragments demonstrating the ability of soil fauna to fragment anthropic inclusions.

Soil test pit 2

Samples recovered from the stratigraphy in soil test pit two demonstrate discrete microstratigraphies with some common observed microfacies. The earliest sediment in the macro-stratigraphy was described in the field as a layer of grey-black sandy soil containing charcoal. It is represented in sample 85 by microstratigraphic unit A. In thin section this sediment is characterised by a channel, chamber and vugh microstructure in an open porphyric distribution with brown organo-mineral fine material (PPL & OIL) and a random poorly sorted coarse mineral arrangement. The coarse minerals are consistent with both aeolian shell sand (shell sand 5-15%, quartz 5-15%) and local geology (rock fragments 5-15%) indicating this is mixed sediment. Anthropic inclusions are cramp (1-5%), large shell fragments (1-5%), rubified minerals (1-5%), woody charcoal (1-5%) and unburned bone fragments (<1%) which further this interpretation as an anthropogenic mixed sediment. The boundary between sediments [9105] and [9103] is irregular and clear, with 'tongues' of the overlying unit reaching down, which is interpreted as due to soil faunal activities.

Despite this the clarity of distinction between the two sediments makes it possible to discern that anthropic mixed sediment [9105] was subject to rapid burial and infill by sediment [9103] prior to bioturbation. This material is recognised in all samples from the east facing section of soil test pit two and recorded as unit B in 85, all of 86, unit A in 87, all of 88, unit A in 89 and unit A in 90 (figure 5.46). In the field this sediment was described as a dark brown organic clay and tentatively identified as 'midden' (Moore & Wilson 2011b) as it is rich in anthropic inclusions.

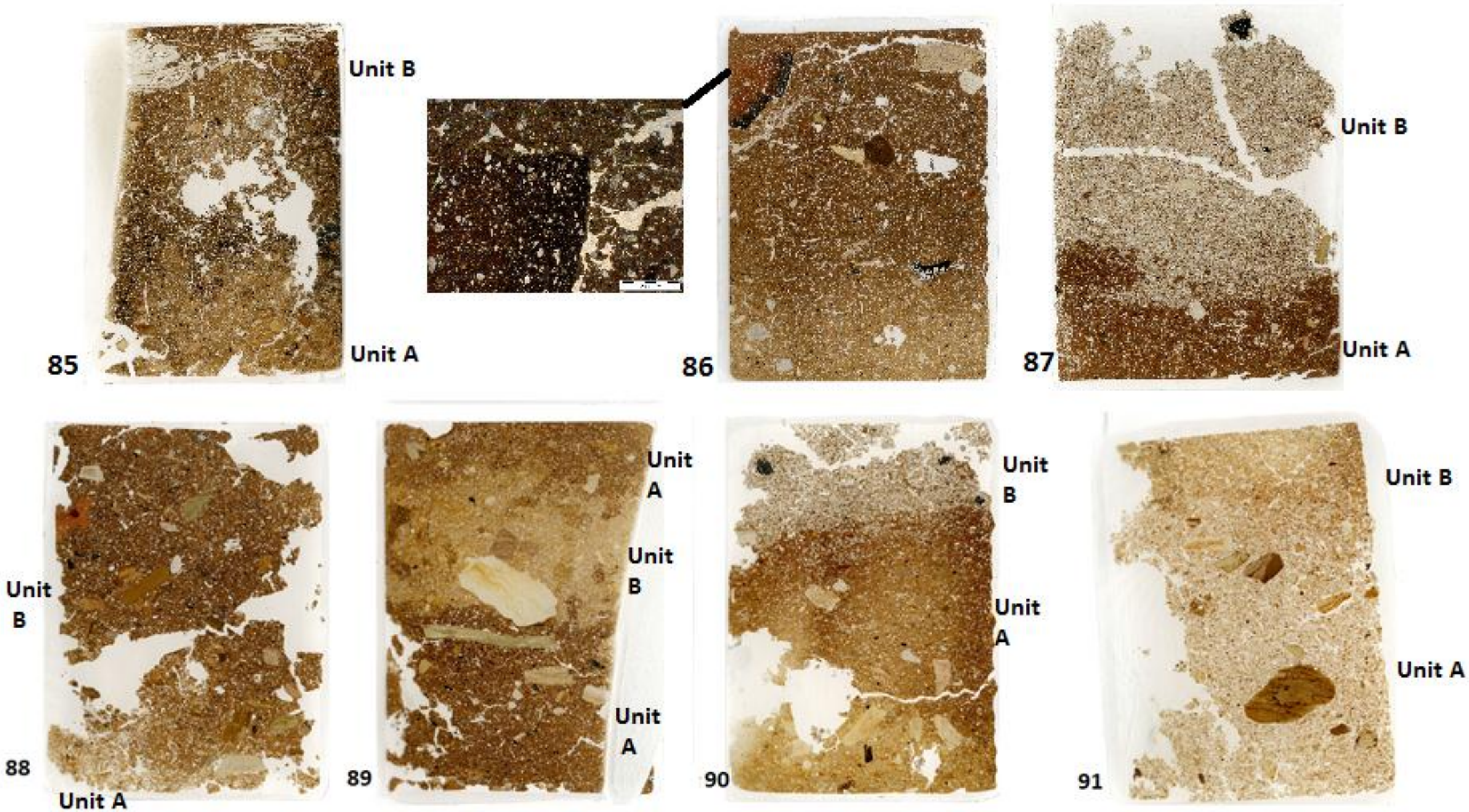


Figure 5.46: Thin section scans of slides 86 to 91. Detail of 86 = pottery fragment (PPL), detail of 82 = burned bone fragment (PPL).

This is confirmed in thin section, with cramp (<1%), large shell fragments (1-5%), rubified minerals (<1%), pottery (<1%), woody charcoal (<1%), charred plant (1-5%), burned peat and turf (1-5%) vesicular char (<1%), burned bone (1-5%) and unburned bone (1-5%), peat ash (<1%), clay aggregates (<1%) interpreted as hearth rake out and phosphatic amorphous material (<1%) observed. Point count results indicate a cumulative figure of 4% ratio for all samples of [9103], this is c.5% less than the structure 9 interior floor samples. The sediment is richer in anthropic inclusions within the northern extent with each unit composed of between 1-5% and 4.4-23.6% individually. Closer to the rubble in the southern extent of soil test pit 2, anthropic material contributes between 0.2-1.8% and 2.3-12.7%. Planar voids in sample 86 and fragmented shell in sample 85 indicate the compaction of this sediment but across the rest of the samples any microstructures have been lost to soil faunal reworking evidenced by channels, chambers and vughs. Coarse constituents in this sediment are randomly arranged and poorly sorted within open porphyric distributions. Minerals are consistent with the local geology with marine shell sand intruding near the boundary between [9103] and overlying sand [9100].

A discrete lens in sample 89 was labelled unit B. This was composed of greyish brown (PPL) fine organo-mineral material which is coloured yellowish brown in OIL. The microstructure is cracked massive with an irregular boundary between sediment [9103] visible across three sides. Anthropic inclusions are limited to a trace (<1%) of woody charcoal and burned bone (<1%). In thin section this material was interpreted as a compact clay, depleted of organic fine material relative to sediment [9103]. SEM EDX analysis of this material demonstrates that it is composed primarily of Si with Al, K and Fe contributing intermediate proportions with Na, Mg, Ca and Ti are present in trace amounts. When compared with sediment [9103] and the glacial till control there is no enhancement of Ca indicating the grey colouration of the material is not related to the presence of calcitic ash, furthermore there is a statistically significant lesser amount of P within the clay lens than the rest of the sample but no difference between the glacial till control and the lens. Mineralogically, chemically and morphologically, the clay lens is the same as the glacial till control which indicates it is a re-deposited lump of this material set within an anthropic sediment. The use of yellow clay as a construction material is noted elsewhere at the Links of Noltland (structure 18, Moore & Wilson 2012) and so the discovery of this in close proximity with large slabs [9101] in soil test pit 2 may be related to wall core. Yellow clay is also described lining boxes and pits indicating that the use of glacial till as a factotum building resource was customary.

Over all sediment [9103] can be described as a homogenous anthropic sediment, composed of hearth waste, large shell and bone fragments and broken pottery within an organo-mineral matrix.

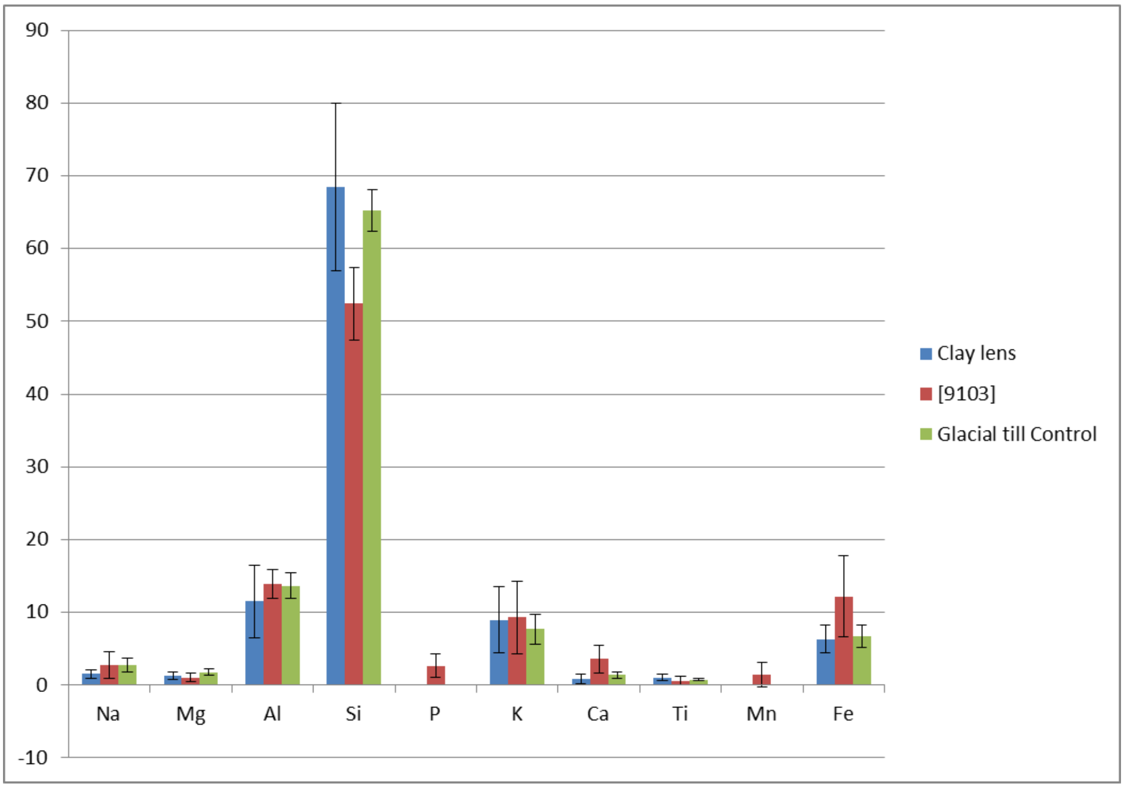


Figure 5.47: SEM EDX analysis results for sample 89, clay lens and sediment [9103]. Results in average percentage ratio, error bars = σ

Samples 87 and 90, recovered from the northern and southern extents of the test pit contain portions of sediment [9100], described in the field as a dark grey-brown loamy sand. In thin section this is characterised by a bridged grain enaulic microstructure containing randomly arranged well-sorted aeolian shell (30-50%) and quartz (15-30%) sand with <1% rock fragments. Vesicular char (<1%), burned peat (<1%) and charred plant remains (<1%) are present.

In thin section the fine material is dark brown organo-mineral with a stipple-speckled micro-crystallitic b-fabric. Pedofeatures are related to movement of fine material (5-10% void coatings, 2-4% silty infill) and shell dissolution (1-2%). The boundary between this sediment and underlying sediment [9103] is clear and sharp indicating a rapid burial. Point count results indicate that the material is very similar to aeolian shell sand overlying disturbed material in trench 19 and cultivated horizons in trench 22, with the addition of anthropic inclusions (Figure). This horizon is interpreted as an aeolian sediment which has incorporated anthropic debris.

The boundary between [9103] and [9100] captured within sample 87 is characteristic of the ard mark model developed by Lewis (2012), containing 'rolled' aggregates of unit A sediment [9103] fine material in the fill (figure 5.49). The Area 5 'field system' lies immediately to the west of soil test pit 2 and so this raises the possibility that sediments [9103] and [9100] represent the cultivation of an exterior occupational surface.

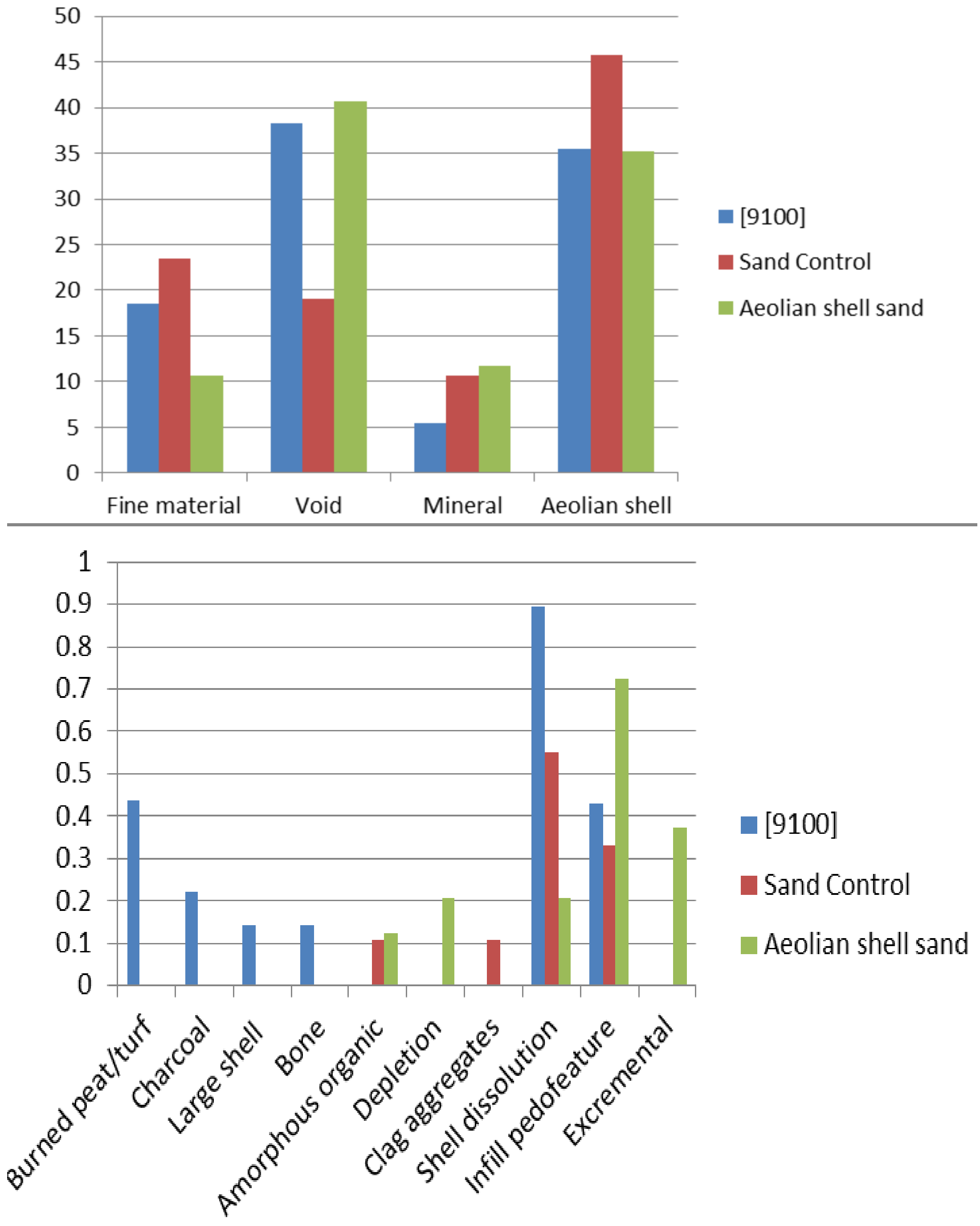


Figure 5.48: Point count results for sediment [9100], Aeolian sand control and aeolian shell sand. Top = Macro constituents, bottom = micro constituents. Results expressed in percent ratios

A final sample was recovered from the west facing section of soil test pit 2 recovering matrix material in which large (possibly structural) slabs [9101] (Moore & Wilson 2011b) were suspended. In thin section this material was entirely devoid of anthropic inclusions but a microstratigraphy was discerned based upon the abundance of aeolian shell sand. The basal unit (A) contained 5-15% shell sand, quartz (1-5%), quartzite and (5-15%) and rock fragments

(5-15%) and clay aggregates of the type associated with windblown sand. One rock fragment exhibits a Fe depletion hypocoating. The microstructure is inter/bridged grain microaggregate with local crumb texture giving an enaulic or close porphyric related distribution with randomly oriented, poorly sorted coarse components. The boundary between this unit and upper unit B is sharp (figure 5.46) and anthropic inclusions are also notably absent from this upper layer. However the microstructure is characterised by channels, chambers and vughs indicating this layer once contained enough organic material to stimulate soil faunal activity. The close proximity of this 'sterile' sediment to exterior occupational surface sediments rich in anthropic inclusions alludes to the possibility that this is a deliberately clean material, perhaps indicative of a sandy organic collapsed wall core.

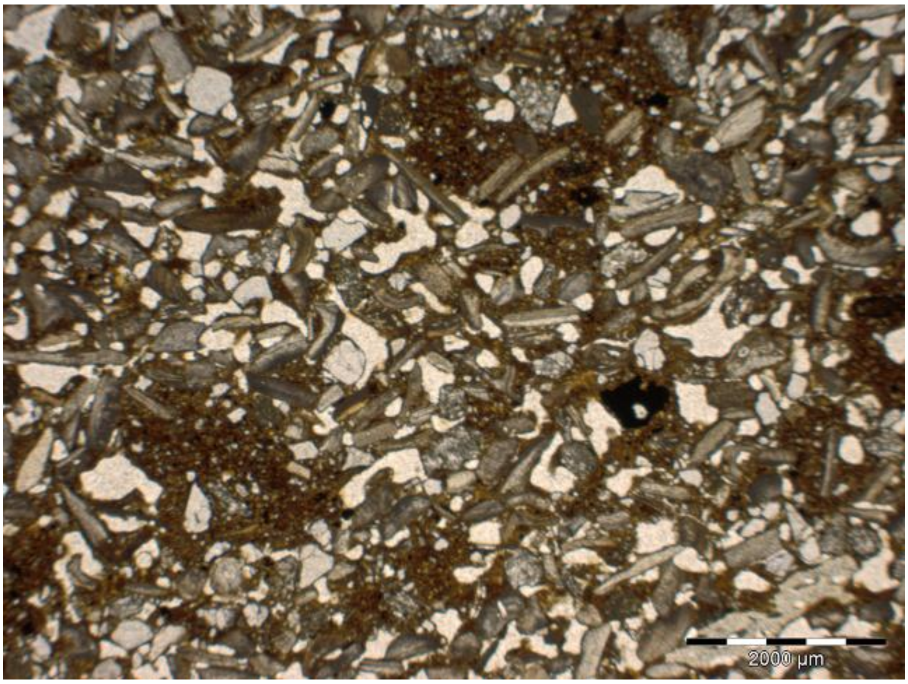


Figure 5.49:'rolled' aggregates in sample 87, microstratigraphic unit B (PPL)

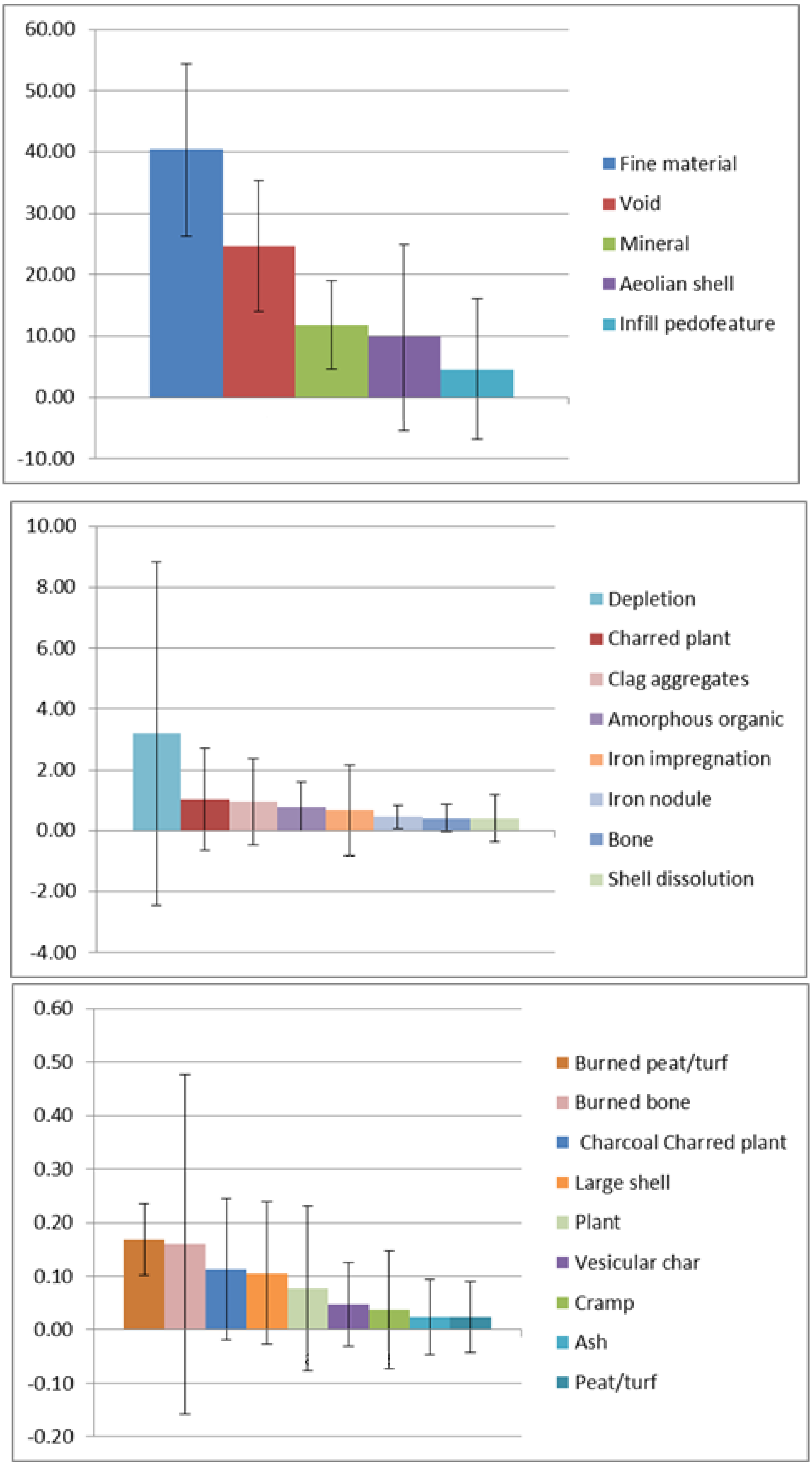


Figure 5.50: Point count results for exterior occupation deposits. Top = Macro-components, middle = intermediate components, base = micro-components. Results in average percentage ratio, error bars = σ

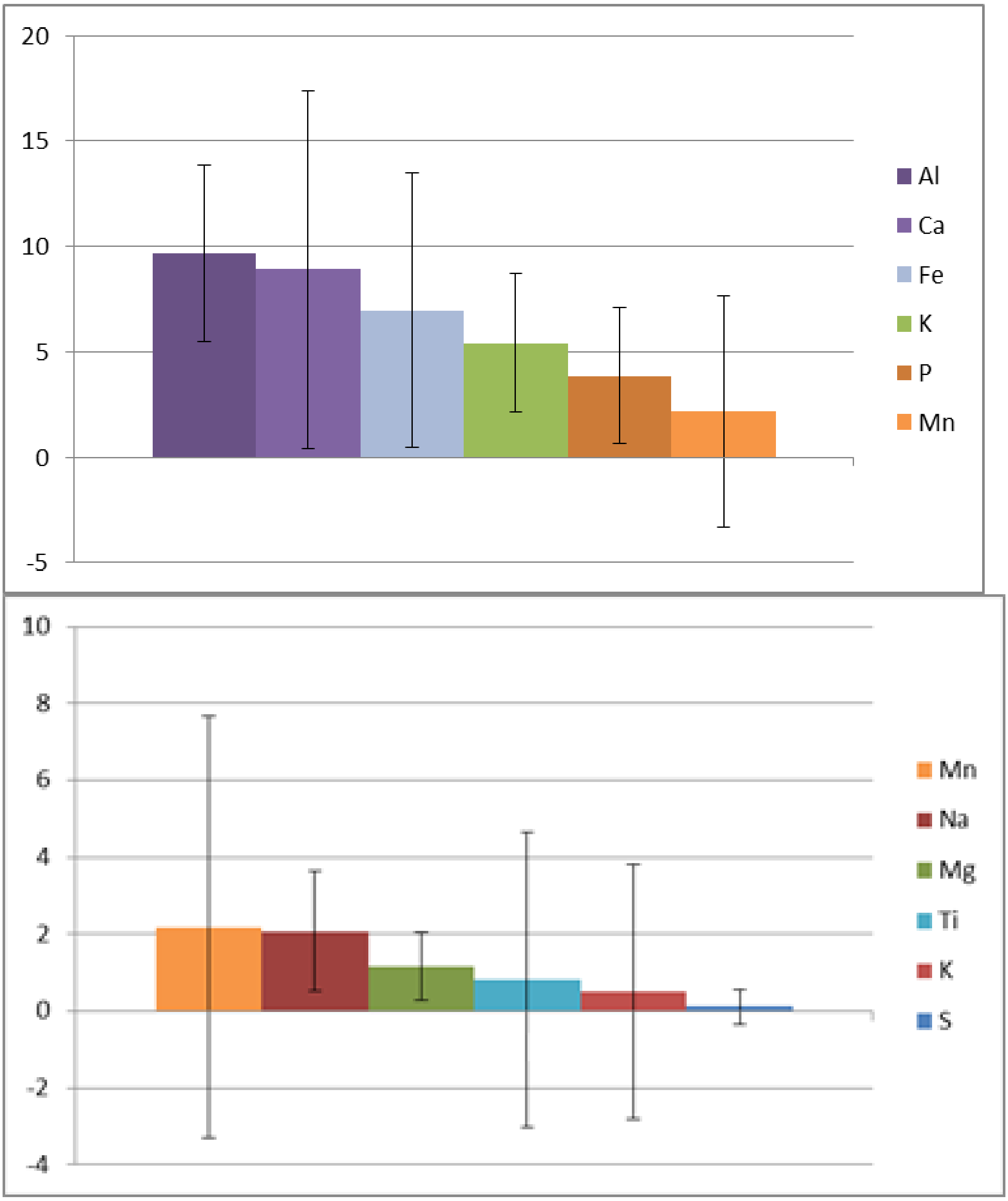


Figure 5.51: SEM EDX results for exterior occupation deposits. Top = Macro elements, Bottom = Micro elements. Results expressed in mean percent ratio, error bars = σ. Si not included, this is the main component at 58.08 ± 14.14 percent ratio.

5.5.5 *Dumped deposits*

Dumped deposits were recognised in association with almost all the structures at the Links of Noltland (Moore & Wilson 2011a & b, 2012). Two areas were sampled opportunistically alongside excavation. The deep sondage against the exterior wall of structure 8 in Area 5 and associated with the use of structure 16.

Deep sondage

Dumped deposits were recognised within the upper profile of the sediment stratigraphy built up against the enclosure wall of the structure 8 complex (figure 4.46) during excavation. The samples recovered from the sondage to investigate these sediments (134-138 and 188, figure 5.52) are reported below.

The set of thin sections appeared to be fairly homogenous on the micro-scale with individual micro-horizons difficult to distinguish. However, the characteristic channel, chamber and vugh microstructures, excremental pedofeatures and truncated coarse constituents (Figure) indicate post-depositional re-working is responsible for disturbance of these sediments. The bioturbated matrix is a mix of porphyric sandy silt with dark brown-grey organo-mineral fine fabric and inclusions of amorphous yellow, black, red and orange organic matter. Coarse fragments of mineral are consistent with the local geology, although these appear strongly weathered. Inclusions of unburned and burned bone fragments, fuel residues and artefacts are suspended within the fine matrix in an unsorted arrangement.

The natural horizon [9192] at the bottom of the profile though the east midden is unsurprisingly void of any cultural materials. It is also quite different to glacial till in control sample 115 although Fe/Mn nodules and redoximorphic features such as Fe/Mn depletion/accumulation are evident in both samples attesting to periods of wetting and drying. Fe/Mn nodules are well developed and have formed in situ.

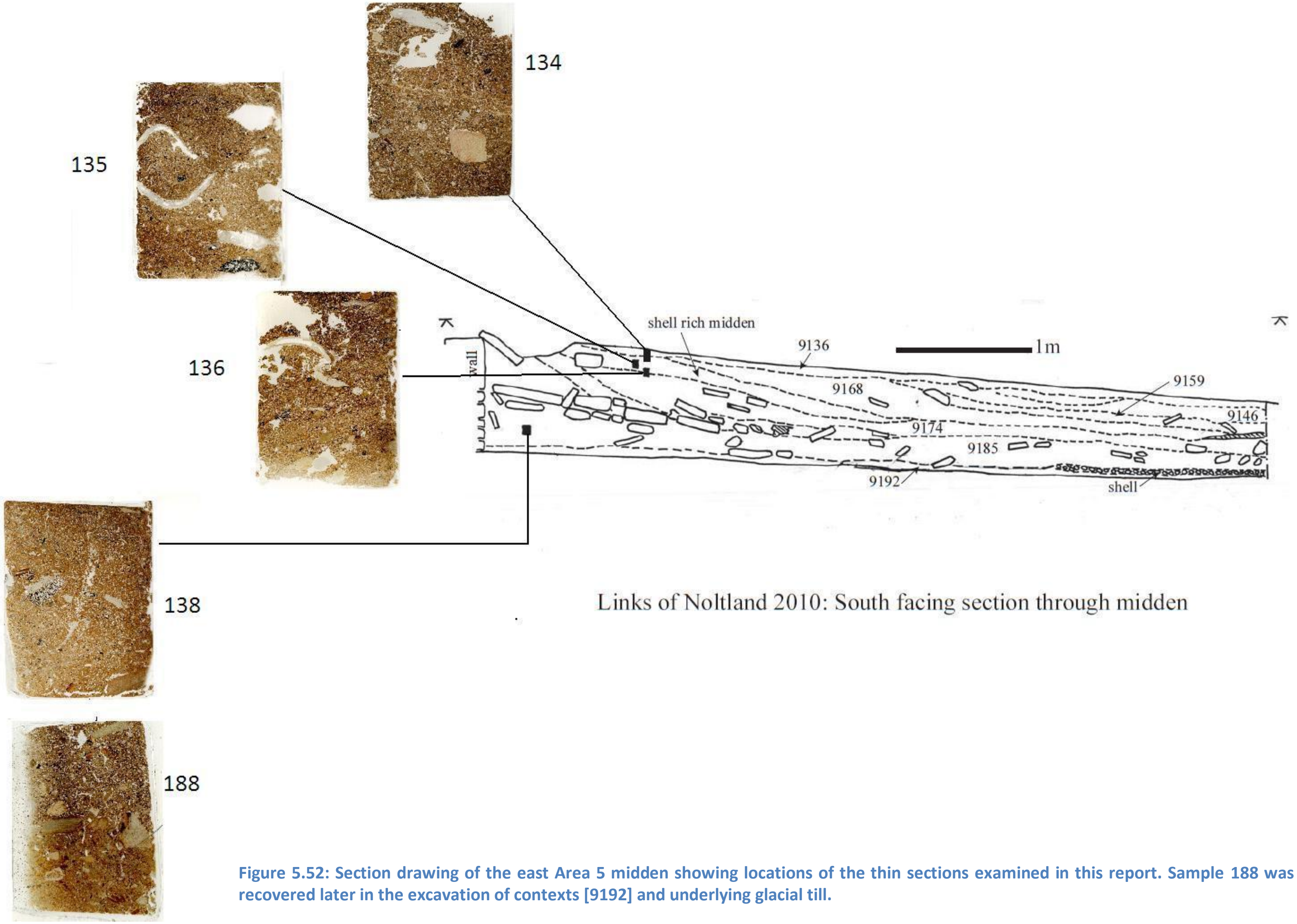


Figure 5.52: Section drawing of the east Area 5 midden showing locations of the thin sections examined in this report. Sample 188 was recovered later in the excavation of contexts [9192] and underlying glacial till.

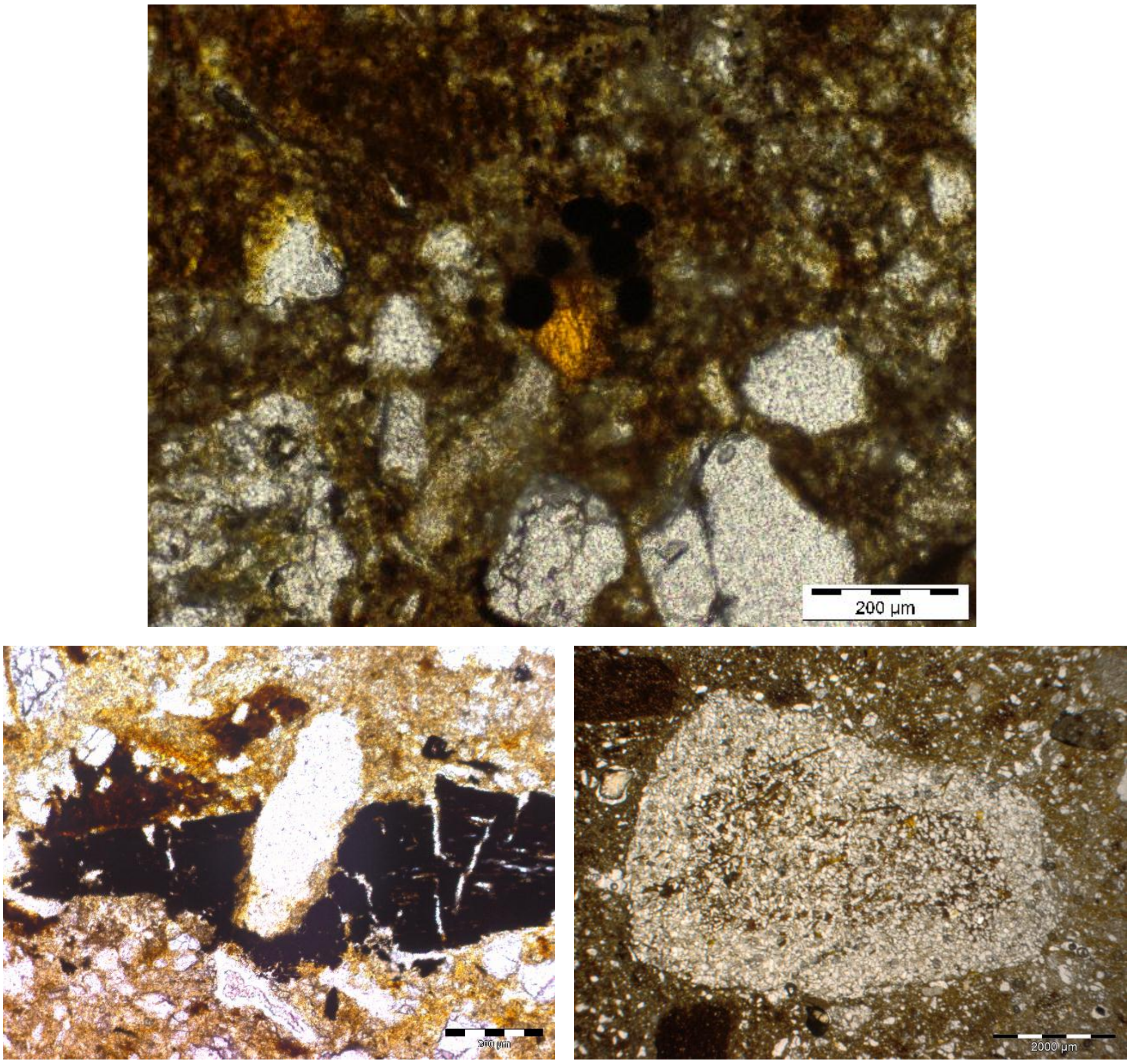


Figure 5.53: Sample 188 unit A, Pyrite framboids in Unit A, sample 188 (PPL) Bottom left = Charred plant truncated by channel/vugh (PPL). Bottom right = depletion hypocoating (bleached stone rim) (PPL).

Unlike sample 115, there is no direct evidence of soil floral remains. However, a cluster of pyrite framboids (figure 5.53) which were identified within the groundmass may countervail this as they have been shown to have formed as pseudomorphs of organic aggregates (Mees & Stoops, 2010) and in association with plant remains (Bullock et al 1985). The occurrence of pyrite framboids demonstrates sulphate reduction occurred, indicating extremely wet, persistently anoxic conditions (Gebhardt and Langohr 1999, Lindbo et al. 2010, Wilkin et al 1996).

Rock fragments in the natural horizon in sample 115 exhibit iron depletion hypocoatings and iron rims, these features are interpreted as evidence for heavy weathering in the presence of reactive organic material at the Scord of Brouster (Romans 1986), and turf derived from podzols at Tofts Ness (Simpson et al 1998).

At the boundary between the natural horizon and overlying sediment [9192] there is a row of pebble sized rocks, oriented parallel to the topography (figure 5.54). Sediment [9192] forms packing material between these rock fragments and so it is possible that they represent a prepared gravel surface or a colluvial deposit. The rock fragments themselves exhibit Fe hypo-/quasi-coatings indicating poor soil drainage and an excess of water (Bullock et al 1985). The lack of these features further up the profile indicates the degree of saturation appears to have been reduced as sediment [9192] developed.

Figure 5.54: Cropped thin section scan of sample 188 showing pebble sized rock fragments at the boundary between unit A (natural glacial till) and unit B, sediment [9192].

Individual layers within anthropic deposits in the deep sondage were described using context numbers [9185], [9174], [9146], [9168], [9159] & [9136]. Contexts [9168], [9159] and [9146] shown further to the east in figure 5.52 were unsuitable for sampling due to their stony matrix but samples 188 and 134-138[3] captured the full stratigraphy occurring up against the

[3] Sample 137 crumbled during transport and is not shown in Figure

enclosure wall of structure 8 complex ([9185], [9174], [9136] & intervening 'shell rich midden').

The earliest phase of midden formation [9185] is represented by unit B in sample 188 which intersected the boundary between this and the underlying glacial till (unit A). It contains unburned (1-5%) and burned bone (1-5%), charcoal/char (1-5%) and phosphatic material (<1%) within dark brown organo-mineral fine material creating a close porphyric related distribution. The microstructure is characterised by channels, chambers and vughs and coarse constituents are randomly arranged and poorly sorted. Coarse minerals contribute 20.2-55.8%. Burned bone fragments exhibit high intensity burn morphology and black punctuations (1-5%) are interpreted as grass char following Umbanhower & McGrath (1998). An allochthonous rubified rock fragment with attached burned turf is present within this unit (figure 5.55). This alongside other anthropic inclusions demonstrates that large fragments of hearth residues accumulated within this sediment, fragments which are larger than those found within interior floor, hearth and exterior occupation deposits.

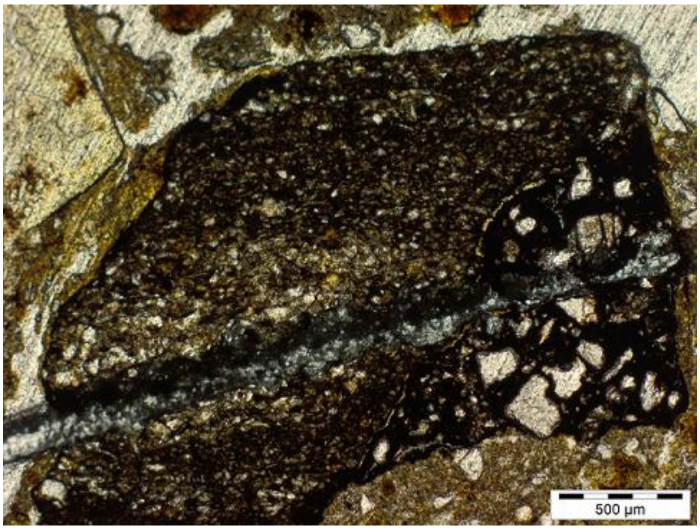


Figure 5.55: Sample 188, unit B. Burned rock fragment with attached turf component (PPL).

Sample 138 represents sediment [9185] which contained an almost complete pot (Moore & Wilson 2011b) and ashy material. In thin section there are two microstratigraphic units labelled A and B (figure 5.56a). Unit A is characterised by a channel microstructure with chambers and vughs indicative of bioturbation (figure 5.56c). The coarse fine related distribution is open porphyric with random, poorly sorted coarse fragments being surrounded by yellowish brown organo-mineral fine material with a speckled micro-crystallitic b-fabric (figure 5.56d). The coarse mineral component contributes up to 11% of the unit (quartz and rock fragments each 1-5% and mica/garnet <1%) with a single large marine shell fragment, large enough to be a scallop shell (<1%). The coarse organic component is comprised of lignified tissues (<1%) and unburned bone (<1%) with well-preserved burned bone fragments (figure 5.56e) and charcoal/charred plant fragments (each 5-15%). The burned bone fragments exhibit a yellow colour with minimal accumulations of carbon and few/no cracks indicative of low to medium intensity burning (Hanson & Cain, 2007). Black amorphous organic fine material (1-5%) exhibits the morphology of all types of fuel sources described by Umbanhower & McGrath (1998) demonstrating the wide utilization of available resources. Yellow amorphous organic material (1-5%) may be linked to food residues as it occurs in association with charred plant remains, Courty et al (1989) describe grass ash as containing yellowish admixture, a plausible origin for yellow amorphous fine material mixed into grey areas of the micromass. Grey material in this sediment includes heavily weathered quartzite which exhibits irregular linear alteration (figure 5.57f). Advanced destruction of quartz in relatively young sediments (<8000 years old) has been reported in tropical dune sands (Pye and Mazzullo 1994, cited in Howard et al 1995), but usually requires extremes of temperature and/or pressure (Howard et al 1995) as silica is extremely resistant to chemical weathering. The weathering intensity of quartz minerals at depth has been studied by Marcelino and Stoops (1996) who noted larger quartz grains tend to be more weathered with soil depth. This was attributed to hydrological and podsolization processes. The presence of such highly degraded quartz relative to the control samples may point to the phenomenon of anthroweathering as discussed by Pope and Rubenstein (1996) in which direct and indirect chemical, mechanical and catalytic processes impact weathering of coarse mineral material.

Although the groundmass has been mostly disturbed by biological reworking, a small fraction of unit A is preserved beneath a large rock fragment which exhibits weakly expressed layers (figure 5.57g) indicating several phases of deposition. Fungal spores are also present within this unit (<1%). Fe nodules are present as pseudomorphs of some charcoal fragments, these well rounded fragments are orthic, have formed in situ.

The boundary between units A and B is very diffuse, as mixing of the two groundmasses has occurred. Unit B is characterised by an open porphyric coarse fine related distribution punctuated by channels, chambers and vughs. The coarse mineral fraction is randomly orientated and poorly sorted and contains 1-5% quartz, 1-5% rock fragments, <1% quartzite and <1% garnet/mica. The coarse organic components are burned peat (1-5%), charcoal/charred plant remains (5-15%) and a trace of almost dissolved bone (figure 5.57h) (<1%). The bone fragment has collected Fe and burning was not apparent. The colouration is similar to amorphous orange fine material (1-5%) and could be the source of this constituent. The darker colouration of the fine organo-mineral material in unit B compared to unit A is due fewer depletion mottles (5-15%) and darker fabric constituents such as orange amorphous material and charcoal fragments. Black amorphous nodules (PPL) were identified as Fe nodules by their bright red appearance in OIL (<1%). Some weakly expressed layering of disaggregated black (peat) and orange amorphous fine material and ash can be observed to the top of the slide (figure 5.57i).

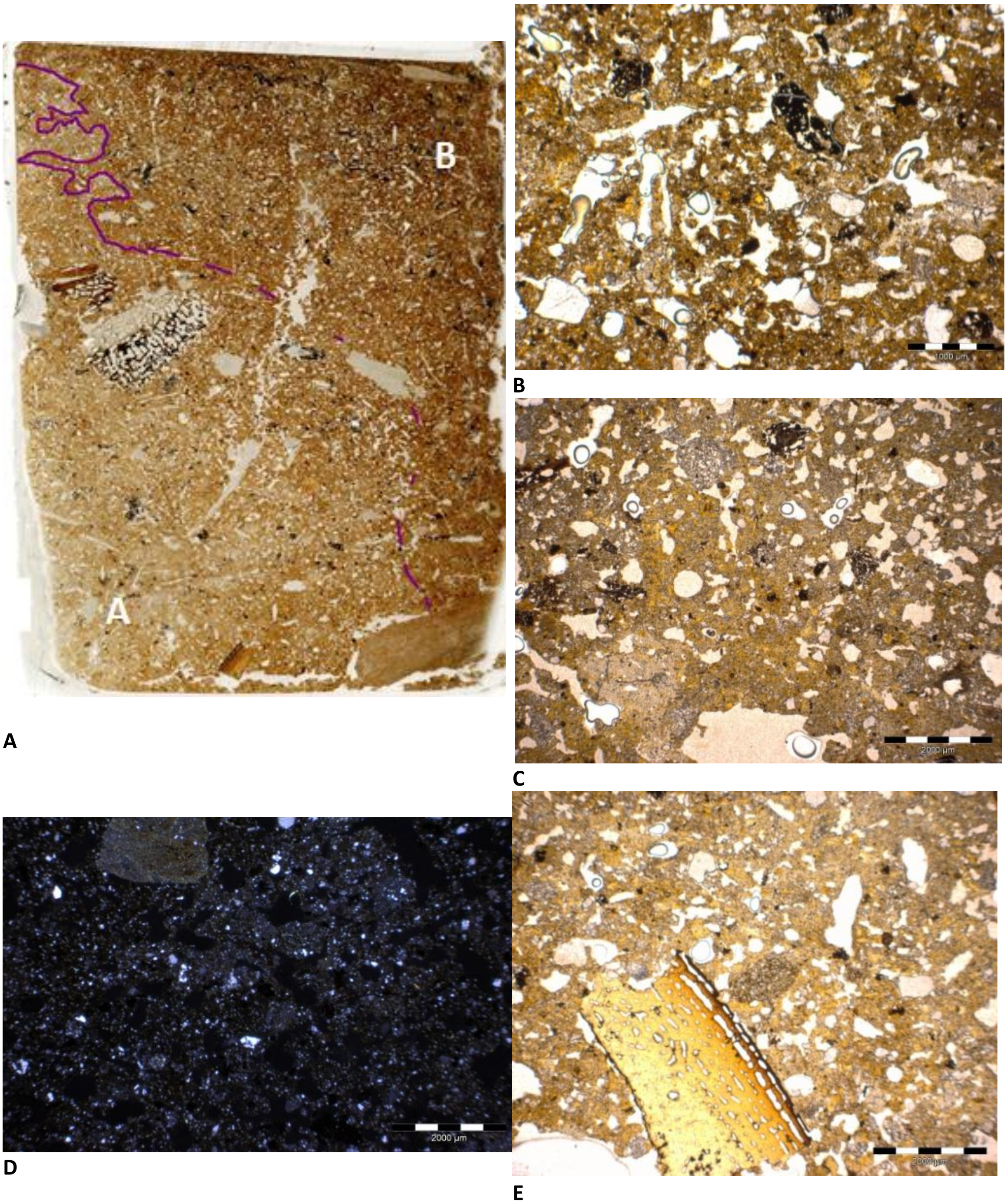
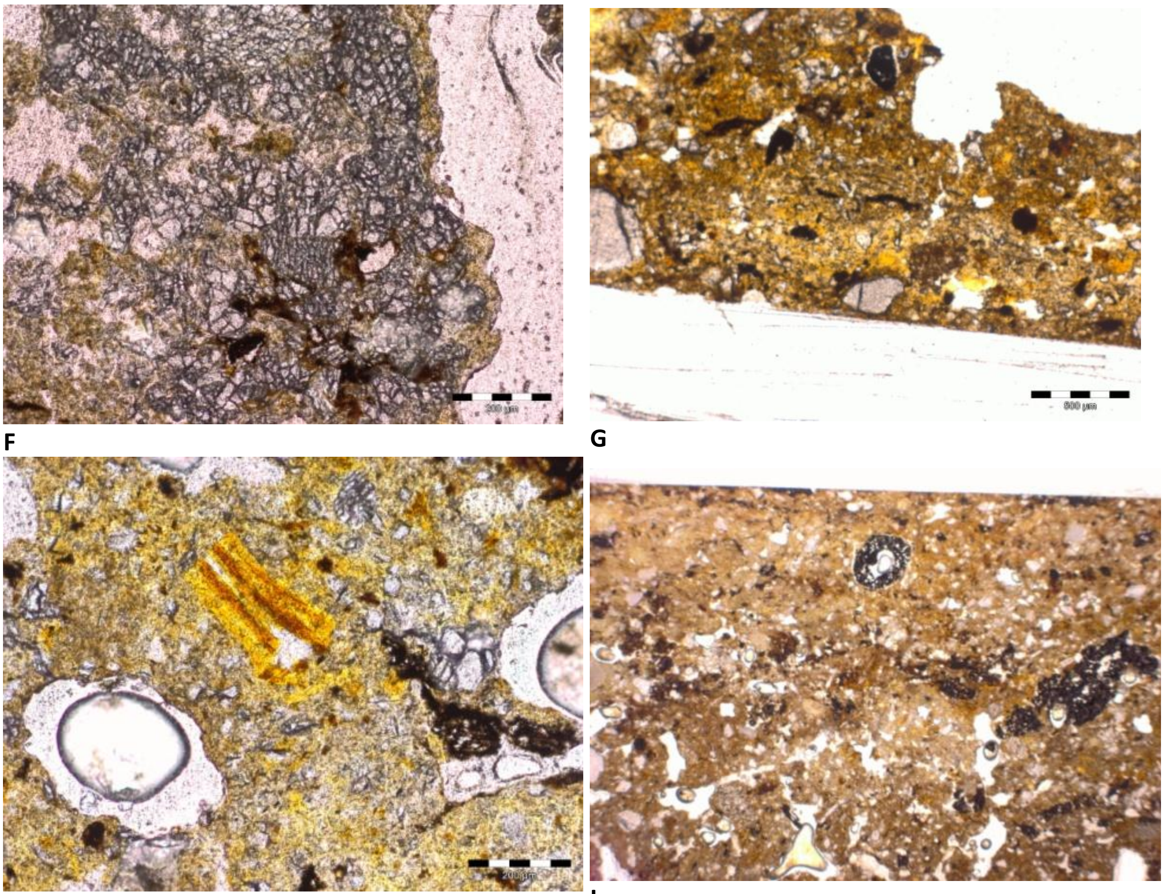


Figure 5.56: (A) Thin section scan of sample 138 showing microstratigraphic units A and B and the boundary between them. (B) Groundmass, unit B (PPL). (C) Channel microstructure with chambers and vughs in microstratigraphic unit A (PPL). (D) Birefringent fabric in unit A (XPL). (E) Burned bone in unit A (PPL).



F G H I

Figure 5.57: (F) Heavily weathered minerals in unit A (PPL). (G) Weakly expressed lamination of amorphous orange deposits and silty groundmass (PPL). (H) Well decomposed burned bone (PPL). (I) Weakly expressed layers in unit B. (PPL).

Morphologically sediments [9192] and [9185] at the base of the profile exhibit similar characteristics to those of exterior surface deposits in soil test pit 2 and in sample 100. This supports the field observations that the earlier deposits may have been generated at the same time as occupational sediments.

Sample 136 was recovered from sediment [9174] described in the field as a mid-brown ashy silty clay, containing notably fewer artefacts as upper layers in the sequence and overlying rubble possibly related to the decay of structure 8. In thin section there are five discernible microstratigraphic units labelled A-E (), all microstructures are characterised by channels, chambers and vughs in an open porphyric related distribution with speckled micro-crystallitic b-fabrics. The earliest formed microstratigraphic unit, ‘A’ exhibits randomly arranged and poorly sorted coarse minerals, contributing 5-15% quartz. 1-5% mica and 1-5% rock fragments.

A trace (<1%) of marine shell represents a single large fragment and is not aeolian. There is also a trace (<1%) of charcoal or charred plant remains but the organic component is mostly fine with even amounts of red/orange, black and yellow amorphous material (each 1-5%) mixed with very light brown, yellow and grey organo-mineral groundmass. Grey material in this sample is associated with heat affected minerals and charred plant remains indicating that the silica features reported within this sample may be related to fuel residues.

The boundary between units A and B is smooth with rock fragments and associated void space in unit B resting upon the upper limit of unit A which is perhaps a continuation of the type of prepared gravel surface reported in sample 188. Sand and silt size coarse grains are randomly arranged in unit B, but larger rock fragments exhibit some weak striation. The coarse mineral component comprises quartz (5-15%), mica (1-5%) and rock fragments (1-5%). Marine shell present (<1%) does not represent aeolian sand. There are traces (<1% each) of charcoal and unburned bone fragments but the unit is mostly composed of fine organic material, amorphous red/orange (5-15%, black (1-5%) and yellow (1-5%) and grey material (5-15%). Pedofeatures related to Fe movement are present (accumulation, 2-5% and nodules, 1-2%) indicating wetting and drying of the profile whilst sandy, dust and limpid clay (1-2% each) textural infill demonstrates down profile movement of organic and mineral material at various energy levels.

A compound pedofeature composed of amorphous fine material forms weakly expressed layers tilted onto their side (Figurea), this forms granostriations around a rock fragment. This is a very similar feature to the granostriated yellow amorphous material in sample 100 and a yellow organic coating of a rock fragment in sample 101.

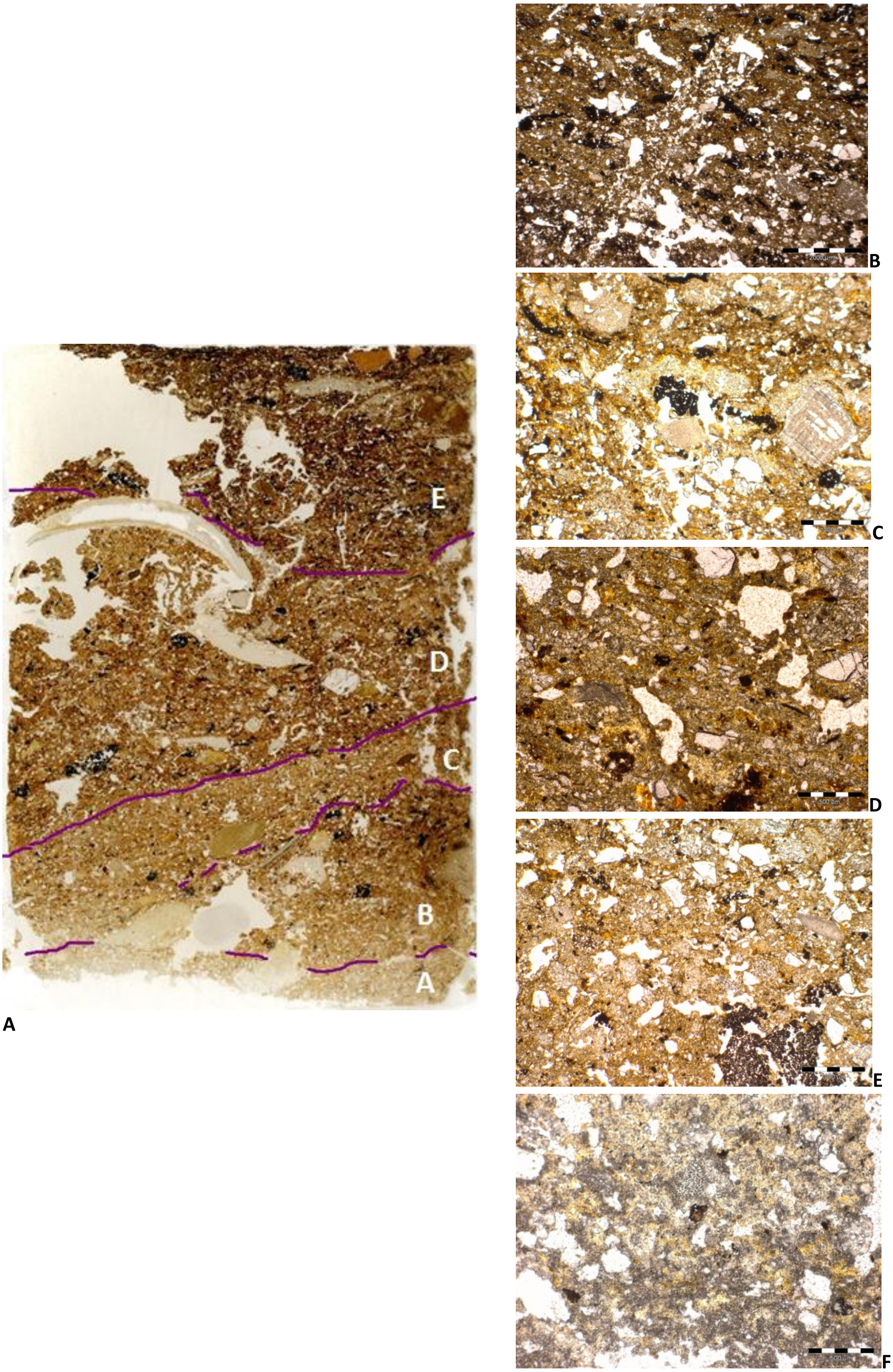


Figure 5.58: (A) Thin section scan of sample 136 showing boundaries between microstratigraphic units. (B) Laminations of amorphous organic fine material within the groundmass of unit E (PPL). (C) Groundmass unit D (PPL). (D) Groundmass unit C (PPL). (E) Groundmass unit B (PPL). (F) Groundmass unit A (PPL).

The boundary between units B and C is diffuse and difficult to discern. This unit is characterised by a more compact microstructure and appears to slope at around 30° which may indicate that unit B reflects the angle of repose of a discrete dumped deposit. The coarse mineral arrangement of unit C is random and poorly sorted but the b-fabric exhibits weak striations which suggests this unit is a discrete surface lens which has been subject to light compaction or trampling (Simpson et al 1999).

Marine shell fragments (1-5%) are poorly sorted but several sand sized particles could be aeolian. Quartz, quartzite and rock fragments all contribute 1-5% of the coarse mineral fraction. Organic material is again mostly fine, with amorphous red/orange and black contributing 5-15% each and yellow 1-5%. The coarse organic components are charcoal/charred plant (1-5%), burned peat (1-5%) and unburned bone (<1%). Bone is also present as calcium iron phosphate (figure 5.58b) mixed with grey material which contributes 5-15% of the unit. The micromass is light brown and grey organo-mineral (PPL), white and light brown (OIL).

The boundary between unit C and D is smooth and distinct representing an abrupt change in deposition. The coarse mineral arrangement is random and poorly sorted although weak striations are present in larger rock and shell fragments. Marine shell contributes 5-15% of the unit. Larger fragments representing almost intact shells, sand sized fragments are well worn and could be possibly be aeolian in origin. Quartz fragments contribute 5-15% and rock fragments 1-5%. There are traces (<1% each) of quartzite and mica. A trace element of pottery is also recorded (<1%).

The micromass is mid-brown and grey organo-mineral (PPL), light brown and white in OIL. The grey colouration is related to mottles of grey material (5-15%). Grey material is present in two forms. Some patches contain coarse minerals and could be weathering products whilst others contain a trace amount of diatoms and phytoliths (<1%, figure 5.59c&d) but very few fine minerals.

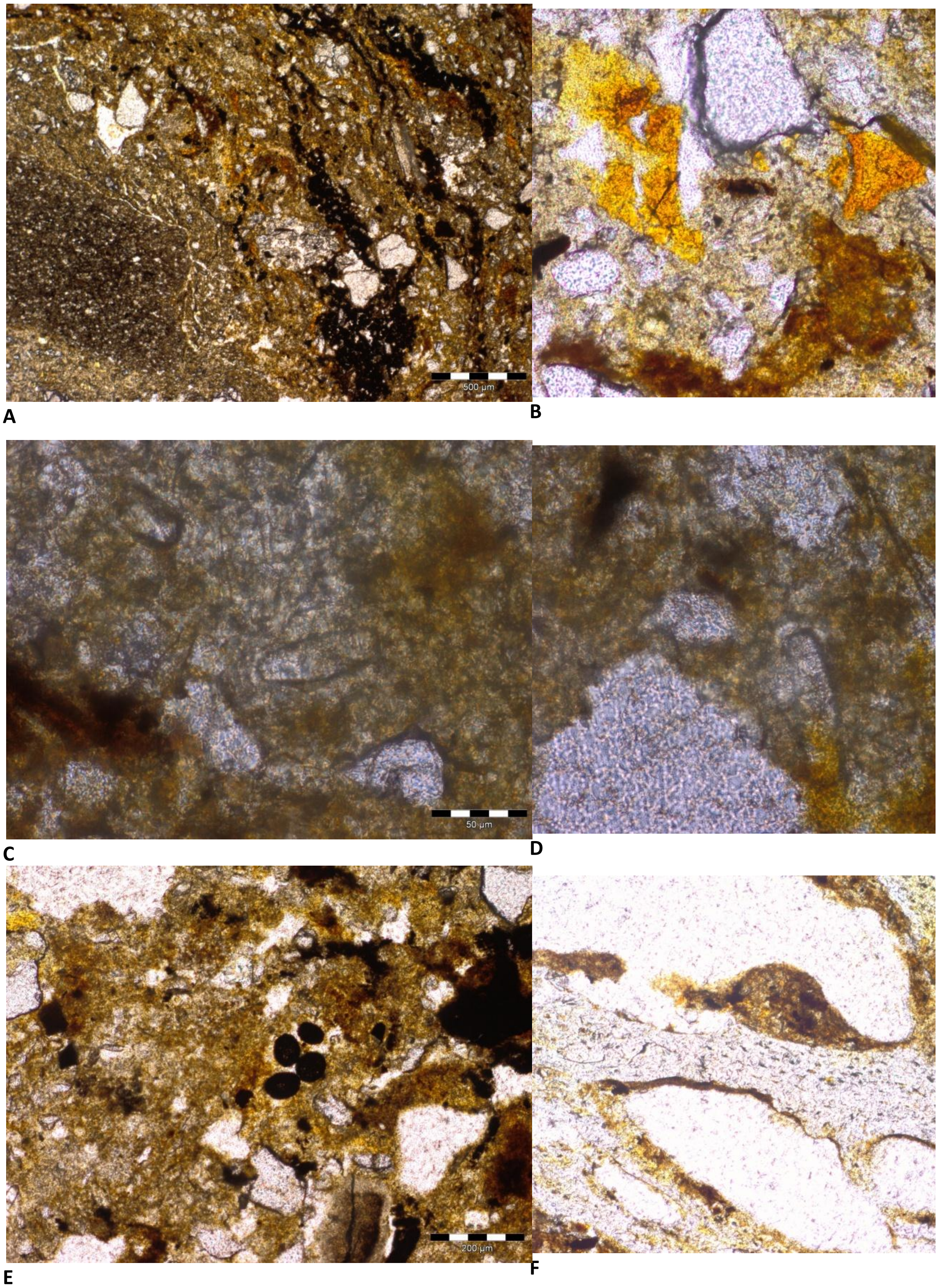


Figure 5.59: Sample 136 (A) Compound pedofeature in unit B (PPL). (B) Calcium iron phosphate in unit C (PPL). (C) & (D) Diatoms and phytoliths in grey material, unit D (PPL). (E) Fungal material in unit D (PPL). (F) Dusty clay infill of bone fragment in unit E (PPL).

This subset of grey features is interpreted as either coprolite or peat fuel residue. Rubified peat is also visible in the coarse organic fraction of the unit (1-5%) and charcoal/charred plant contributes 5-15%. Fragments of unburned bone are also present (1-5%).

The boundary between units C and D is smooth and distinct. Within unit D the coarse mineral arrangement is poorly sorted and predominately random with some weakly developed striations. The coarse mineral component is comprised of marine shell (5-15%), quartz (5-15%), rock fragments (1-5%) and traces of mica, quartzite, cramp and pottery fragments (<1% each). Larger shell fragments are coarse sand sized to a very large well preserved scallop shell fragment, the smaller grains are angular and probably not aeolian. The micromass is mid brown and grey organo-mineral (PPL) or light brown and white in OIL, the birefringent fabric is speckled microcrystallitic related to decomposition of sand sized grains. The coarse organic component comprises charcoal and charred plant remains (5-15%), burned peat (1-5%) and unburned bone (1-5%). Grey material contributes 5-15% of the unit (white in OIL), this contains phytoliths and diatoms (<1%, figure 5.59c&d). Heat altered clay aggregates (<1%) with the characteristics of those interpreted as hearth rake out are present within this unit allowing the interpretation of a hearth maintenance deposit. The organic fine material is composed of amorphous red, black and yellow residues (1-5% each). Fungal material is present within the organo-mineral micromass (<1% figure 5.59e) and there are some indications of iron movement (Fe/Mn accumulation 1-2%). Dusty coating/infill pedofeatures (1-2%) originate from down profile movement of fine particles.

The boundary between units D and E is fairly smooth but at higher magnification is diffuse. Unit E contains coarse fragments surrounded by dark brown organo-mineral fine material (PPL) which reflects light brown in OIL. The poorly sorted coarse minerals are typically randomly arranged although some weakly formed striations are present. The b-fabric is speckled micro-crystallitic. The coarse mineral component is comprised of quartzite (5-15%), marine shell (<1%), mica (<1%), rock fragments (<1%) and pottery fragments (<1%). Charcoal/ charred plant remains (5-15%) and burned peat (5-15%) contribute to the coarse organic component along with unburned bone fragments (1-5%) and burned bone fragments (<1%). Grey material is frequent (30-50%) and contains diatoms (<1%). The fine organic component is typical of microstratigraphic units represented in this sample comprising amorphous red/orange, black and yellow material (1-% each). Organic material forms micro-laminated layers (138b) which have been severely truncated by later faunal activity. Dusty clay coatings attest to the down profile movement of fine material.

Sample 135 was recovered from a sediment described in the field as a 'shell midden'. In thin section this can be further described as a sandy deposit containing fuel residues. The groundmass is fairly homogenous although two discrete units, labelled A and B have been discerned based upon differences in the coarse mineral component and birefringent fabric of the two areas. Figure 5.60a demonstrates the rough boundaries between these two units but they are well mixed. The microstructure of both units is characterised by channels, chambers and vughs which are mostly unconnected in an open porphyric coarse fine related distribution (figure 5.60b). The randomly arranged, poorly sorted coarse mineral component in unit A is comprised of marine shell fragments (5-15%), quartz (5-15%), quartzite and rock fragments (<1% each) with two very large shell fragments visible in the macroscale (figure 5.60a) and a disturbed layer of burned shell fragments (figure 5.60d). The coarse organic components are charcoal/charred plant (5-15%) and burned bone (1-5%). Some bone fragments exhibit weak histological structures and carbon deposits (figure 5.60e), the optical signals for high intensity burning whilst others are yellow with preserved histology, indicators of low intensity burning(Hanson & Cain 2007). The fine material is dark brown and grey organo-mineral (PPL) and the b-fabric is speckled micro-crystallitic. Grey material contributes 5-15% of the unit and is well mixed into the micromass. A trace amounts of diatoms (<1%) indicate a wet origin for some components and could suggest the peat ash input. Fine organic material includes punctuations (1-5%), amorphous orange (5-15%), amorphous black (5-15%), amorphous yellow (5-15%) and pigment (<1%). These amorphous constituents form weakly expressed, disturbed banded layers and have a similar appearance to carbonised layers identified as burned bedding in middle stone age cave deposits in Sibudu shelter, South Africa (Miller & Sievers 2012). It seems likely that these deposits represent some form of settlement maintenance activity, perhaps in situ burning of a secondary or tertiary grassy deposit (Shillito & Matthews 2011).

There are trace amounts of Fe/Mn accumulation, hypocoatings and depletions (<1% each) and limpid clay coatings of voids (<1%). Heat altered clay is also present (figure 5.60f), indicating hearth rake-out. Coarse minerals in unit B are few, contributing marine shell (1-5%), quartz (<1%), mica (<1%) and rock fragments (<1%). The coarse organic component contains well decomposed plant material (<1%) but is mostly comprised of carbonised plant and charcoal (1-5%). Fine organic material is well mixed into the micromass, orange amorphous being the most prevalent (5-15%) whilst black amorphous and black punctuations contribute 1-5% each and yellow amorphous and pigment add <1% each. Fe/Mn impregnation of rock fragments and the micromass is identified as rubification in OIL (figure 5.60g) and limpid coatings/infill of voids are occasional (2-5%), some are limpid clay and some are composed of amorphous fine organic material (figure 5.60g).

Sample 134 was recovered from the uppermost sediment in the stratigraphy, described in the field as a dark brown-black silty clay or humic soil [9136]. The thin section captured the boundary between this sediment and underlying 'shell midden'.

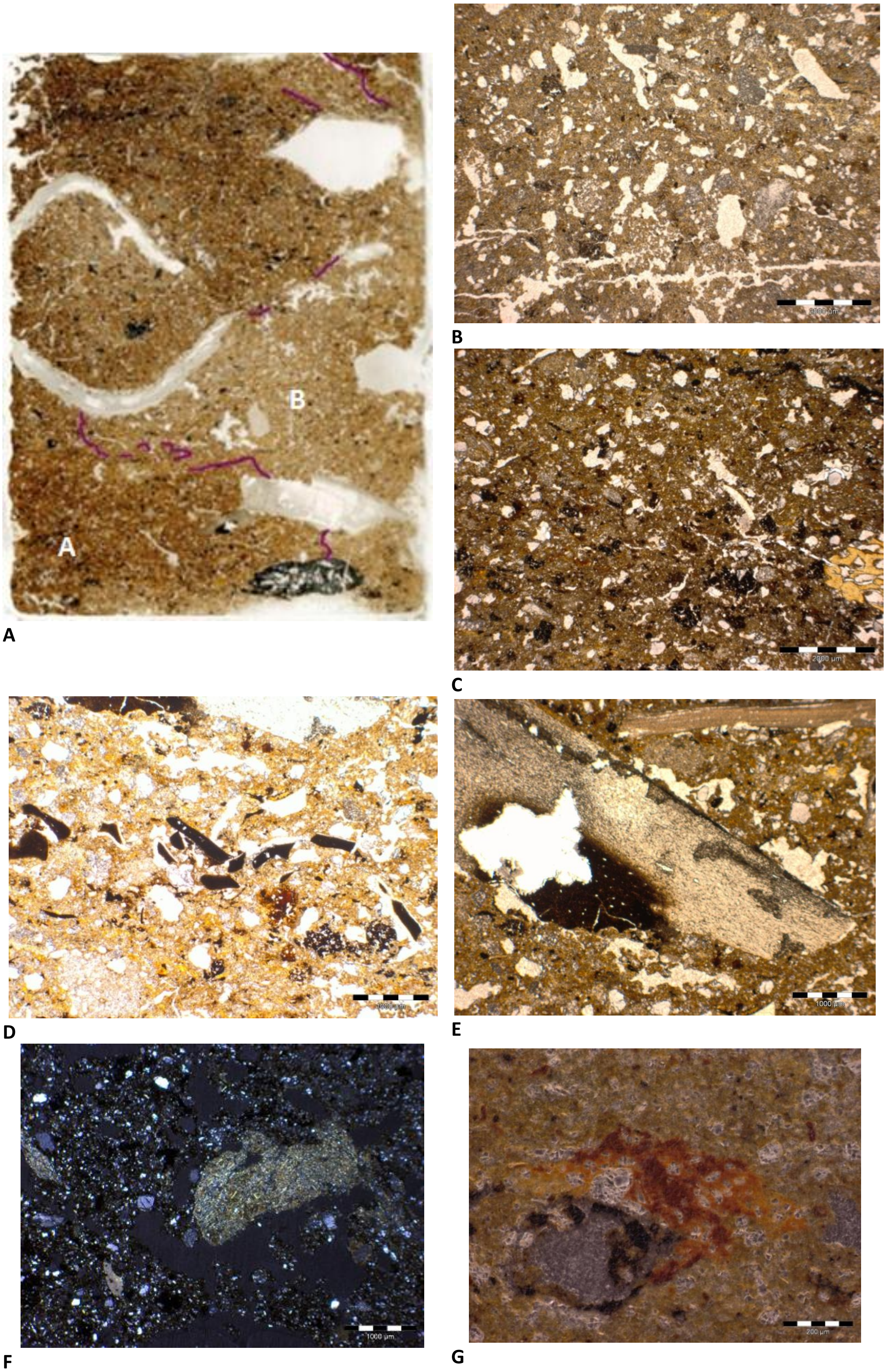


Figure5.60: (A) Thin section scan of sample 135 showing diffuse boundaries between units A and B. (B) Groundmass in discrete unit B (PPL). (C) Groundmass in discrete unit A (PPL). (D) Burned shell fragments in unit A (PPL). (E) Bone burned at high intensity in unit A (PPL). (F) Clay aggregate in unit A (PPL). (G) Fe impregnation of micromass and amorphous black coating of void in unit B (OIL).

In thin section there is no visible distinction between the two contexts described in the field, but a crust of grey material (figure 5.61**a**) may represent a hiatus in formation. The internal birefringent fabric of the grey crust exhibits directional striation (figure 5.61**c**) indicating compaction of fine material. The groundmass of the slide is uniform throughout, characterised by channels, chambers and vughs with some unconnected vertical fissures (figure 5.61b). The coarse fine related distribution is open porphyric and the coarse mineral distribution is random and unsorted. The coarse mineral component is comprised of sand sized marine shell (1-5%) with rounded morphology which could be aeolian but also includes one very large fragment to the top left (figure 5.61**a**). Also present is quartz (5-15%), quartzite (1-5%), rock fragments (1-5%) and heat altered clay (<1%). The birefringent fabric is speckled micro-crystallitic, related to decomposition of the coarse mineral grains and ash. Grey material contributes 30-50% of the slide forming mottles in dark brown (PPL) (mid-yellowish brown, OIL organo-mineral fine material). Diatoms (<1%) are associated with grey material. Coarse organic material is notably less present than in other slides. With 1-5% charcoal/charred plant remains, <1% burned turf fragments, and burned bone (1-5%) heated at high intensities. Bone is also present as calcium iron phosphate features. Fine organic material includes punctuations (1-5%) orange amorphous (5-15%), black amorphous (5-15%), yellow amorphous (1-5%) and fungal spores (<1%). Amorphous organic material forms microlaminations as described within sediment [9174] and the 'shell midden' layer. Fe/Mn accumulation impregnates turf and rock fragments and bone 2-5% and traces of dusty clay infill can be identified in black amorphous fine material, postdating it. Excremental pedofeatures can be distinguished in this slide (figure 5.61**e**). This is the only representation found in the profile samples which may be due to compaction.

Many discrete lenses were identified within the deep sondage deposits reflecting changing formation processes and depositional events. The general formation processes represented are interpreted as very similar in appearance to exterior occupational surfaces, although anthropic activity seems to be more intensive, reflecting in higher levels of inclusions and amorphous organic material (figure 5.62). The earliest sediments exhibit intense reduction and organic matter charring under reducing conditions. Fe/Mn accumulation coats channels and vughs indicating that re-precipitation of reduced iron/manganese postdates void formation – therefore, faunal channels formed before increased wetness became persistent.

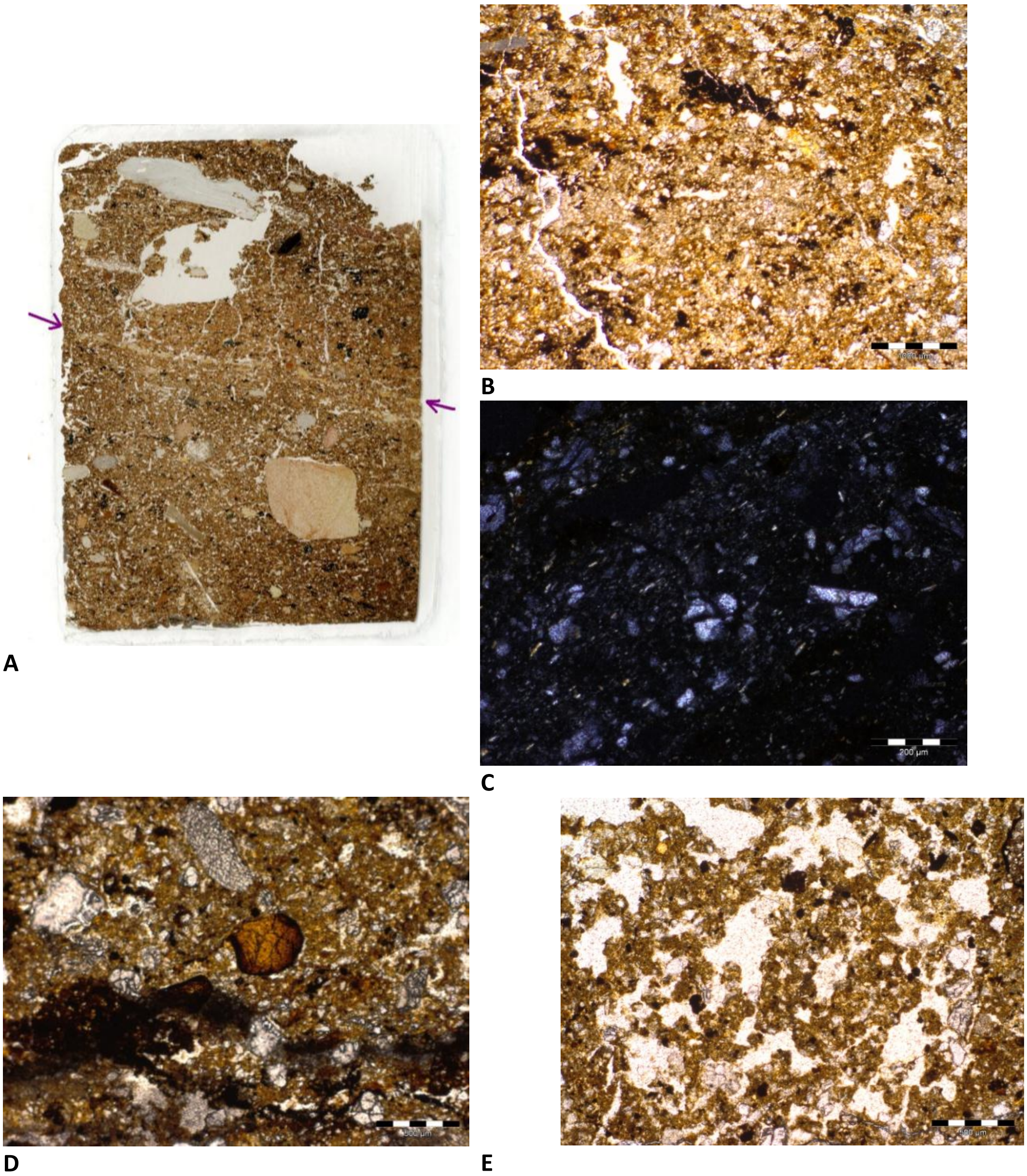


Figure 5.61: (A) Thin section scan of sample 134 arrows point to grey crust. (B) Groundmass (PPL). (C) Striated birefringent fabric in grey crust (XPL). (D) Heat altered clay fragment (PPL). (E) Excremental pedofeatures (PPL).

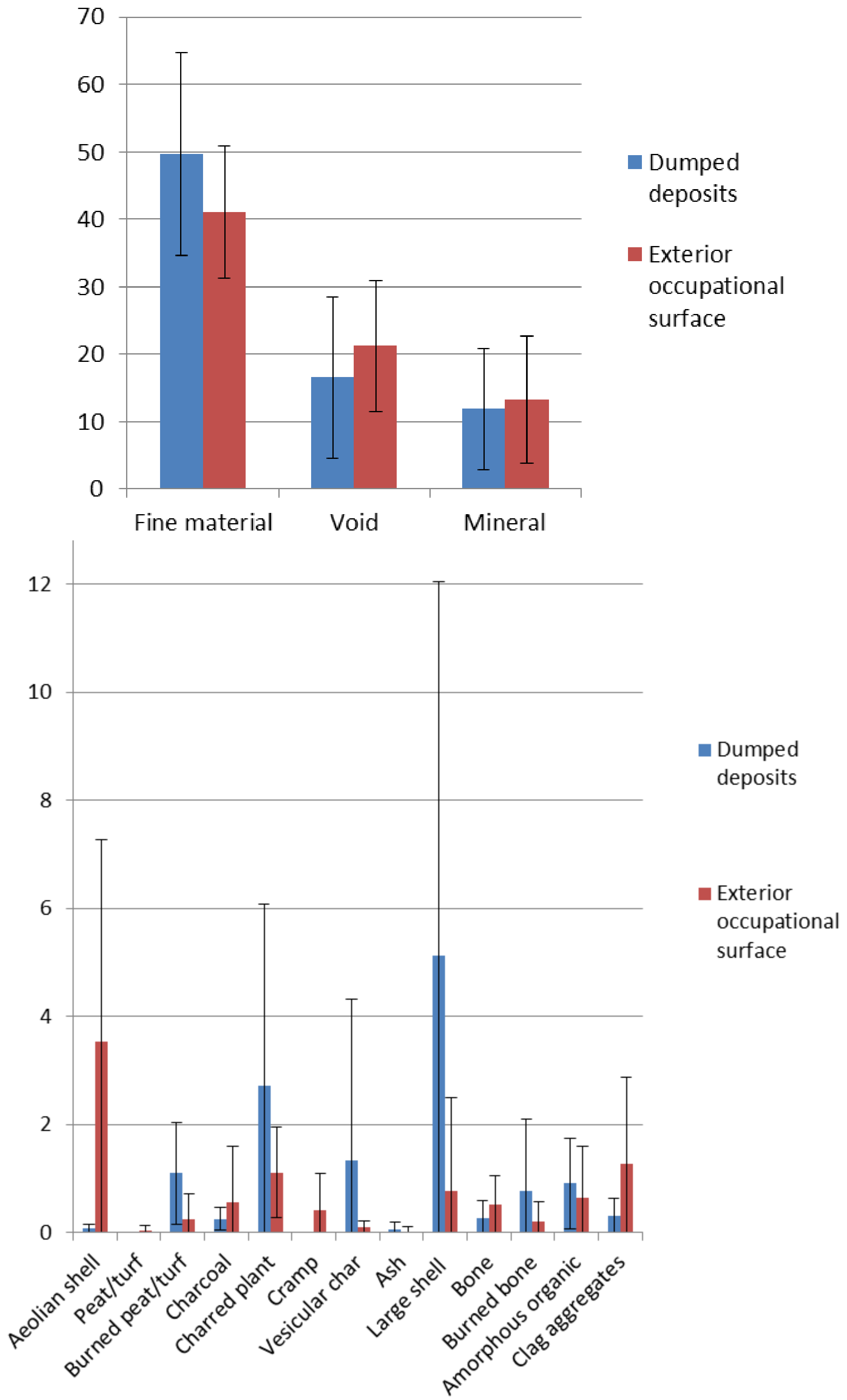


Figure 5.62: Point count results comparing dumped deposits samples 188b, 138, 136, 135 and 134 with exterior occupational surface samples 85a, 85b, 87, 88. 90 and 100 Top = Macro elements, bottom = micro elements. Results expressed as mean percent ratio, error bars = σ

The sediments formed above the layer of rubble, possibly representing the decay of structure 8 indicate a continuous formation process characterised by discrete dumps of material and microlaminations of amorphous organic material reminiscent of in situ burning of grassy materials but highly bioturbated. Despite soil reworking, the level of in situ decomposition of organic remains implies that these deposits were allowed to remain in situ following initial deposition.

Structure 16

Like many of the structures at the Links of Noltland, structure 16 was part of a pair with structure 17, their entrances facing each other (Moore & Wilson 2012). The dumped deposits associated with these structures were described in the field as postdating the use of structure 17 (an ancillary to structure 16) but formed whilst structure 16 was in use (Moore & Wilson 2012). The sediments were described as a 0.4m deep sequence of midden rich deposits, containing at least 12 stratigraphic layers and were contained by a wall [9863] (ibid.)

In thin section 195, four microstratigraphic units are described (figure 5.63) representing two periods of aeolian sand intrusion (A and C) and two periods of anthropic sediment accumulation (B and D). These units correspond to sandy sediments [9813] (unit A) and [9811] (unit C) and red brown silty clay interpreted in the field as hearth waste [9812] (unit B) and dark brown/ black silty sand containing frequent shell and occasional small stones [9810] (unit D).

Unit A is characterised by aeolian shell sand (30-50%) in an enaulic or locally close porphyric related distribution with complex packing voids and brown organo-mineral fine material (PPL and OIL). Fine material has entered unit A from unit B, this is evidenced by many (5-10%+) silty coating pedofeatures. Anthropic inclusions have also entered the unit in this manner and are limited to charred plant fragments (1-5%). The boundary between these two units is therefore faint under magnification but in the macro-scale is clear enough to suggest the deposition of sediment [9812] was rapid.

Sediment [9182], unit b, is characterised by a bioturbated channel, chamber and vugh microstructure which is otherwise open porphyric with randomly distributed, poorly sorted coarse minerals (aeolian shell sand, 5-15%, quartz 1-5%, quartzite 1-5%). Fine material is brown organo-mineral (PPL), coloured brown/yellow/bright orange in OIL reflecting pockets of peat ash. Black and orange amorphous (5-1% and 1-5% respectively) microlaminations and peat ash (1-5%) (recognised by its strong orange hue in OIL) or grey material (5-15%). The arrangement of these materials is indicative of multi-sequence in situ burning layers (Courty et al 1989). Discrete lenses of black amorphous material exhibit a cracked microstructure (figure 5.63, left detail) and similar morphology to black laminations in sample 76, 77 and 78 interpreted as charred herbivore dung. These lenses are better preserved in sample 195 and are associated with calcium spherulites (figure 5.63).

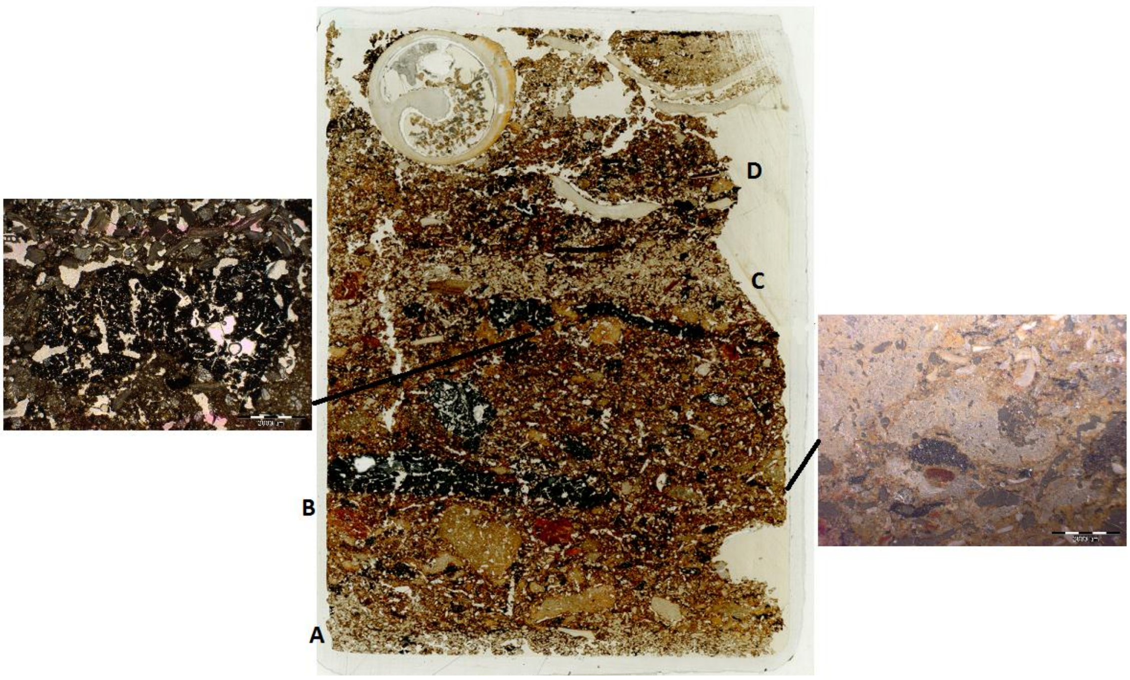


Figure 5.63: Thin section scan, sample 195. Left detail = herbivore dung (PPL), right detail = in situ burning (OIL).

Investigation of these features using Canti's method (1998) for identifying dung spherulites was employed which positively identified dung spherulites (figure 5.64). Amongst reference samples that contain spherulites of this type there is a strong tendency for higher numbers to be produced by herbivorous animals grazing plants from soils with pH higher that 6 (Durand et al 2010). Alkaline conditions promote the survival of these spherulites and so the input of calcareous marine shell sand is likely to have decreased pH and allowed their survival. No evidence was found in the Area 5 deposits for dung spherulites, this may be due to their dissolution under acidic, reducing conditions. The presence of bone fragments in unit B is limited to <1% unburned specimens, given the preservation of dung spherulites it seems unlikely that the absence of bone is due to dissolution and so it appears deliberate bone deposition was not employed in the formation process of sediment [9812]. The formation processes at work within this sediment are the in situ burning of peat, woody charcoal, grassy material and herbivore dung.

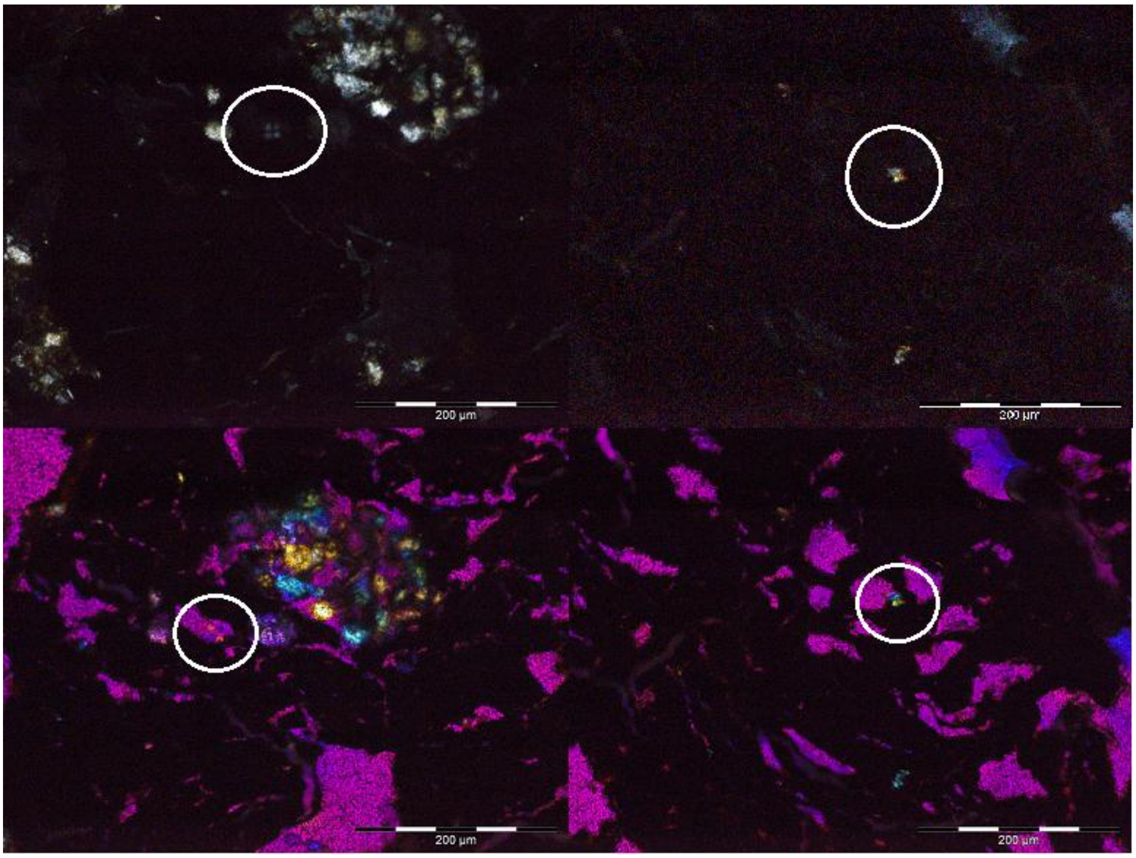


Figure 5.64: Calcium spherulites associated with herbivore dung in sample 195. Top row = XPL, bottom row = using Canti's method (1998) for detecting low order and high order banded interference colors using a λ plate and a quartz wedge.

Grey material containing diatoms contributes 5-10% of the unit fabric. This is dealt with in more detail below (4.5.1.2). Excremental pedofeatures are occasional in unit B to common in unit C which demonstrates the organic rich nature of the sediments. Unit C is a very thin layer of aeolian sand which has been truncated by soil faunal activity and mixed with fine material and anthropic inclusions from units B and C. It does however remain recognizable as a distinct sand blow event.

The final sediment recovered within sample 195 is sediment [9810], unit D. This material shares characteristics with unit B but is more heavily disturbed by soil faunal reworking and deposition of large shell fragments. It is interpreted as a continuation of formation processes described for unit B with additional shell deposition and mixing superimposed upon this. Laminated black amorphous material at the extreme upper edge of the slide indicate the in situ burning process continued following large shell deposition. Some shell fragments also exhibit evidence of burning.

5.5.5.1 *Grey material*

Although the sequence of sediments in the deep sondage were described in the field as 'ashy' no diagnostic evidence for large amounts of either calcitic wood ash or peat ash was observed through standard micromorphology. Due to the level of bioturbation, any fuel residue derived ash deposited at or near the surface would have been easily comminuted and distributed throughout the profile so the presence of highly amorphous grey patches composed of aggregates too small to be viewed with the BX-50 microscope presented a challenge.

The morphology and colour of these features was indicative of depletion pedofeatures which can give an ashy texture in the field. To test whether the grey aggregates represent ash or depletion, SEM EDX analysis was conducted to test whether enrichment of elements associated with ash could be detected and comparisons with fine material from the sample were made to test whether loss of elements characteristic of the groundmass was evident.

Eleven sites of interest containing grey aggregates were chosen from regions across the deep sondage sample set and eleven from the sediment matrix and the standard protocol was applied.

The inorganic contents of both wood and peat ash depend to some extent upon the locally available materials but the main components tend to be Ca, K, Fe, Mg and P (Mandre et al 2010) with peat ash containing higher concentrations of Fe and Ca than wood ash but lower concentrations of K and P.

The grey features contain less Mg, Al, P, K, Ca, Fe, Ti, and Mn than the sediment matrix (figure 5.65), this is confirmed statistically (P=0.05) with a Kruskall-Wallis test and post hoc pairwise comparisons for Mg, P, Ca, Mn and Fe. K, Al and Ti are perhaps more complicated due to high background levels in control samples. Levels of Na, Si and Cl were higher in the grey features, but only Si was confirmed as statistically significant. Heightened Si and lowered Ca were reported in experimentally burned cow dung (Braadbaart et al 2012), but ratios of Ca:Si are similar between grey features, sediment matrix and published cow dung ash (55:45, 54:46 and 52:48 respectively) and so this is a cautious interpretation.

The grey features are not calcitic or peat ash and there is no evidence of fuel residues in particular association with the grey material. They do however exhibit evidence of Mg, P, Ca, Mn and Fe depletion relative to the sediment matrix. This may be due to post-depositional redoximorphic conditions. Fe/Mn accumulation, nodules and hypocoatings of voids are evidenced throughout the sondage samples and so the grey features could be part of a complex cycle of wetting and drying.

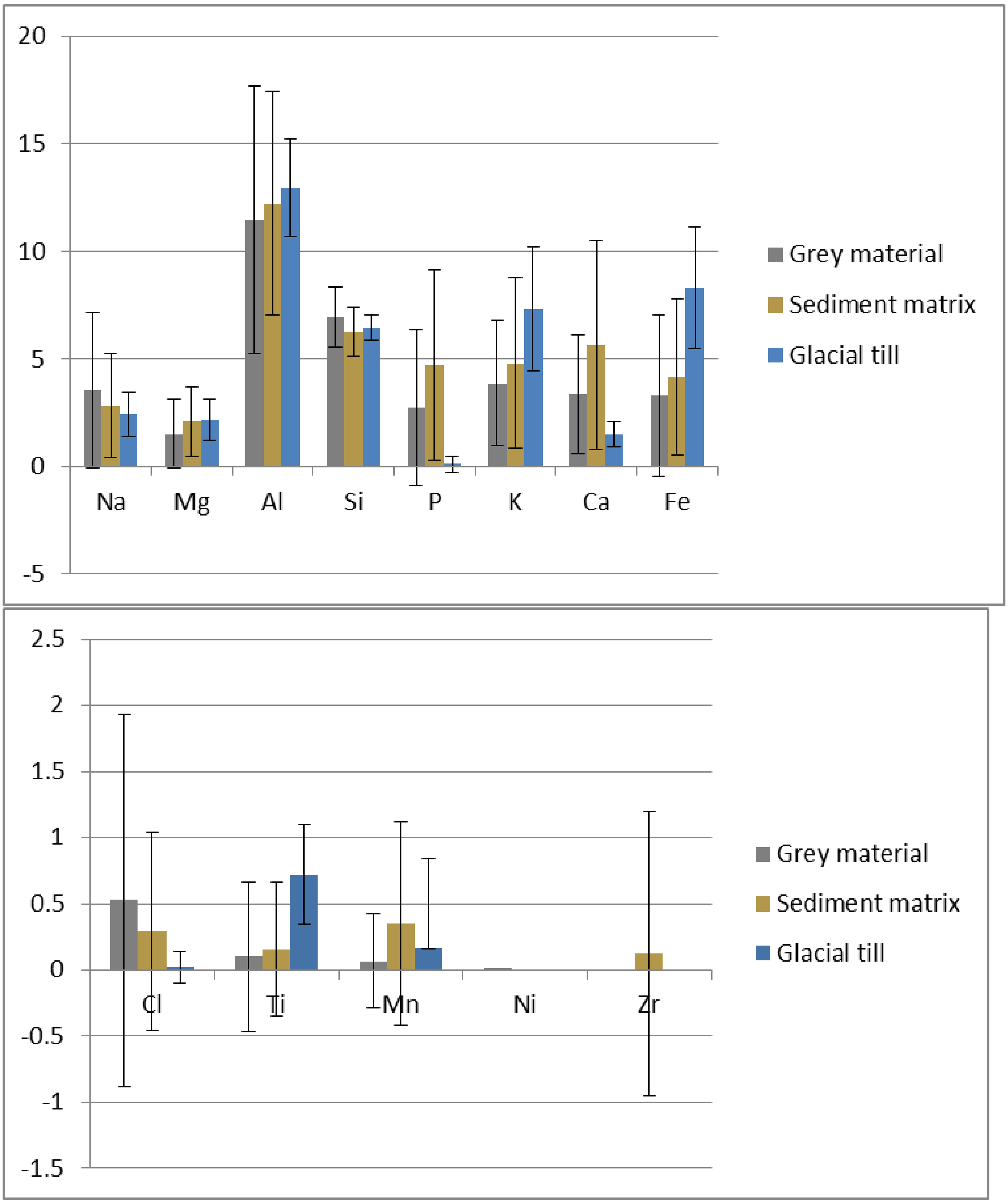


Figure 5.65: SEM EDX analysis results for grey aggregates and sediment matrix present with the deep sondage. Top = macro elements, bottom = micro elements. Results expressed as precent ratio with Si divided by 10. Error bars = σ.

However this does not explain the presence of diatoms and phytoliths found with some patches of grey material (figure 5.59c & d). Phytoliths and diatoms are reported diagnostic indicators of both peat/turf (Guttmann et al 2003, Simpson and Barrett 1996, Simpson et al 2003) and herbivore dung (Guttmann 2001, Guttmann et al 2008, Shahack-Gross 2011). Their preferential recognition within the grey material could be due to their high relief when depleted of organic material, as this may otherwise obscure their presence. Burned peat and turf fragments are however recognised throughout the sample set by fibrous textures, different b-fabrics and rubification. A complex process has taken place within the sondage sediments if burned peat/turf has been both well preserved and depleted to amorphous grey material. SEM EDX analysis supports the 'herbivore dung' interpretation. This coupled with the presence of both phytoliths and diatoms and the preservation of burned peat/turf elsewhere in the sample set advocates the theory that these grey features are coprolitic material.

5.5.6 *Building infill*

Ruinous structures were infilled with a mixture of rubble and anthropic sediments representing dumping and post-abandonment activities. Archaeological interpretations repeatedly refer to the use of anthropic materials to deliberately cover up or mark the end of use of buildings (Moore & Wilson 2009c, 2011b, 2012). Samples were recovered opportunistically alongside archaeological excavation and where the sediment was reasonably free of rubble to allow the insertion of a Kubiëna tin.

Alcove-like feature, associated with Structure 8

Accumulated deposits [9131], [9132] and [9133] within a small alcove-like feature were recovered for analysis (sample 97). The alcove was blocked up with rubble and dumped material [9127], [9029] and [9141] from which sample 96 was collected.

In thin section the lower, accumulated deposits [9131] etc. can be described as compact silty sand mixed with clay forming three microstratigraphic units (figure 5.66). The microstructure throughout the slide is characterised by channels, chambers and vughs in an open porphyric related distribution with randomly arranged, poorly sorted coarse constituents. The boundaries between the three units are faint and diffuse, defined by a subtle colour change within the fine organo-mineral fine material. The first sediment in the accumulation deposits is represented in unit A and is light brown and grey in PPL. Grey fine material contributes 30-50% of the total area of the unit and is white in OIL compared to light brown fine material which stays brown under OIL. Grey material has been investigated above, the grey material in this sample exhibits the same morphological characteristics but has not been subject to SEM EDX analysis to confirm chemical composition. Amorphous organic material is dominant within the unit, black matter contributes 5-15% of the unit, yellow <1% and orange matter associated with diatoms (<1%) contributes 15-30%.

The orange organic matter contains no discernible structure (figure 5.66) but its association with diatoms may indicate a possible parallel with red fibrous material interpreted as peat at Scatness (Guttmann et al 2003), here exhibiting class 3 or 4 decomposition (Stolt and Lindbo 2010). All organic matter within this slide exists in a similar state of decomposition although charred plant material has survived intact (<1%). Charred material is less susceptible to decay and so implies that the amorphous organic matter is derived from the input of unburned organic material into this sediment. A similar process is evidenced in bone fragments. Burned bone (<1%) is well preserved whilst unburned bone (<1%) has lost histology and birefringence indicating decay (Karkanas and Goldberg 20105).

Unit B is slightly darker than unit C due to a smaller percentage of grey material (15-30%) and higher concentration of Fe/Mn related pedofeatures. Fe/Mn nodules are anorthic and have been inherited from a Fe reorganised soil.

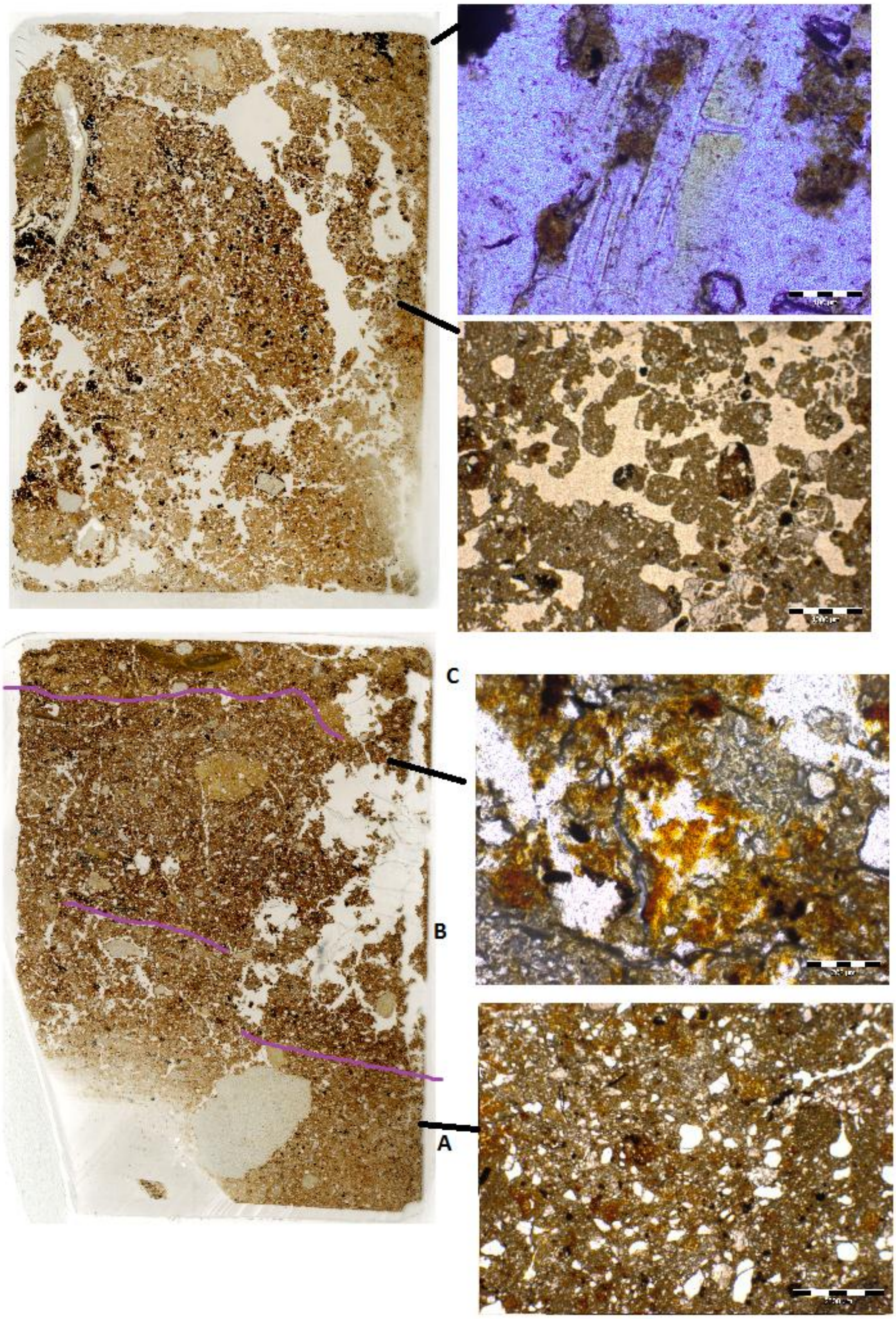


Figure 5.66: Thin section scans, samples 96 (top) and 97 (bottom) showing microstratigraphic units in sample 97. Detailed images (top to bottom): Phytoliths (PPL), groundmass sample 96 (PPL), orange amorphous (PPL), groundmass sample 97, unit A

This hypothesis is supported by the presence of clay aggregates (1-5%) and a locally micro-cracked microstructure (figure 5.66) upon which the dominant channel/vugh/chamber structure has been superimposed. Fine organic material contributes 5-15% reddish orange, 1-5% black and <1% yellow matter. Together this evidence suggests that formation processes involved the collection of silty clay material from an area of redoximorphic conditions which was mixed with grey material (likely to be herbivore dung) then dumped upon a highly organic sediment. Subsequent bioturbation has further mixed unit B and Fe/Mn movement has continued post-deposition. Anthropic inclusions are charred plant (1-5%), burned bone and unburned bone (<1% each) and a large shell fragment (>1% of total area of unit).

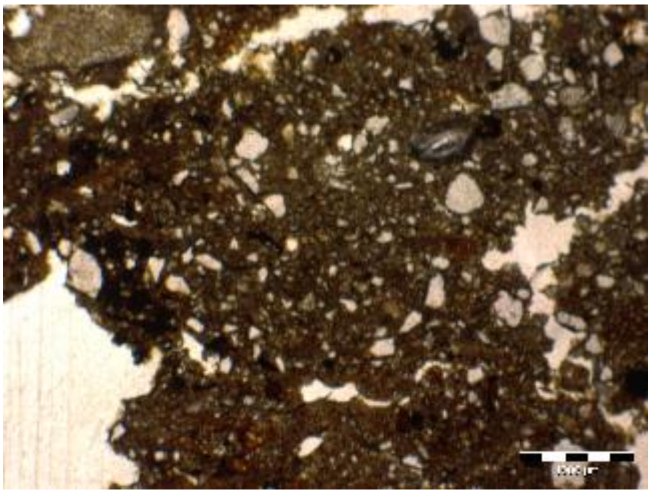


Figure 5.67: Example of silty clay domains in units B and C, sample 97 (PPL).

The uppermost unit within this slide, unit C, contains a higher proportion of allochthonous silty clay material than unit B and fewer anthropic inclusions (limited to burned and unburned bone, both <1%). Grey material contributes 1-5% of the unit and iron accumulation is more advanced (5-10% accumulations, 5-10% nodules). The post-depositional processes within this slide indicate that unit B can be described as a transition layer, representing mixing of material from unit A and unit B.

Further up the profile, sample 96 evidences a completely bioturbated (excremental) crumb or granular microstructure (figure 5.66) with associated channels, chambers and vughs. Despite this, heavily degraded bone fragments (1-5%) were recognised as well as black amorphous organic material associated with articulated phytoliths (figure 5.66) and woody charcoal (<1%).

The heavily bioturbated nature of this sediment precludes in-depth assessment of its formation processes, but it also demonstrates that it was highly organic and favorable to soil faunal activity. Microstructures such as this are frequently attributed to tillage (Adderley et al 2010, Jongerius 1983, cited in Lewis 2012) but are also typical of biologically active organic rich (mull, mollic) topsoil horizons (Davidson and Carter 1998, Gerasimova and Lebedeva-Verba 2010, Lewis 2012, Stoops et al 2010). This indicates that the fill of the alcove-like feature was a highly organic sediment (containing bone fragments) and formed an Ah-horizon.

In the field, sediment captured in sample 101 described as the fine matrix material of rubble infilling structure 8 ('mid to light brown silty clay', Moore & Wilson 2008), which was also found to contain limpet shells, animal bone and peat ash. In thin section this sediment [8016] exhibits a micro-stratigraphy which has been labelled units A-E (figure 5.68).

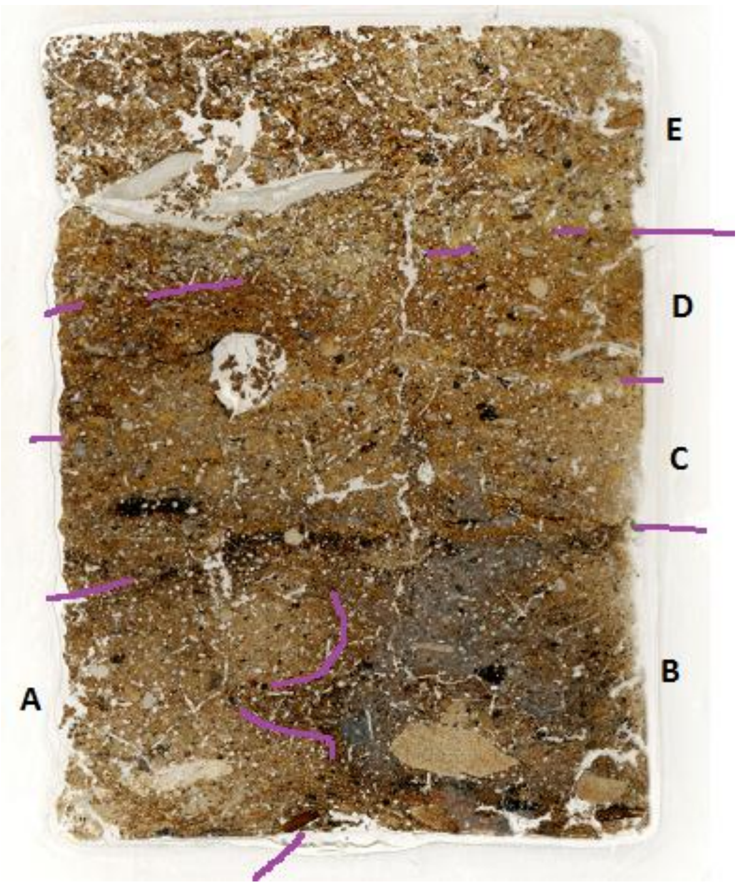


Figure 5.68: Thin section scan, sample 101, showing microstratigraphic units.

The slide is characterised by a superimposed vugh and channel structure, with chambers surviving within Unit E. At the base of the slide, in microstratigraphic unit B, a discrete dump of anthropic materials is noted. This contains rock fragments, medium intensity burned bone and charcoal. Large rock fragments were then deposited over it. The fine matrix of unit A is dark greyish brown organo-mineral (PPL) (mixed white and brown in OIL). Anthropic inclusions of the whole unit included burned bone (5-15%), charcoal (<1%), charred plant (5-15%) and clay aggregates indicative of hearth rake-out (1-5%). Grey material indicative of dung ash is also incorporated (1-5%). Unit A represents a deposit of grey material containing burned bone (1-5%), charred plant remains (1-5%) and hearth rake-out clay aggregates. Together units A and B appear to form dumped material from two different sediments which both contained burned bone and fuel residues.

Unit C is a layer composed of light brown and grey organo-mineral fine material (PPL) (yellowish grey, OIL) containing microlaminations of yellow and black amorphous organic material (5-15% each). Yellow amorphous material of this type has been described in detail above. Within this sample it is strongly associated with black punctuations which exhibit grass, leaf and wood char morphology (Umbanhower and McGrath 1998). The boundary between underlying dumps (units A and B) and unit C is sharp and distinct. Amorphous black fine material forms a discrete layer at this boundary, with yellow amorphous material immediately above it. This layer appears to represent an in situ burn event which has subsequently undergone bioturbation and chemical changes related to the processes described above.

The boundary between units C and D is also sharp and distinct, indicating rapid burial. The overlying unit D is composed of dark brown organo-mineral fine material mixed with yellow and grey materials. The unit is more compact and contains large shell fragments (5-15%) and aeolian sand including weathered quartz grains (5-15%), quartzite (<1%) and rock fragments

(<1%). Dissolution of shell sand is evidenced by $CaCo^3$ pedofeatures and bone fragments (<1%) are very poorly preserved indicating an acidic deposit. The sediment contains limited anthropic input (charred plant <1%, unburned bone <1%) and is interpreted as a possible turf based cap for the burn event described in unit C.

Unit E represents the ingress of aeolian sand deposition. The boundary between units D and E is diffuse with aeolian shell sand becoming gradually more frequent up profile. Fine organo-mineral material is light yellowish grey (greenish yellow in OIL). Highly decomposed organic matter contributes 1-5% black material and 1-5% orange and excremental pedofeatures (2-5%) form a locally crumb structure indicating a heavily bioturbated sediment at or near a surface (Davidson and Carter 1998, Gerasimova and Lebedva-Verba 2010, Lewis 2012). Anthropic inclusions are limited to charred plant remains (1-5%) but yellow amorphous material containing sand grains, phytoliths and diatoms without shell sand are present and interpreted as coprolitic material. A large shell fragment is incorporated into the unit.

Structure 17

Samples 197 and 198 were recovered from a greyish brown silty clay mottled with bright yellow silty clay [9889] set within a rubble matrix [9874] interpreted in the field as a rubble infill of structure 17. In thin section both samples were sandy and shared a common microstructure characterised by complex packing voids and intergrain microaggregates. Point count results indicate aeolian sand contributes c.29% of the samples as a whole and other coarse minerals which are limited to quartz and siltstone rock fragments contribute a further c.8%. Coarse fine related distributions are monic in the lower sample and enaulic in the upper sample. Pebbled sized orange clay aggregates present in larger amount in 197 are close porphyric and contain phosphatic nodules (see 5.4.4).

The aeolian sand matrix is highly porous in both samples (38.19 ± 0.08 average percent ratio void space) with fine material contributing 17.76 ± 7.24 (average percent ratio). Locally the fine material forms intergrain microaggregates, the formation of which represents an evolutionary process from monic distribution patterns exhibited elsewhere in the samples (Wilson & Righi 2010). Pore spaces are coated with fine silt or clay textual pedofeatures which are indicative of a wet sediment profile drying out (Kühn et al 2010). Black organic matter infill is also associated with textual clay coatings creating compound pedofeatures, this material, black in UV light, is interpreted as monomorphic illuvial organic materials (Wilson & Righi 2010). Organic matter is reduced to a gel-like state through fungal production of complexing organic acids (Wilson & Righi 2010) and so its presence within compound pedofeatures indicates a hierarchical process (Fedoroff et al 2010). In this case, monic sand evolved to enaulic with fine organ-mineral material filtering down-profile to create complex packing voids and microaggregates. As this phase continued under moist conditions, organo-mineral fine material was fairly mobile between coarse sand grains. Monomorphic organic matter then filtered down into the profile infilling gaps between microaggregates and coarse grains, forming compound pedofeatures. This may indicate the input of small amounts of organic slurry higher up the profile which could have taken the form of an anthropic sediment. Alternatively, this may represent the translocation of finely dispersed humus eluviated from upper horizons through a process of podzolisation (Lewis 2012). The former explanation is more likely given the cultivation remains described over structures 16 and 17 in the field (Moore & Wilson 2012). Anthropic inclusions within these slides are limited (3.73 ± 1.35 percentage ratio), however, rubified minerals, large shell fragments, woody charcoal, charred plant remains, burned peat and burned and unburned bone are present though bone fragments were not picked up by point count analysis. Black amorphous material (1-5%) is interpreted as herbivore dung based upon interpretations from other anthropic sediments across the site.

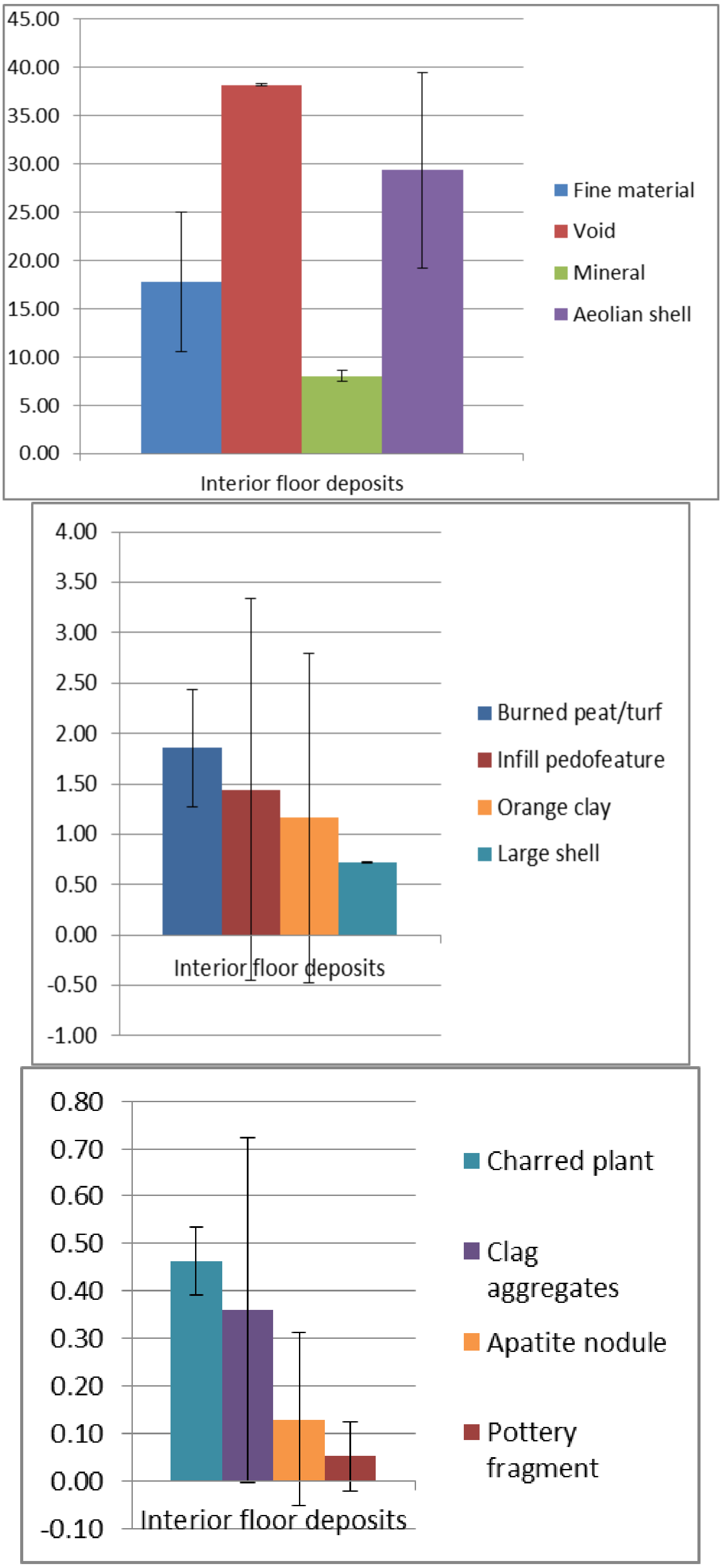


Figure 5.69: Point count results structure 17 'interior floors' or infill. Top, macro-components. middle, intermediate components. Bottom, micro-components

Thin section analysis demonstrates that microstructures are more consistent with 'secondary discarded deposits' described by Matthews et al (1997). However, the formation process evidenced here is very different from secondary discard 'dumped deposits' described above indicating different cultural activities lead to their formation.

5.5.7 *Summary of anthropic sediment formation*

Early anthropic sediments at the Links of Noltland are composed of organo-mineral silty clay and quartzose sand derived from glacial till. Microscopic inclusions indicative of anthropic activities are fuel residues, clay aggregates formed through hearth-maintenance activities, burned and unburned bone, cramp and pottery. These residues are ubiquitous across all anthropic sediments groups examined with the exception of cramp which has been further explored above and pottery which was observed only in exterior occupational deposits and interior floors within anthropic sediment groups. Discrete activities were interpreted within the dumped deposits and exterior floor surface deposits indicative of animal penning and burning of animal dung in situ as well as open-air burning of grassy/heath wood material. In situ burning was also evidence within the infill of structure 8. Secondary deposition of hearth and kitchen waste occurred in dumped deposits but this was also incorporated into exterior ground surfaces and to a lesser extent within sediments infilling buildings.

Later anthropic sediments are distinguished by the presence of aeolian marine shell sand. They were recovered from structure 13 and structure 17 interiors and dumped deposits associated with structure 13. These dumped deposits are essentially better preserved examples of dumped deposits from Area 5 with hearth rake-out secondary deposition and in situ burning evidenced. However marine shell sand ingress continues throughout the profile. This is also the case in both structure interiors as organic clay becomes less common and aeolian shell sand more frequent. The interior floor in structure 13 was the only example of a 'later' floor sediment evidenced in thin section and demonstrated secondary deposition of coarse components related to hearth waste. Later biological activity has further destroyed organic material but is it still possible to discern the presence of an in situ, albeit marine shell sand rich floor. Structure 17 was filled in with aeolian sand, organic matter and possible dog/pig and herbivore coprolites.

5.6 Anthrosols at the Links of Noltland

Anthrosols were identified by extensive auger survey and archaeological excavation. Point count analysis and micromorphology will assist in a semi-quantification of anthropic amendment of these soils and sediments and elucidate the activities they represent. Thin section description tables for anthrosols are presented in Appendix III. Detailed morphological description and initial interpretations are given below.

5.6.1 *Field bank*

Samples 74, 78, 82 and 131 were recovered from the field bank [9058] overlying the Area 5 Neolithic settlement to investigate how it was constructed and whether is post-dates the settlement substantially.

In the field, the bank was sectioned and a stratigraphy detected. Thin sections 74 and 82 were manufactured from Kubiëna tin samples which were positioned across the boundary between the upper [9058] and lower [9073] stratigraphic units. In thin section the boundary between the two units was visible in sample 74 as a subtle and diffuse colouration change with more iron movement evidenced throughout. A microstratigraphy was not apparent at all in sample 82. All samples exhibit microstructures characterised by channels, chambers and vughs, this supported by excremental pedofeatures indicates that the stratigraphy has been bioturbated by soil microfauna.

The homogeneity of field bank slides allows point counting analysis to better quantify the composition of the sediments. Fine material contributes around 59% of the structure contrasted with 9% pore space (figure 5.70), the coarse fine distribution is open porphyric for all slides and coarse minerals are randomly arranged and poorly sorted or unsorted. The organo-mineral fine material is mixed, appearing light greyish brown, yellowish grey, brown, dark brown or very dark brown in PPL and brown, brownish orange, dark yellowish brown, yellowish brown or yellow in OIL. Darker coloration mottling of fine material within this sample set is attributed to Fe/Mn accumulation. Birefringent fabrics are stipple speckled, microcrystallitic and are related to the weathering of coarse mineral component. Coarse minerals are consistent with the local geology (quartz, quartzite, feldspar, mica, and rock (silt/sandstone) fragments). Aeolian shell sand is present in one slide, occurring in association with a collapsed chamber and is also described as a sandy infill pedofeatures. Point count results demonstrate this contributes 1% of the cumulative total. These features strongly indicate that the bank construction occurred during a period of stable weather conditions and utilized material collected from a shell-sand free locality.

Anorthic iron nodules and turf fragments containing phytoliths allude to the use of an allochthonous A horizon in construction of the bank. This was mixed with anthropic inclusions of burned and unburned bone, pottery and large shell fragments, charcoal, charred plant material, burned peat, vesicular char and cramp. This material is not dissimilar to exterior occupational deposits which underlie the bank feature with coloration and inclusions possibly indicating that underlying material was scraped up and mixed with imported grassy turf and sandy silt to deliberately form a bank.

Post-depositional features indicate wetting and drying of the bank sediment. Silty/dusty clay textual pedofeatures coat void spaces and in places form bridges across channels indicating disturbance and a wet post deposition environment. Periodic wetting and drying of the profile is evidenced by the formation of orthic Fe/Mn nodules. These have formed within the matrix but ferruginous nodules have also formed as pseudomorphs of plant material. These are distributed throughout the upper most sample in the set (78) but occur with less frequency in lower samples.

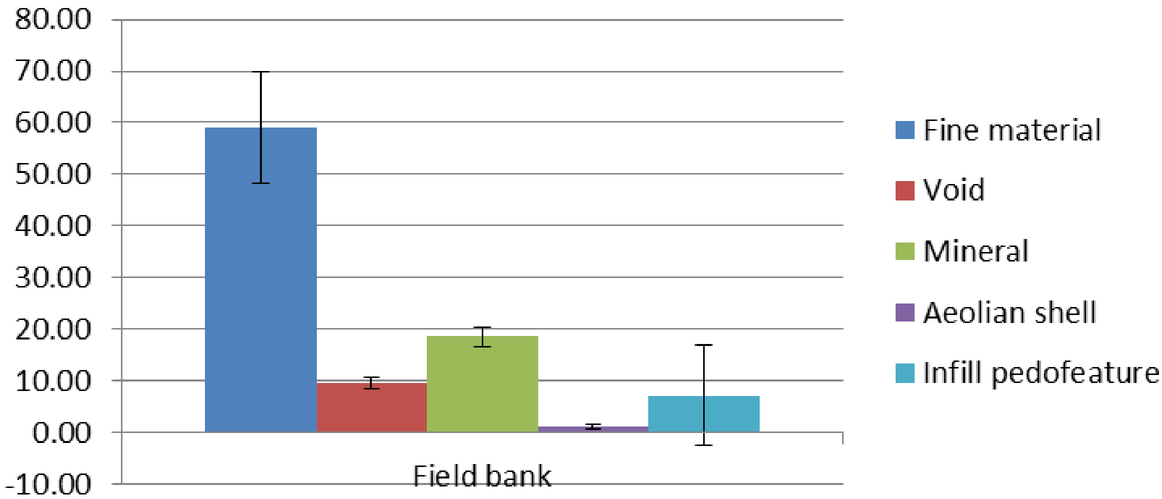


Figure 5.70: Point count results. Major components of field bank sample group. Results expressed in mean percentage ratio and 1σ

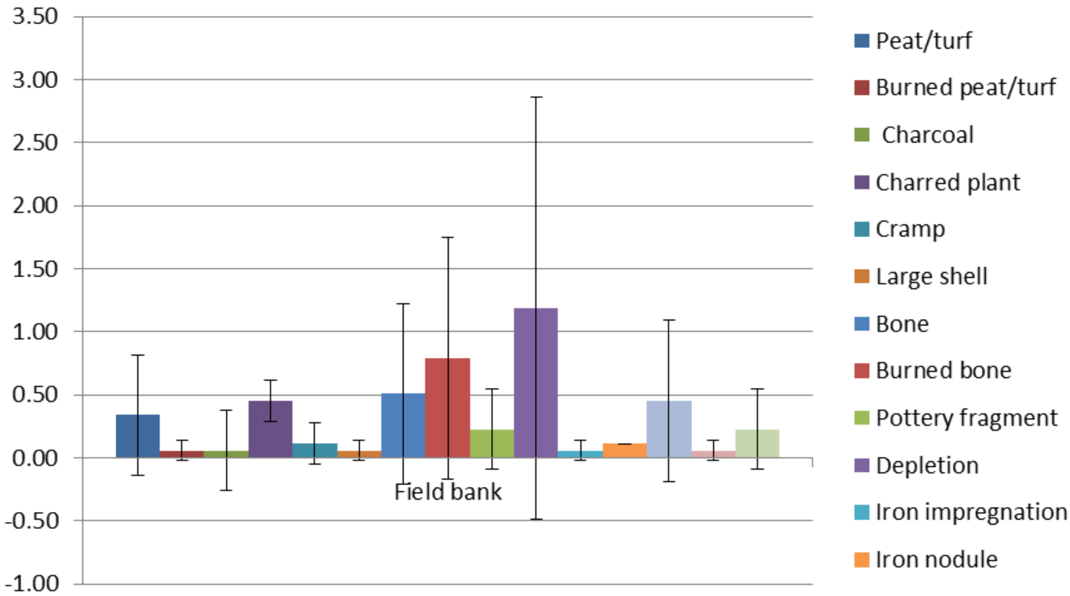


Figure 5.71: Point count results. Minor components of field bank sample group. Results expressed in mean percentage ratio and 1σ

At least part of the amorphous black component can be further divided into sand/silt sized Fe/Mn nodules and leaf charcoal fragments. Black punctuations of fine organic material are present as are amorphous reddish orange and black matter. Black amorphous material may be related to Fe/Mn nodule formation. Rounded Fe/Mn nodules and pseudomorphic ferruginous nodules after plant material.

5.6.2 *Old ground surfaces/activity surfaces and cultivated soils*

Old ground surfaces exhibiting evidence of anthropic amendment of activity were encountered in a variety of contexts. Across the area of auger survey grid 1, samples 83 and 84, 92 – 95, 117 and 119-124 were recovered to explore these activities and to test the hypothesis that tillage had been carried out in that area. Samples 79, 80 and 81 were recovered from contexts overlying anthropic sediments associated with the occupation of the settlement and are therefore interpreted as post-dating it, these are directly associated with the previously described field bank and are also possibly cultivated.

Soils and sediments which exhibit direct evidence of tillage through the presence of ard marks were sampled in test trench 22 (samples 216-218), to the south east of auger survey grid 2 and near to structure 13 (samples 174-177)

5.6.2.1 *Tillage of sandy soils*

Ard tillage breaks up ground surfaces rather than turning and is most effective when conducted in two different directions, creating criss-cross patterns (Parker- Pearson 1993, Turner 1998). Ard marks at the Links of Noltland form criss-cross patterns (figure 5.72) as also described at Tofts Ness, Jarlshof, Rosinish, Cladh Hallan and various sites in the Shetland isles.

Kubiëna tin samples 174-177 were recovered from a soil profile containing ard marks (figure 3.39). This alongside earlier work described above provides a basis for recognition of microstructures diagnostic of tillage elsewhere within calcareous regosols.

Figure 5.72: Ard marks in North East transect - near structure 13 at the Links of Noltland. Image reproduced from Moore & Wilson 2012:27

Sample 174 was collected from soil underlying the ard marks. Described in the field (Moore & Wilson 2012) as dark brown sand [9585], in thin section this sediment exhibits a single grain and bridged grain microaggregate microstructure with dominant (50-70%) aeolian marine shell fragments. The coarse: fine distribution is monic and locally enaulic with random, perfectly sorted coarse minerals. Fine material (>1%) is brown organo-mineral (PPL) or yellowish brown (OIL). There are no anthropic inclusions or pedofeatures. Micromorphological interpretation is that this sediment is clean, undisturbed aeolian sand which has not undergone any soil pedogenesis or retained any fine material which may have been eluviated from the cultivated horizon.

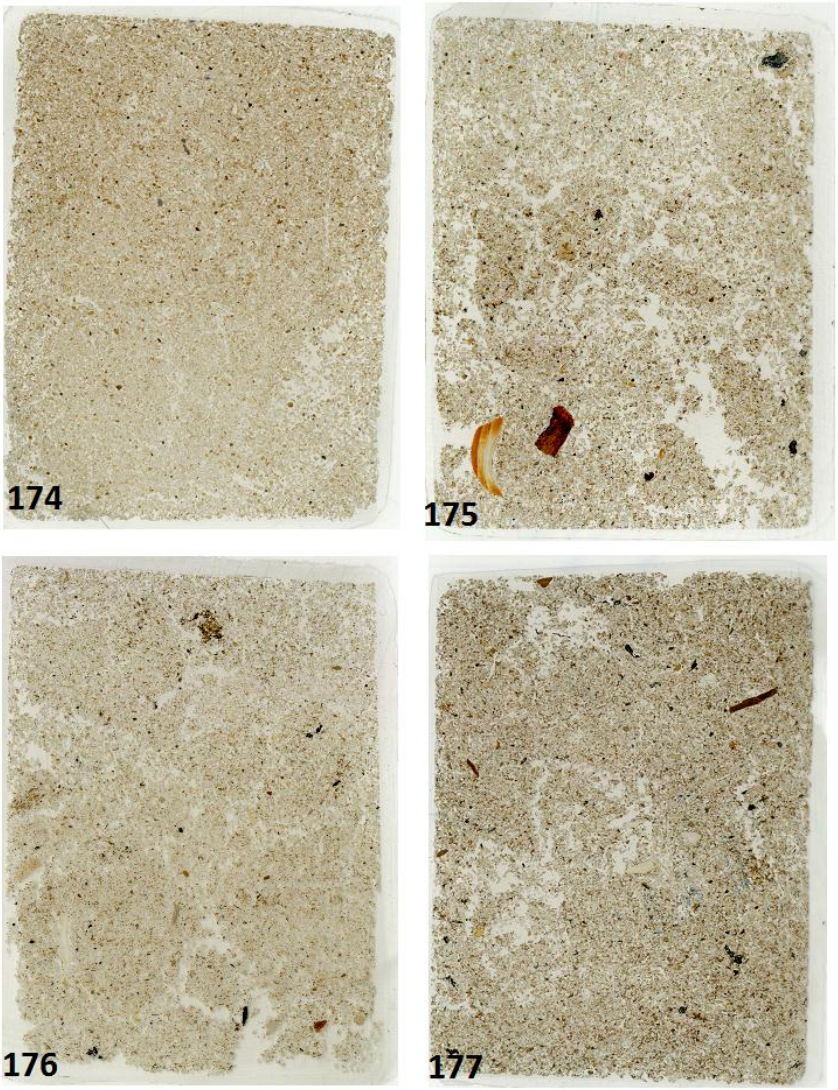


Figure 5.73: Thin section scans from soil profile containing ard marks.

Sample 175 was recovered from sediment fill directly above an ard cut. Described in the field as a pale brown sand containing lenses of clean white sand, in thin section this material also exhibits a single grain and bridge grain microaggregate structure with a monic or locally enaulic related distribution. Aeolian marine shell sand contributes 34% (point count data) of the slide area with dark brown (PPL) organo-mineral fine material (brown in OIL) adding 3.8%. Anthropic inclusions are charcoal (<1%), charred plant (<1%) and unburned bone (<1%). The section drawing (figure 3.39) indicates that this sample was recovered from an ard cut travelling at a perpendicular angle to the section cut and so it is possible that subtle subangular aggregates identified in the thin section scan (figure153) have formed through mixing of underlying sediment [9565] and [9558] as per the schematic representation by Lewis

(2012). A trace amount (<1%) of well decomposed plant material was observed and phosphatic material (5-10%) is interpreted as plant remains.

Sample 176 intercepted a second layer of ard marks, cut into [9558], these were filled with a thin layer of dark brown to black sand (Moore & Wilson 2012). In thin section no microstratigraphy was noted between these two sand layers, the microstructure continues to exhibit a single grain and bridged grain microaggregate formation with monic, enaulic and chitonic coarse: fine related distributions. Marine shell sand contributes 30-15% of the slide and coarse constituents are randomly arranged and well sorted. Anthropic inclusions are limited to a single disoriented fragment of topsoil (figure 5.74) and <1% well decomposed plant material was distributed throughout the slide. A similar facies type is observed for sample 177, recovered from the mid brown sandy silt over [9543] the infill of the ard marks. This material was noted to extend below the outer wall of structure 13, demonstrating the chronological relationship of ard cultivation and occupation of these buildings. The uppermost sample contained charcoal (<1%), vesicular char (<1%), burned peat/turf (<1%) and well decomposed plant material (<1%) distributed throughout the slide.

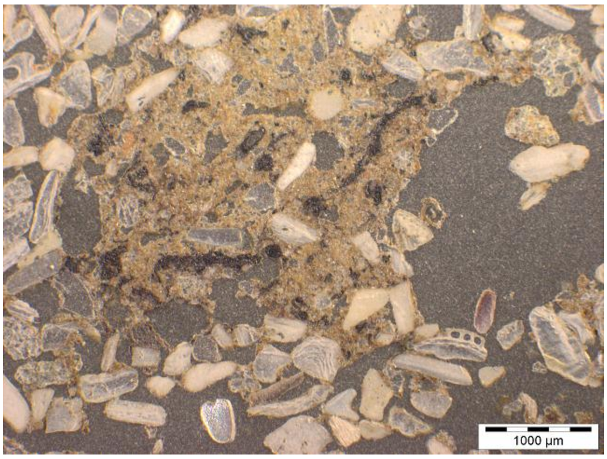


Figure 5.74: Sample 176, fragment of topsoil (OIL)

The cultivated calcareous regosol profile is characterised by enaulic marine shell sand containing few anthropic inclusions and enough fine material to allow colour distinctions to be made in the field and cohesion of aggregates (sample 175). The underlying shell sand is monic, with almost no fine organo-mineral material which is interpreted as undisturbed sediment which was rapidly buried, protecting it from the gradual ingress of fine material which is observed in the aeolian sand control. Usually fine material is eluviated from ploughed horizons to form a 'plough pan' (Fisher and Macphail 1985, cited in Lewis 2012), but in the case of less clayey soils this is unlikely (Adderley et al 2010). Tillage is normally undertaken to break down soil structure (Lewis 2012) but this does not seem necessary within this soil profile as the underlying sediment has been described as loose sand. Nevertheless, disoriented topsoil may represent a remnant of a soil formed in situ upon the aeolian sediment (Mücher et al 2010). The percentage of anthropic inclusions and fine material fall below that noted in earlier research at the Links of Noltland (McKenna and Simpson 2011) and so this episode of ard tillage is interpreted as very light.

Figure 5.75: ard marks in test trench 22

A second area of ard marks was sampled to the south of auger grid 2 in test trench 22 (figure 5.75). These features overlay an area of complex archaeological deposits which have not been excavated and are separated by windblown sand (Moore and Wilson 2012). Sample 216 intercepted the boundary between this windblown sand and overlying red brown silty clay [9427] which lies beneath the 'cultivation soil' (ibid.). In thin section the distinction between these two layers is clear (figure 5.76). Windblown sand is characterised by an intergrain microaggregate microstructure with complex packing voids and light brown organo-mineral fine material (PPL) in an enaulic related distribution. Coarse minerals are randomly arranged

Figure 5.76: Thin section scans of sample 218, 217 and 216 (top to bottom) indicating archaeological context numbers.

and poorly sorted with frequent (30-50%) aeolian shell fragments and heavily weathered quartzite (1-5%). Yellow amorphous material (1-5%) is slightly reactive under UV light and preserves the ghost of fibrous material and so is interpreted as decomposed plant roots. This demonstrates that this was once an Ah horizon. Anthropic inclusions are unburned bone (<1%) and rubified minerals (<1%) and there are many (5-10%) dusty clay textural pedofeatures which form link cappings and fill complex packing voids. The boundary between this windblown sand and overlying [9427] is wavy and distinct indicating a rough surface, buried rapidly. The 'silty clay' is very sandy in thin section, containing 5-10% marine shell fragments, 1-5% quartz and <1% feldspar. It is compact, with a microstructure characterised by channels, chambers and vughs with a close porphyric coarse: fine related distribution. Fine material is brown organo-mineral (PPL). Anthropic inclusions are charcoal (<1%), burned peat/turf (<1%), burned bone (1-5%), peat ash (<1%) and clay aggregates indicative of hearth rake-out. Amorphous reddish orange material is interpreted as completely decomposed plant matter, whilst yellow amorphous organic material is associated with phytoliths and may represent coprolitic or plant fragments. The micromorphological interpretation of this material is that it represents a rich anthropic sediment dump which may also represent a plough pan. Such features are recognised as an attempt to improve soil structure and/or fertility for agriculture (Lewis 2012, Verill and Tipping 2010).

Sample 217 was recovered from the light brown sandy silt which contained the ard marks (Moore and Wilson 2012). In thin section this was characterised by an apedal microstructure which contained channels, chambers and vughs and locally bridged grain microaggregates. The coarse: fine related distribution is equally complex, locally close porphyric, gefuric and enaulic. Coarse components are randomly arranged and moderately sorted and are composed of both marine shell sand and large shells (15-30%), quartz (<1%) quartzite (1-5%), feldspar (<1%) and flag stone rock fragments (1-5%). Anthropic inclusions are burned peat/turf (1-5%), peat ash (<1%) and burned bone (<1%) and clay aggregates formed through mixing and cohesive forces, or 'rolling action' (Lewis 2012). Fine organic material contributes 1-5% as punctuations and <1% each black and yellow amorphous matter. Organic carbon coats voids (5-10%) and dusty clay pedofeatures account for 1-2% of the sediment. Sand in sample 218, immediately above 217 is much the same but without any anthropic inclusions and less fine material.

The two soil profiles described above are distinctive but both indicative of ard tillage having been carried out upon windblown sand horizons. In the first profile, anthropic inclusions were rare but present and fine material was almost absent in both the plough zone and underlying sand. The survival of ard marks in situ precludes the disturbance and subsequent loss of fine material through aeolian processes. There is little evidence for biological activity related to soil fauna so it is suggested that the lack of fine material and very few anthropic inclusions is genuine. If this is indeed the case, the tilth would have been viable for cultivation but not reaching full potential.

In the second horizon, a silty organo-mineral fine material mixed with anthropic inclusions was deposited upon the surface of windblown sand before ard tillage which mixed the profile and created a loose tilth with composted organic materials which would have provided nutrients and stability for plant growth.

These two methods may represent changing land management practices over time. Chronological determination using stratigraphic relationships may be possible using auger survey grid 2 data and archaeological interpretations around structures 1, 2 , 3, 16 etc. but there was insufficient time to carry out this analysis for this project.

Ground/ activity surfaces over Area 5

Sediments encountered covering structure 9 in Area 5 were interpreted as an old ground surface associated with the field bank described above and underlying strata interpreted as spread of late midden deposits (Moore & Wilson 2011b). Chronologically these sediments postdate the settlement of structure 9 and are attributed to the Bronze Age (ibid.). The model for cultivation of Neolithic midden by later communities (Guttmann 2005, Guttmann et al 2006) seems appropriate and although no ard marks were described in the field, scrapes and incisions on underlying rubble were attributed to ard tillage (Moore & Wilson 2011b). The sequence of sediments recovered within this strata (sample 81) begin with the interface between underlying anthropic sediment [9031] (from which several notable artefacts including a clay figurine were found, Moore and Wilson 2011b) and [9036], the disturbed upper surface of [9031] (figure 3.38).

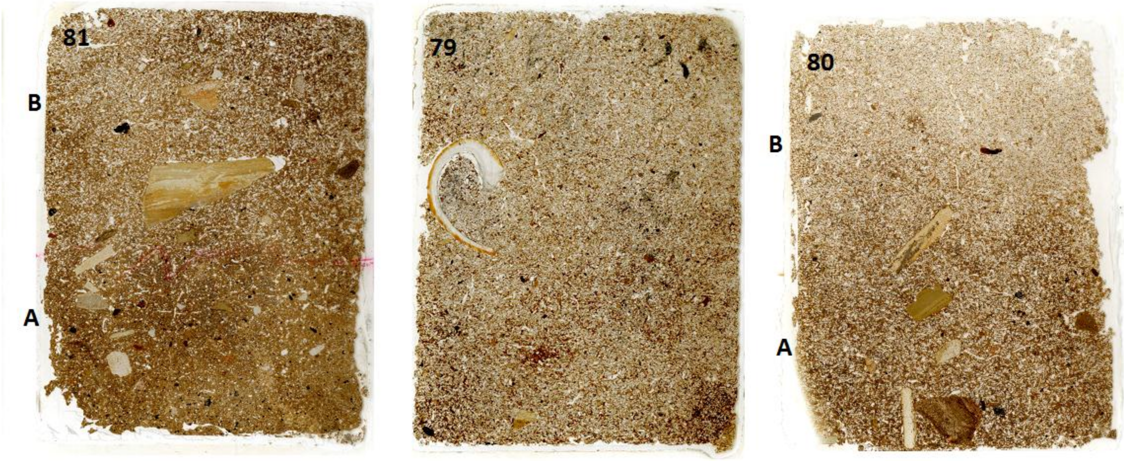


Figure 5.77: Thin section scans, samples 80, 79 and 81 demonstrating position of microstratigraphic units.

In thin section sample 81 exhibits two microstratigraphic units labelled A (lower) representing [9031] and B (upper) representing [9036] (figure 5.77). The boundary between these two sediments is diffuse and has been subject to mixing which has incorporated marine shell sand from unit B into the fine material of unit A. The microstructure present in unit A is consistent with bioturbation, with vughs, channels and chambers predominating and a massive structure developed locally where non-laminated isotropic dusty clay pedofeatures infill channel pores (figure 5.78). This evidences the movement of fine material down profile

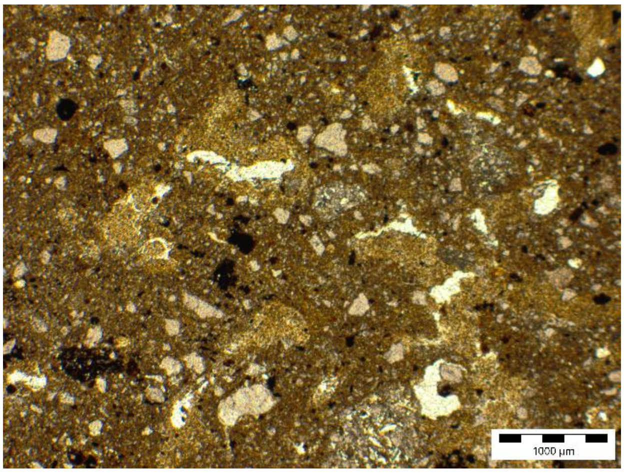


Figure 5.78: Dusty clay infilling vughs and channels, sample 81, unit A (PPL).

due to disturbance in overlying layers. The presence of these features in channels and vughs related to soil faunal activity indicates a hierarchical relationship. The sediment was biologically active prior to burial and disturbance, possibly representing a relict surface deposit. Well decomposed plant material (<1%), articulated phytoliths (<1%) and excremental pedofeatures (2-5%) related to organic material support this interpretation. Anthropic inclusions within this unit are charcoal (<1%), burned peat fragments (<1%) and unburned bone (<1%). Amorphous black (5-15%), red (1-5%) and yellow (<1%) fine organic material are also present. Many Fe/Mn nodules are present throughout the slide (5-10%, unit A and 2-5% unit B) but have not formed in situ, they may be anorthic or disorthic. Sediment [9036], unit B shares a vugh, channel and chamber microstructure with [9031]. These are filled with the same dusty clay fine material as in [9031]. The fine fabric in both sediments is light greyish brown (PPL), (brown in OIL). Anthropic inclusions are also present within this sediment (charcoal, <1% and unburned bone, <1%). The major difference is the fraction of aeolian marine shell, in unit B this contributes 30-50% of the sediment and rock fragment frequency also increases from 1-5% in [9031] to 5-15% in [9036]. The density of these shell sand components causes the coarse: fine related distribution to graduate from open porphyric in [9031] to close porphyric in [9036].

Sediment [9036] evolves into ground surface [9035] very gradually. In the field this was described as a pale brown silty sand and in thin section it is noted as a brown organo-mineral silty sand composed of aeolian marine shell (50-70%), quartz (1-5%) and quartzite (<1%) in a gefuric distribution. The microstructure is inter/bridged grain microaggregates with channels and complex packing voids evidencing some soil faunal activity. Non-laminated isotropic dusty clay infill pedofeatures are not present and anthropic inclusions are limited to turf fragments (<1%) and unburned bone (<1%). Micromorphological analysis supports the field hypothesis that mixing of sandy and underlying anthropic sediments took place. The bank feature described above was formed upon material which had not been mixed with marine shell sand indicating it was constructed prior to mixing. Sample 75 which was recovered from sediment [9072], equivalent to [9031] (Moore & Wilson 2009c) was also free of marine shell sand, indicating that 11m to the north of structure 9 this surface was not disturbed. However, non-laminated isotropic dusty clay infill pedofeatures typical of sediment [9031] also fill channel and vugh voids here presenting a challenge for interpretation. This will be dealt with in detail below.

Soil test pits- auger survey grid 1 area

Sediments investigated within the auger survey grid 1 area presented three quite different formation processes. Soil test pit 1 encountered loamy sand [9099] which rested upon bedrock. Test pit 3 recorded a stratigraphy containing a lynchet and test pit 5 uncovered a further series of ard marks. In thin section, [9099] exhibits a dense, massive microstructure composed of light brown organo-mineral fine material (PPL, yellowish brown in OIL) with randomly arranged, poorly sorted aeolian shell sand (marine shell 5-15%, quartz 1-5%, quartzite <1%) and siltstone rock fragments (15-30%) consistent with glacial till mineralogy and indicating mixing of shell sand and underlying glacial till. Anthropic inclusions are limited to charcoal (<1 -5%) and well decomposed plant material (<1%) is present along with fine organic amorphous black (<1%) and reddish orange (<1%) matter. Non-laminated isotropic dusty clay/silt infill pedofeatures fill in what were once channels and vughs.

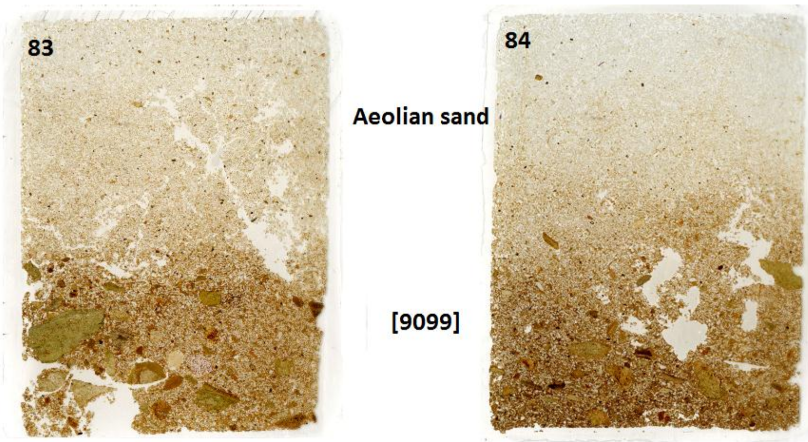


Figure 5.79: Thin section scans of samples from soil test pit 1

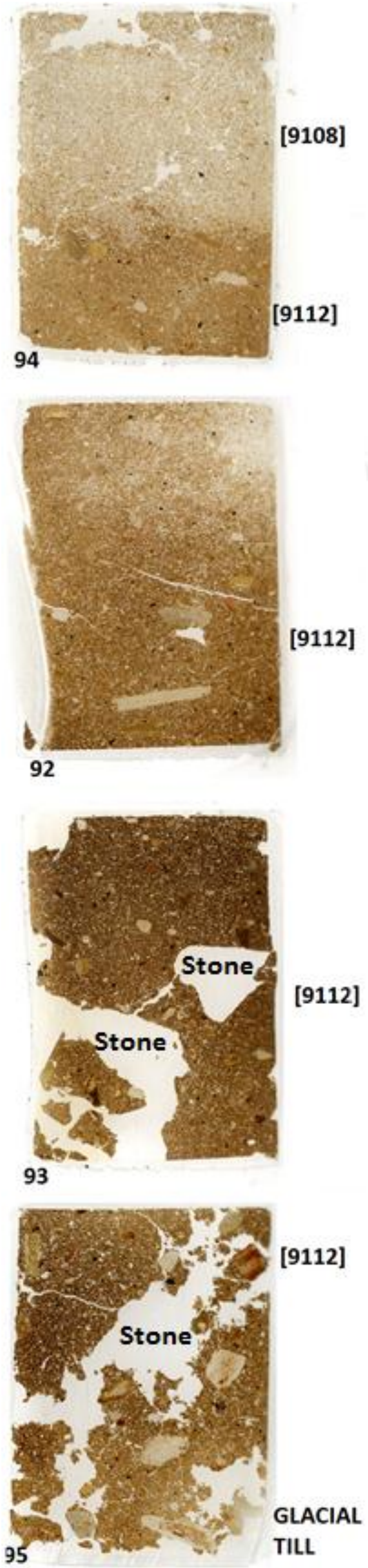


Figure 5.80: Thin section scans of samples taken from soil test pit 3

These observations lead to the interpretation that this was once the vegetated, biologically active surface horizon of a soil developed on a thin layer of glacial till. Charred plant remains may represent local vegetation burning or may have entered the profile through aeolian processes from further afield. The boundary between [9099] and overlying aeolian sand was captured in thin section (figure 5.79). This is both gradual and diffuse demonstrating mixing of the two horizons. Chambers, channels and vughs in the lower half of the aeolian sand unit indicate that soil faunal activities were on-going despite sand accretion. Near the top of the slides, the sand grades to monic well sorted with 50-70% of the area composed of aeolian marine shell with 1-5% quartz and <1% quartzite.

In soil test pit three, a stratigraphy was recorded beneath aeolian sand. Four samples were recovered here for thin section micromorphology (figure 5.80), the lowest horizon was glacial till which was overlain by a compact stony loamy clay [9112] containing anthropic material in the form of bone and large shell fragments. This formed a banked feature, possibly a lynchet (figure 5.81) and was overlain by a mid-brown sandy soil [9108]. In thin section a soil formed upon glacial till is observed in sample 95. The microstructure is massive with channels, vughs and stone voids. Coarse mineral components are quartz (5-10%), quartzite (1-5%) and siltstone rock fragments (5-15%), these mostly exhibit Fe stained rims but some also display depletion hypocoatings. Root fragments are discernible but these appear to be charred. Plant char accounts for 5-15% of the sediment with a trace of charcoal (<1%), burned bone (<1%) and rubified minerals (<1%) also present. Disorthic Fe/Mn nodules contribute <1%. Anthropic inclusions and stoniness increases slightly up profile as fine material gets steadily lighter and silty/dusty clay infill pedofeatures begin to fill channel voids until a massive microstructure is created within sample 94 (figure 5.82). In thin section the boundary between [9112] and [9108] is very clear although a small degree of mixing is evidenced by the presence of aeolian marine shell fragments in the upper portions of sample 93 and in unit A ([9112] in sample 92. Sediment [9108] is also characterised by a channel and vugh microstructure and contains 5-15% marine shell sand with 1-5% quartz and <1% mica. It is notably less stony than [9112] (<1% rock fragments). Anthropic inclusions are rubified minerals (<1%), charcoal (<1%), charred plant remains (5-15%), burned bone (<1%) and unburned bone (<1%).

Figure 5.81: Possible lynchet in soil test pit 3, sloping from top left to bottom right.

The aeolian marine shell component of [9108] increases up profile until a gefuric structure is noted. Within this material there are no silty infill pedofeatures observed.

Micromorphological observations in soil test pit 3 allow the interpretation of environmental and anthropic formation processes.

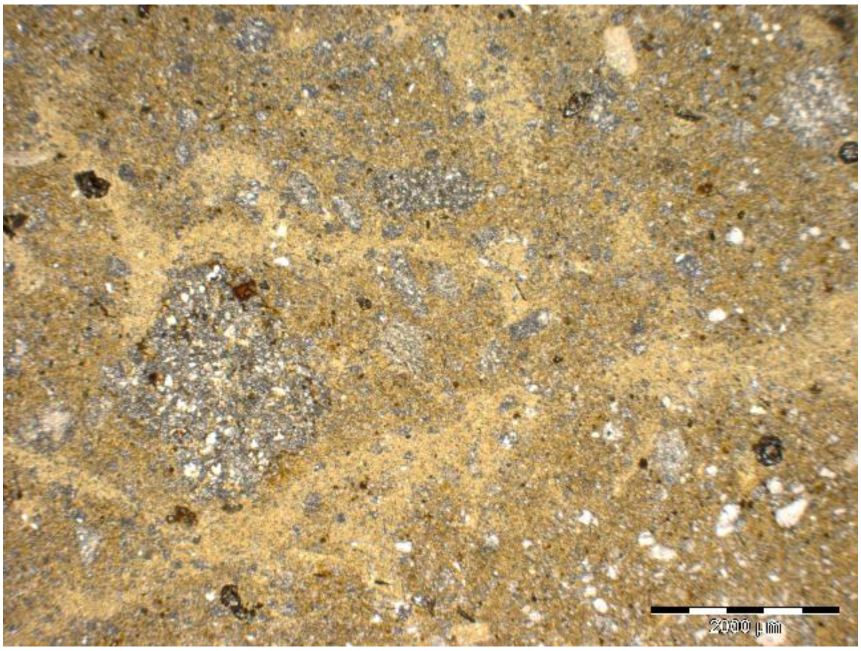
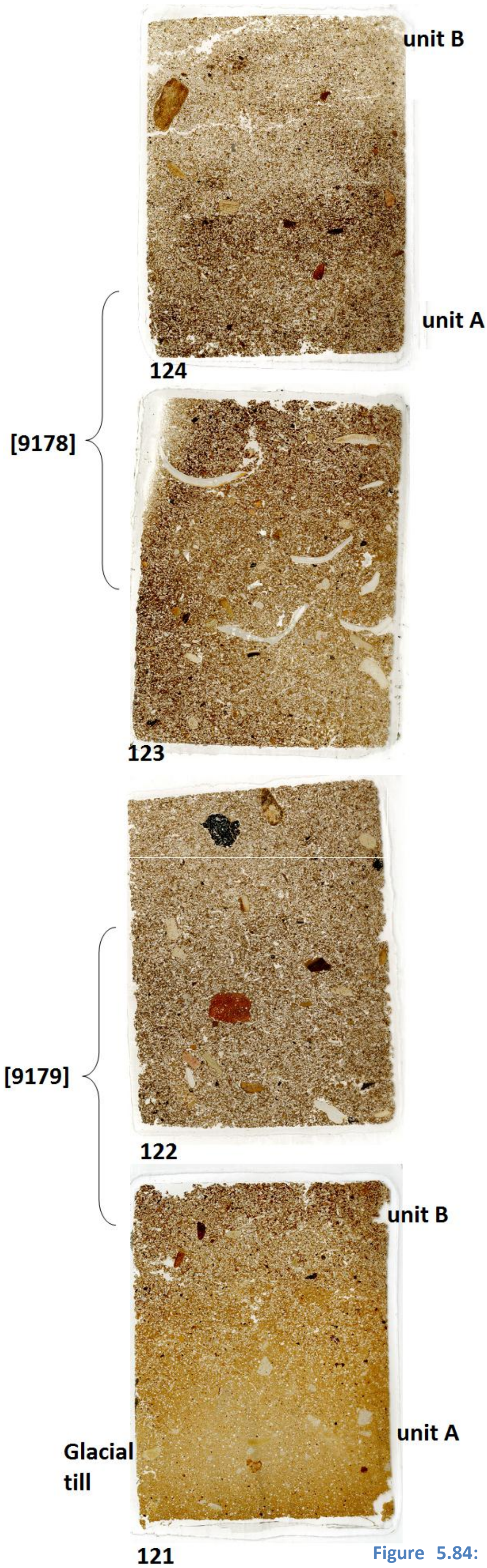


Figure 5.82: Massive microstructure in upper portion of [9112], sample 84, microstratigraphic unit A (PPL).

The presence of both iron stained stone rims and depletion hypocoatings (observed throughout the Links of Noltland samples) have been given as evidence of the development of acid brown soils evolving toward weakly developed podzolation in soils of the Ettrick Association (Romans and Robertson 1983). Calcareous brownsoils are described as possiblities within the Fraserburgh association (Soil Survey for Scotland 1982) and so it is suggested here that a palaeo-brown soil developed under deciduous vegetation is evidenced by these features. The presence of charred plant roots indicates in situ burning of vegetation. Prehistoric in situ vegetation burning has also been suggested at Stronsay (Tisdall et al 2013) and at Tofts Ness (Guttmann 2001) and bioturbation features indicate a reasonable organic matter content. The presence of anthropic inclusions is treated with some caution as the soil lies down slope from the settlement in Area 5 but could indicate anthropic amendment of the soil. The lynchet type feature and the mixing of the profile evidenced by incorporation of aeolian sand and disorthic iron nodules indicate that this may well represent an Ap horizon superimposed upon a brown soil B horizon. If this is the case, this sample set represents a sequence of events beginning with woodland clearance, though to cultivation and possible amendment and eventual aeolian shell sand inundation.Further towards the coast, soil test pit five recorded possible ard marks and a further lynchet or bank feature. Samples were recovered from the full stratigraphy of this feature (figure 5.80). The bank was formed upon dark brown sandy loam [9277] overlying glacial till (figure 5.80). This is the equivalent material into which the possible ard marks were cut ([9179]) which contained limpet, winkle and oyster shells. In thin section this sediment exhibits a crumb microstructure under the bank (samples 120 and 119) with light brown (PPL & OIL) organo-mineral fine material and an enaulic or locally monic and concave gerfuric related distributions. Coarse minerals are randomly arranged and well sorted. These contribute 30-50% aeolian marine shell sand, 5-15% quartz, 1-5% quartzite and <1% rock fragments. Potentially anthropic inclusions are charred plant remains (<1%) and rubified minerals (<1%). In the vicinity of the ard mark features (samples 122 and 121), the sediment is characterised by vughs and channels with local areas of

Figure 5.63: Thin section scans of samples from soil test pit 5, lynchet or bank feature

intergrain microaggregates creating an open porphyric or enaulic distribution. Fine material is organo-mineral and is mid brown (PPL, yellowish brown OIL) reflecting a higher organic component than beneath the bank. Charred plant material contributes 1-5% of the sample and burned bone (<1%), charcoal (<1%) and rubified minerals (<1%) are also present. Black amorphous fine material (up to 5%) is associated with phytoliths (<1%) and is comminuted or cracked and associated with phytoliths. Based upon comparative observations in Area 5 these features are interpreted as charred herbivore dung. Coarse sand sized subrounded burned clay aggregates are similarly interpreted as hearth rake-out features (<1%). These features in association demonstrate that hearth waste was deposited here. Excremental pedofeatures contribute <1%) to the sample supporting the interpretation that this sediment was biologically active. Crumb microstructures are normally indicative of very high levels of biological activity under the presence of organic matter and near to surface horizons (Davidson and Carter 1998, Gerasimova and



Lebedva-Verba 2010, Lewis 2012). Where the original microstructure is known the presence of a crumb structure in a suspected tilled horizon might indicate manuring (Adderley et al 2010, Jongerius 1983, cited in Lewis 2012). A consideration of the microfacies related to aeolian sand microstructures at the Links of Noltland indicates that crumb structures associated with anthropic inclusions were observed in soil test pit 2 above anthropic sediments and in soil test pit 5, around 15m to the north west of soil test pit 2. A crumb structure without anthropic inclusions was also observed in sample 91, unit A, soil test pit 2. The aeolian sand control microfacies was observed in soil test pit 3 and under the Ap horizon in sample 216, unit A associated with anthropic inclusions. Therefore, the crumb microstructure cannot in this instance be diagnostic evidence of manuring as it seems the complexities of aeolian sand movement (accretion /erosion/deflation) have affected these sediments (e.g. Barber 2011). However, excremental pedofeatures and anthropic inclusions do support this interpretation and so

Figure 5.84: Thin section scans from sediment profile associated with possible ard marks, soil test pit 5.

this sediment is interpreted as an amended aeolian sand which has accumulated over glacial till.

The material which overlies the amended sand is the banked sediment [9184] described in the field as a dark greyish brown firm loamy sand containing shell fragments. In thin section this material exhibits a complex microstructure (crumb/ channels/vughs/ compact packing voids/intergrain microaggregates) with randomly arranged, moderately sorted coarse components and many excremental pedofeatures (5-10%). Coarse minerals are aeolian marine shell sand (30-50%), quartz (5-15%), mica (<1%) and siltstone rock fragments (<1%). The fine material is dark brown organo-mineral (PPL) which hues reddish brown in OIL indicating an element of peat ash. Other anthropic inclusions are charred plant remains (<1%) and unburned bone (<1%). The crumb structure and many excremental pedofeatures does seem likely to evidence a high presence of organic matter, but this is totally broken down, no amorphous fine material other than the organo-mineral fabric are observed. Some horizontal orientation of shell sand is noted near the top of the slide (sample 117), this type of occurrence has been interpreted as a likely deflation feature at Cladh Hallan (French *in prep*). The close proximity of this sediment to the modern day surface makes it impossible to discern whether this is a relict or modern feature.

5.6.2.2 *Non-laminated isotropic dusty clay pedofeatures*

Features of this type are observed in probable tilled deposits in soil test pit 1 and 3, within anthropic sediments in soil test pit 2 (0) and in Area 5. All of these descriptions are immediately beneath suspected Ap horizons and so it is tempting to interpret these features as diagnostic of tillage. Sediments which have otherwise very similar microfacies but do not immediately underlie suspected Ap horizons do not contain these features (table 5.4). Using hierarchical discernment (Fedoroff 2010) the presence of these infillings within channels and vughs created by soil faunal activity implies that organic sediments were not tilled immediately following deposition as organic matter had been partially composted in situ first.

Table 5.4: Collation and comparison of microfacies which are associated with non-laminate isotropic dusty clay pedofeatures and samples which share microfacies but do not contain these features. Microfacies type 1 = Massive with channels and chambers containing anthropic inclusions. Type 2 = Massive with channels and chambers, no anthropic inclusions. Type 3= Compact, with channels and chambers containing anthropic inclusions.

Sample number	Context	Non-laminated isotropic dusty clay pedofeatures	Associated immediately overlying Ap?	Microfacies type
84	**[9099] brown earth at the base of soil test pit 1**	✓	✓	**1**
90	**[9103] soil test pit 2 above rich anthropic sediments**	✓	✓	**2**
94 & 94	**[9112] brown earth at the base of soil test pit 2**	✓	✓	**1**
75	**[9072] anthropic sediment in Area 5**	✓	✓	**1**
80	**[9035] Old ground surface over anthropic sediments in Area 5**	✓	✓	**3**
81	**[9031] Mixed sediment over anthropic sediments in Area 5**	✓	✓	**3**
115	**Glacial till, soil test pit 5**			**2**
121	**Glacial till, soil test pit 5**			**2**
95	**Glacial till, soil test pit 3**			**1**
78	**[9058] bank over Area 5**			**1**
92	**[9108] the suspected Ap horizon, soil test pit 3**			**3**

5.6.3 *Elemental enhancement comparisons between anthropic sediments and anthrosols*

Following micromorphological interpretation of sediments, those which could be identified as cultivated soils (tables 22 & 23) were selected for SEM EDX analysis and statistical testing to estimate macro (P, K, Ca) and intermediate (Mg, S) nutrient enrichment (Limbrey 1975, Rapp and Hill 2006) in the landscape relative to controls and potential availability within anthropic sediments (after the methods of Golding et al described in 4.4.2.1). Cultivated soils were subdivided into three types. Type 1 (CS1) is the process whereby anthropic material is dumped upon aeolian sand and then tilled, type 2 (CS2) is where the natural brown earths were cleared and tilled and type 3 (CS3) is where in situ anthropic sediments were tilled.

Calcium levels are assumed to be affected by the $CaCO_3$ contribution of marine shell sand and so the cumulative nutrient totals are presented with and without Ca (table 24). Nitrogen was not detected within any of the samples. Unless otherwise stated tests are accepted as statistically significance if p=<0.05. Results are considered almost significant if p=≤0.09.

Table 5.5: Samples selected for statistical analysis.

Sample number	Microstratigraphic unit	Group	Number of units analysed	Total number of spectra per sample
76	**Single**	**Exterior occupational surface**	**1**	**35**
77	**A & B**	**Exterior occupational surface**	**2**	**70**
78	**Single**	**Field bank**	**1**	**35**
80	**A & B**	**CS3**	**2**	**70**
81	**Single**	**CS3**	**1**	**35**
82	**A & B**	**Field bank**	**2**	**70**
84	**A**	**CS2**	**1**	**35**
85	**B**	**Dumped deposits**	**1**	**35**
88	**Single**	**Exterior occupational surface**	**1**	**35**
92	**Single**	**CS2**	**1**	**35**
93	**Single**	**CS2**	**1**	**35**
96	**Single**	**Dumped deposits**	**1**	**35**
97	**Single**	**Infill**	**1**	**35**
100	**A & B**	**Exterior occupational surface**	**2**	**70**
101	**A-F**	**Infill**	**6**	**210**
106	**A & B**	**Exterior occupational surface**	**2**	**70**
109	**A**	**Interior floor deposits**	**1**	**35**
109	**B**	**Interior floor deposits**	**1**	**35**
110	**Single**	**Interior floor deposits**	**1**	**35**
115	**Single**	**Glacial till control**	**1**	**35**
116	**Single**	**Aeolian sand control**	**1**	**35**
118	**B**	**Dumped deposits**	**1**	**35**
119	**Single**	**CS1**	**1**	**35**
123	**Single**	**CS1**	**1**	**35**
125	**Single**	**Hearth**	**1**	**35**
126	**A**	**Hearth**	**1**	**35**
126	**B**	**Hearth**	**1**	**35**
127	**Single**	**Interior floor deposits**	**1**	**35**
128	**Single**	**Interior floor deposits**	**1**	**35**
134	**Single**	**Dumped deposits**	**1**	**35**
135	**Single**	**Dumped deposits**	**1**	**35**
136	**Single**	**Dumped deposits**	**1**	**35**
138	**Single**	**Dumped deposits**	**1**	**35**
174	**Single**	**CS1**	**1**	**35**
175	**Single**	**CS1**	**1**	**35**
178	**A**	**Interior floor deposits**	**1**	**35**
178	**B**	**Infill**	**1**	**35**
179	**A**	**Infill**	**1**	**35**
179	**B**	**Infill**	**1**	**35**
195	**B - D**	**Dumped deposits**	**3**	**105**
197	**Single**	**Interior floor deposits**	**1**	**35**
198	**Single**	**Interior floor deposits**	**1**	**35**
216	**B**	**CS1**	**1**	**35**

Sample number	Microstratigraphic unit	Group	Number of units analysed	Total number of spectra per sample
217	**Single**	**CS1**	**1**	**35**
218	**Single**	**CS1**	**1**	**35**

Table 5.6: Group sizes and number of total spectra acquired each group.

Context group	Type	Number of units	Number of spectra per group
Cultivated soils type 1	**Anthrosol**	**7**	**245**
Cultivated soils type 2		**3**	**105**
Cultivated soils type 3		**3**	**105**
Field bank		**3**	**105**
Dumped deposits	**Anthropic sediment**	**10**	**350**
Exterior occupational surfaces		**1**	**15**
Hearth		**3**	**105**
Infill		**10**	**351**
Aeolian sand	**Control**	**1**	**35**
Glacial till control		**1**	**35**

Table 5.7: SEM EDX analysis, mean and σ of nutrient elements for each sample group with cumulative totals and variability.

Group		Mg	P	S	K	Ca	Cumulative total (without Ca)	Variability Max	Variability Min
CS1	**Mean**	**1.49**	**1.01**	**0.20**	**2.80**	**42.02**	**83.49**	**95.21**	**71.76**
	σ	**1.24**	**2.63**	**0.38**	**3.02**	**29.08**	**(12.39)**	**(11.17)**	**(13.60)**
CS2	**Mean**	**1.52**	**1.06**	**0.04**	**6.56**	**8.46**	**38.56**	**35.43**	**41.69**
	σ	**0.93**	**1.59**	**0.18**	**4.05**	**14.35**	**(15.75)**	**(18.51)**	**(12.99)**
CS3	**Mean**	**1.29**	**1.63**	**0.08**	**5.87**	**17.67**	**51.85**	**53.30**	**50.40**
	σ	**0.85**	**1.58**	**0.30**	**3.68**	**19.21**	**(14.97)**	**(17.96)**	**(11.99)**
Dumped deposits	**Mean**	**1.34**	**3.86**	**0.20**	**4.89**	**11.15**	**42.56**	**43.13**	**42.00**
	σ	**0.99**	**3.09**	**0.45**	**3.50**	**13.56**	**(17.86)**	**(20.83)**	**(14.88)**
Exterior occupational surfaces	**Mean**	**1.15**	**3.87**	**0.11**	**5.42**	**8.90**	**35.35**	**39.27**	**31.43**
	σ	**0.89**	**3.22**	**0.46**	**3.31**	**8.48**	**(17.97)**	**(21.46)**	**(14.47)**
Field bank	**Mean**	**1.32**	**0.81**	**0.13**	**4.17**	**34.81**	**84.48**	**82.67**	**86.30**
	σ	**1.09**	**1.24**	**0.33**	**4.48**	**36.44**	**(13.24)**	**(13.05)**	**(13.42)**
Glacial till Control	**Mean**	**2.16**	**0.11**	**0.00**	**7.32**	**1.52**	**15.89**	**22.20**	**9.59**
	σ	**0.97**	**0.36**	**0.00**	**2.88**	**0.59**	**(13.79)**	**(19.17)**	**(8.40)**
Hearth	**Mean**	**1.93**	**4.64**	**0.21**	**5.30**	**9.18**	**35.08**	**42.82**	**27.33**
	σ	**1.51**	**3.42**	**0.51**	**3.29**	**5.59**	**(20.30)**	**(24.46)**	**(16.14)**
Infill	**Mean**	**1.23**	**3.72**	**0.09**	**4.87**	**17.91**	**55.99**	**55.81**	**56.18**
	σ	**1.25**	**3.42**	**0.28**	**3.65**	**19.86**	**(18.23)**	**(20.00)**	**(16.46)**
Interior floor deposits	**Mean**	**1.41**	**3.12**	**0.15**	**4.84**	**14.58**	**47.87**	**48.49**	**47.24**
	σ	**0.88**	**2.71**	**0.45**	**3.18**	**17.00**	**(16.29)**	**(19.34)**	**(13.24)**
Aeolian sand control	**Mean**	**2.60**	**0.63**	**0.21**	**4.07**	**33.59**	**74.89**	**82.34**	**67.44**
	σ	**1.58**	**0.73**	**0.35**	**4.67**	**26.81**	**(14.49)**	**(15.16)**	**(13.82)**

5.6.3.1 *Magnesium*

All groups have reduced levels of Mg compared to glacial till (GTC) and aeolian sand (ASC) controls. This difference is confirmed statistically for cultivated soils type 1, 2 and 3, the field bank, dumped deposits and interior floors (figure 5.85).

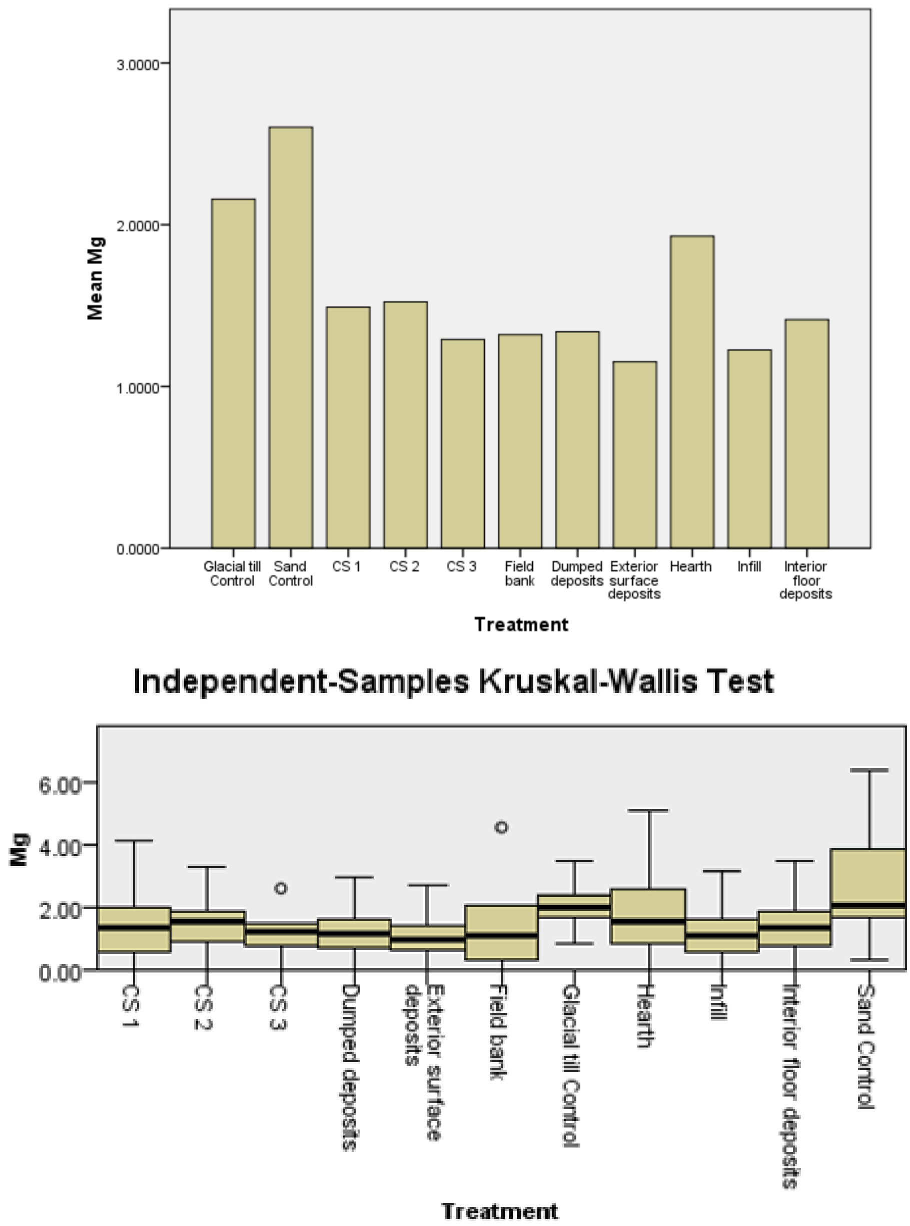
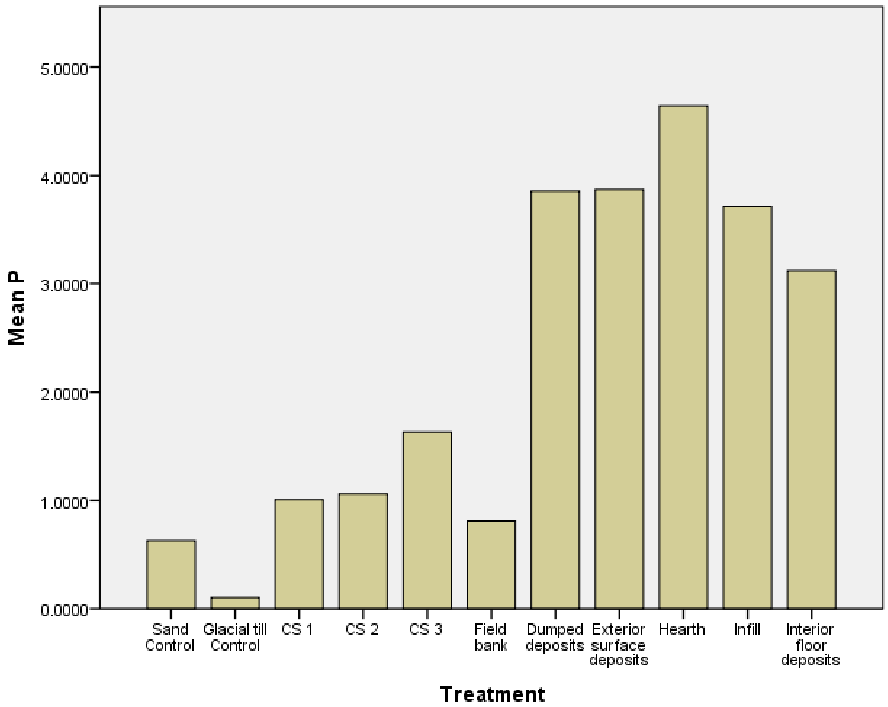


Figure 5.85: Top = Mean % ratio of Mg across groups. Bottom = visualization of Kruskal-Wallis test, with the null hypothesis "the distribution of Mg is the same across all groups"

The hearth group is enhanced compared with all other non-control groups and this is confirmed statistically compared with the exterior occupational surfaces (EOS), infill and dumped deposits. Cultivated soils type 1 and 2 are enhanced compared with non-control groups excluding the hearth group, this is confirmed statistically compared to EOS and between CS2 and infill. Enhancement of interior floors compared with EOS and infill is also confirmed.

5.6.3.2 *Phosphorous*

The distribution of phosphorous across the site is less complex (figure 166). All groups have higher levels of P compared with GTC and ASC but this is only confirmed statistically between GTC and CS3, interior floor, infill, EOS, dumped deposits and hearth and between ASC and interior floor, infill, EOS, dumped deposits and hearth. All cultivated soils and the field bank have lower levels of P than all anthropic sediments groups and this is confirmed statistically. Between the cultivated soils and field bank groups, CS3 has notable P enhancement but this only statistically significant between CS1 and CS3, although between the field bank and CS3 this was very close to statistical significance ($p=0.59$). The interior floor has lower P levels than the hearth group, infill, EOS and dumped deposits (confirmed statistically for dumped deposits and hearth comparisons). It should be noted that SEM EDX does not differentiate between different types of P (Rapp and Hill 2006) but analysis of the GTC accounts for natural geological phosphate and allows comparison.



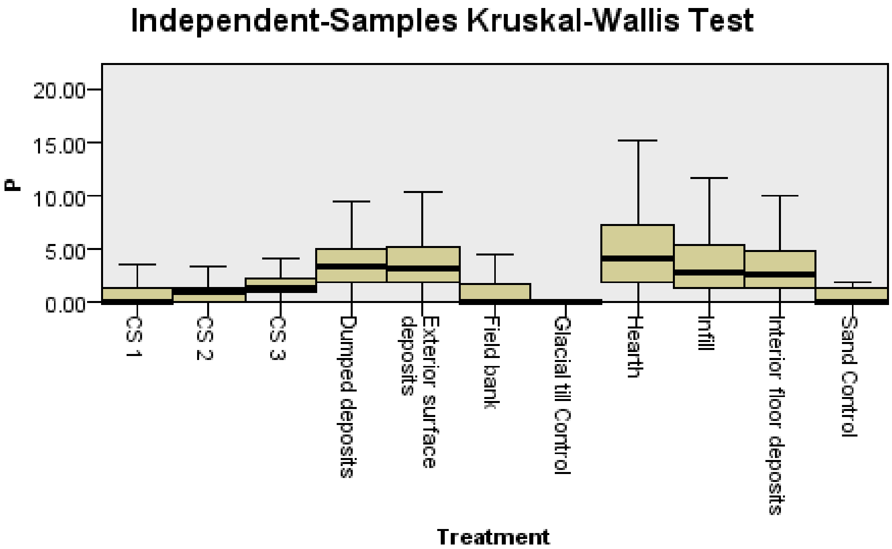
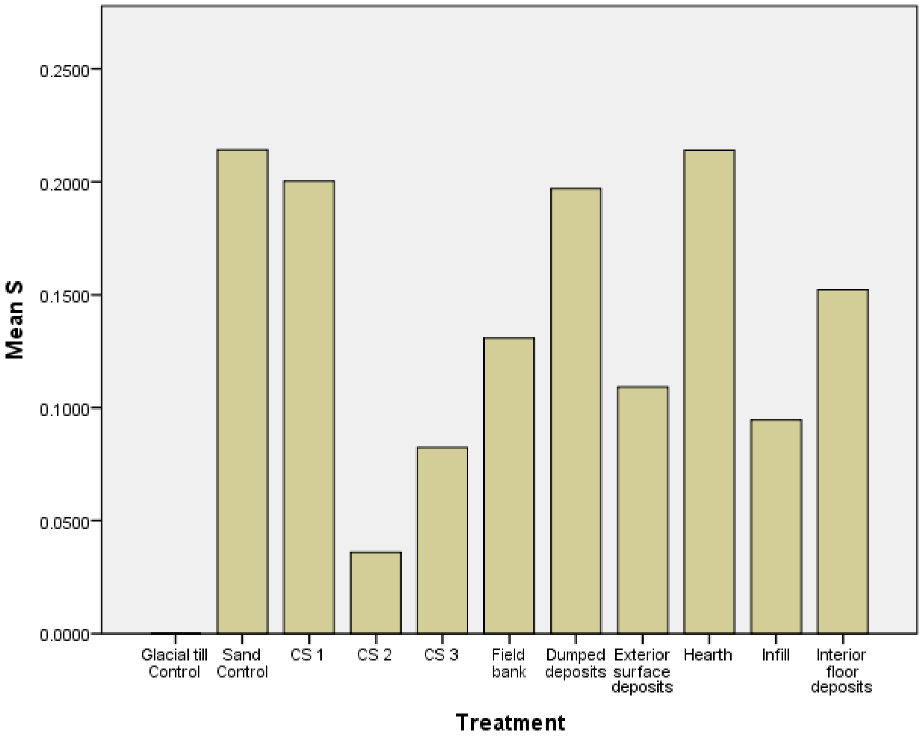


Figure 5.86: Top = Mean % ratio of P across groups. Bottom = visualization of Kruskal-Wallis test, with the null hypothesis "the distribution of P is the same across all groups"

5.6.3.3 *Sulphur*

Levels of sulphur were over all very low (<0.24 mean % ratio). The GTC contained 0% whilst the ASC contained 0.25% ± 0.35%). ASC, CS1, dumped deposits and the hearth contained the highest levels (>0.20) whilst CS2, CS3, EOS, field bank, infill and interior floors contained ≤0.15% (figure 167). CS 2 contained the lowest values for archaeological groups but this was only demonstrated as significant between CS1, ASC and possibly the hearth (p=0.74). A significant difference was confirmed for enhancement of the dumped deposits and CS1 relative to EOS and infill and CS1 and CS3.



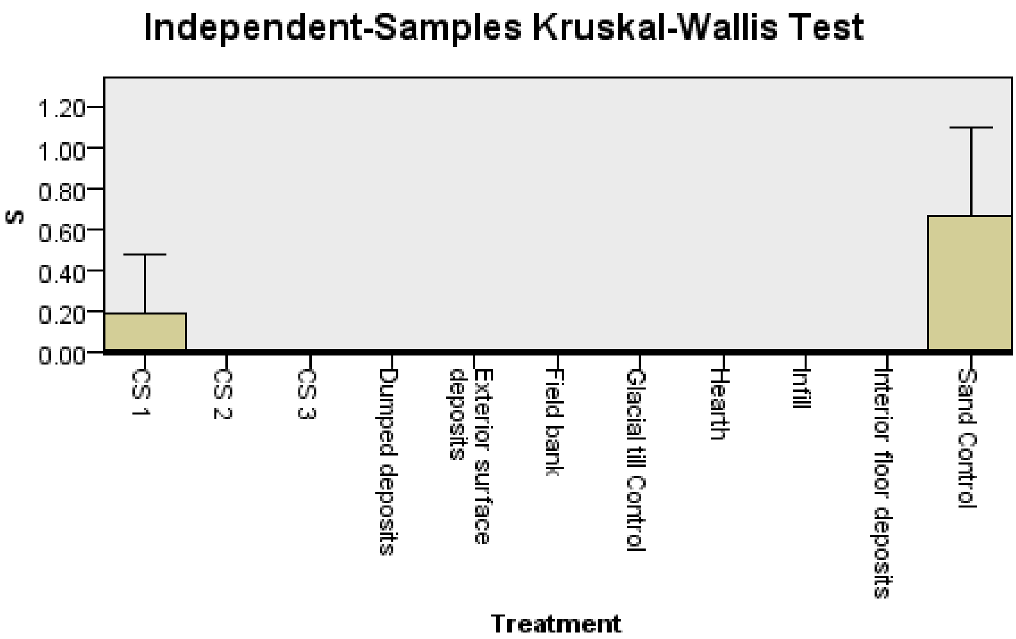
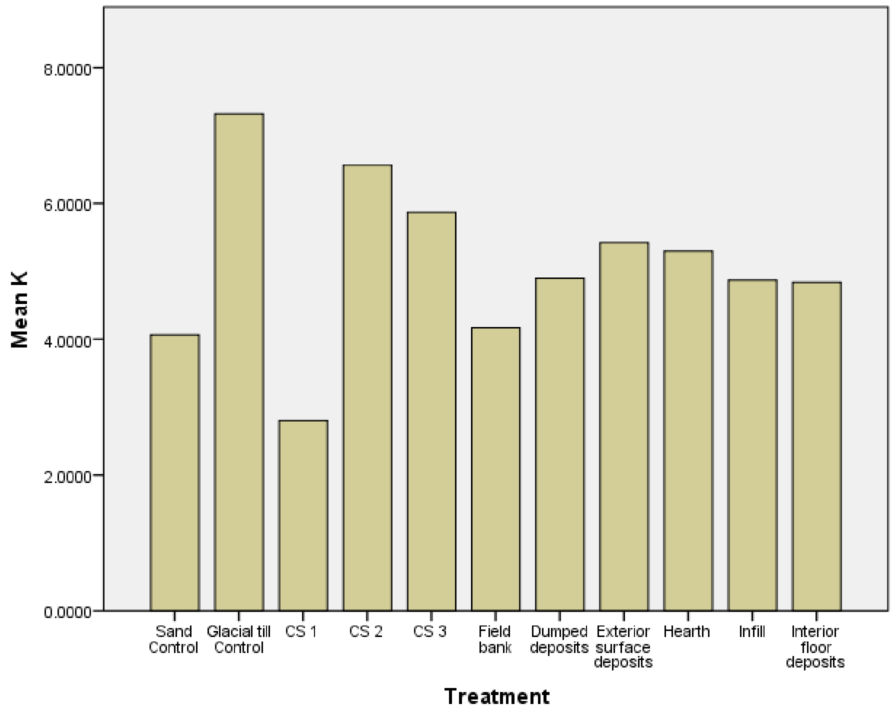


Figure 5.87: Top = Mean % ratio of S across groups. Bottom = visualization of Kruskal-Wallis test, with the null hypothesis "the distribution of S is the same across all groups"

Sulphur is used by plants in the synthesis of essential amino-acids (Limbrey 1975) and so its parcity in the GTC and CS2 may have been problematic to plant growth. However, mixing aeolian shell sand with brown earths as seen in CS2 would have remedied this situation. High levels of sulphur in the dumped deposits could be due to redoximorphic effects and the formation of pyrite whilst the hearth enrichment may be due to the presence of ash. It seems as though several modes of sulphur ingress are at work at the Links of Noltland but the two main pathways are marine shell and ash.

5.6.3.4 *Potassium*

The potassium content of the GTC is significantly higher than all groups including the ASC (figure 168). All anthropic sediments appear enriched in K compared with the ASC but this is not confirmed statistically. Nevertheless, a statistically significant enhancement is confirmed for CS2 compared to the ASC whereas CS3 exhibits significantly lower levels compared to ASC. CS1 is significantly lower than all anthropic sediments and the field bank but is enhanced compared to CS2 and CS3. CS2 is enhanced when compared to all groups except GTC but this is only confirmed statistically for the field bank, infill, dumped deposits and interior floors. The field bank also contains significantly less K than CS3 and the EOS and almost significantly less than the hearth ($p=0.73$). These results indicate that the distribution of K is highest amongst the Ap which mixed brown earth into aeolian sand. The low relative concentrations in CS1 are probably due to the low levels of fine material present within that context. A more complex relationship is suspected for anthropic sediments but K is not a useful indicator of anthropic enhancement of the cultivated areas with such high background levels.



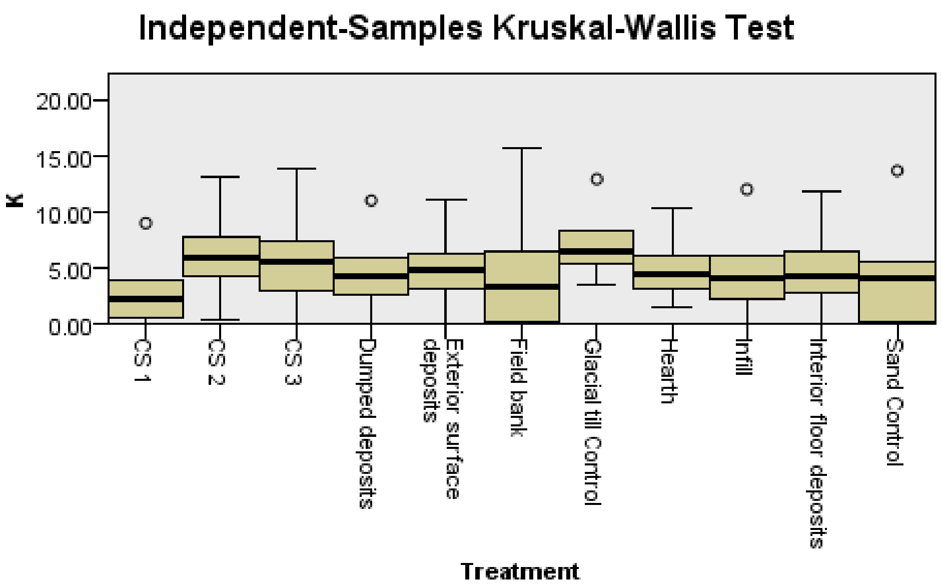
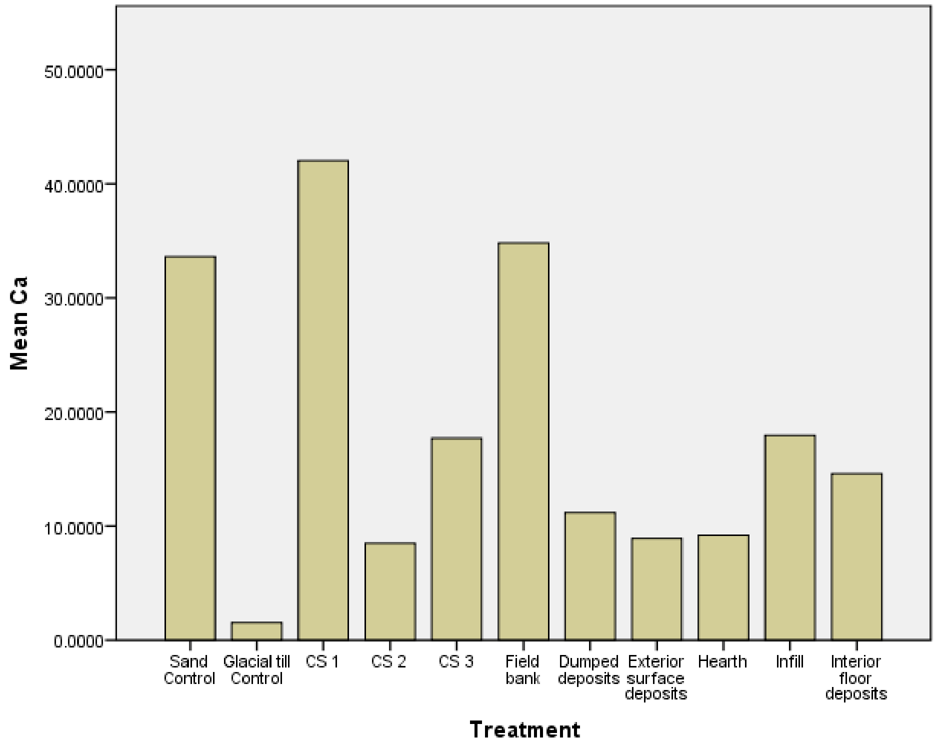


Figure 5.88: Top = Mean % ratio of K across groups. Bottom = visualization of Kruskal-Wallis test, with the null hypothesis "the distribution of K is the same across all groups"

5.6.3.5 *Calcium*

Calcium exhibits the most complex relationships between groups examined out of all nutrients analyses. The GTC contains the least mean % ratio and this is a significant difference compared to all other groups including the ATC. All anthropic sediments have significantly less Ca (infill is at p=0.79) than the ASC, no doubt due to $CaCO_3$ content. However, CS1 appears to be enriched in Ca compared to ASC but this is not confirmed statistically. The field bank contains similar amounts of Ca compared to ASC and CS1 exhibits significant Ca enrichment compared to all other groups excluding ASC.



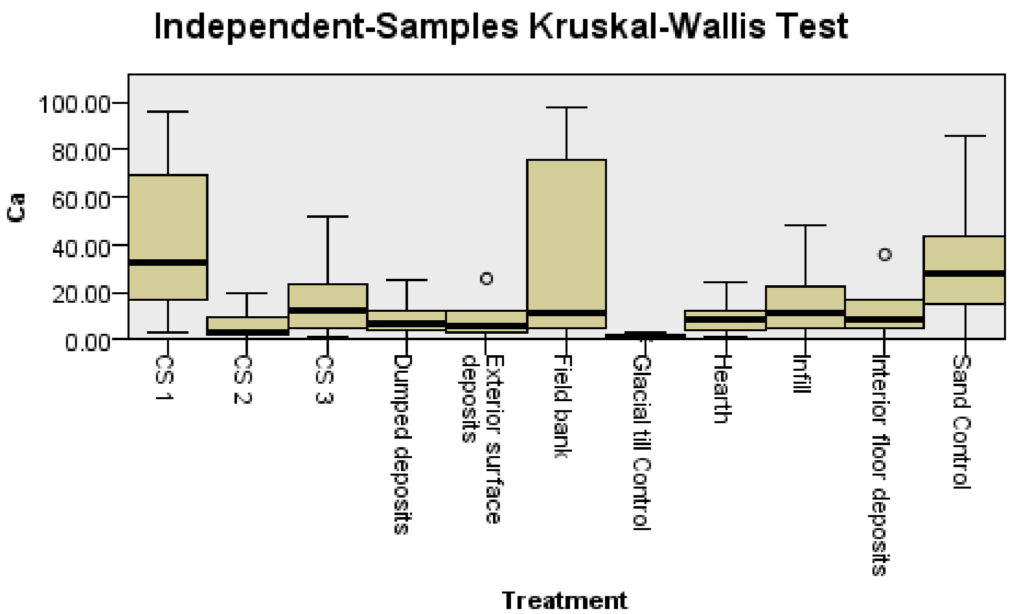
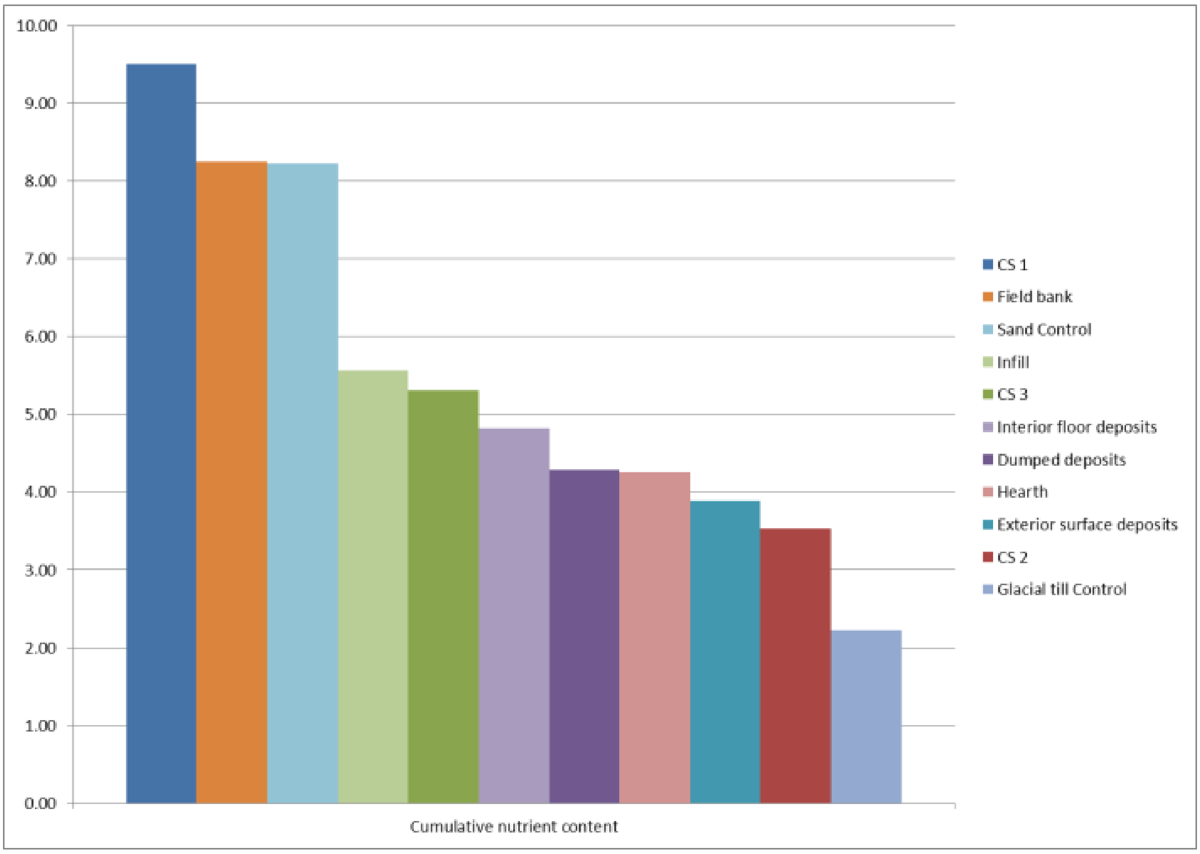


Figure 5.89: Top = Mean % ratio of Ca across groups. Bottom = visualization of Kruskal-Wallis test, with the null hypothesis "the distribution of Ca is the same across all groups"

Infill deposits are enhanced compared to CS2, EOS and dumped deposits but no statistical significance was noted between infill and CS3 or the hearth. Interior floor enrichment was significant compared to CS1 and the field bank (field bank accepted at p=0.051) and dumped deposits were enriched compared to CS2. Enrichment of the hearth was only significant compared to CS2.

5.6.3.6 *Cumulative nutrient loadings*

The cumulative nutrient content of each group is presented in figure 169. When Ca is included anthrosols CS1, CS3 and the field bank demonstrate statistically significant nutrient enrichment relative to anthropic sediments and the GTC but CS2 is only enhanced compared with the GTC. Only CS1 demonstrates nutrient enrichment compared with the ASC and this is not confirmed statistically. When Ca is excluded from the analysis, anthropic sediments contain the highest cumulative nutrient contents whilst that of the anthrosols falls below the GTC with CS2 and CS3 above the ASC (not confirmed statistically) and CS1 slides to the bottom of the table (confirmed statistically compared to GTC only) confirming that Ca content is affecting the results. The retention of the null hypothesis is suggested for comparisons between CS2 and CS3 and anthropic sediments, indicating that cumulative nutrient content is not significantly higher within either anthropic sediments or anthrosols.



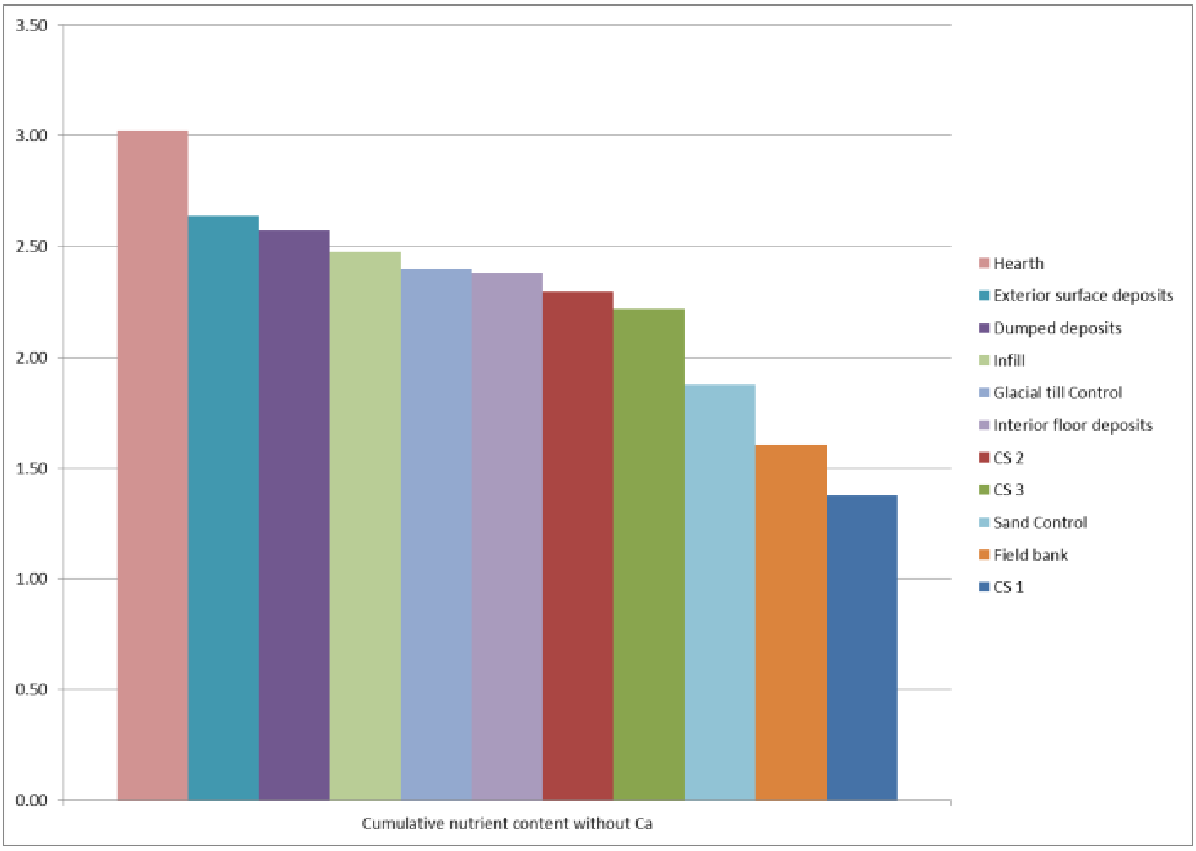


Figure 5.90: Cumulative mean nutrient loadings across groups, with Ca (top) and without Ca (bottom)

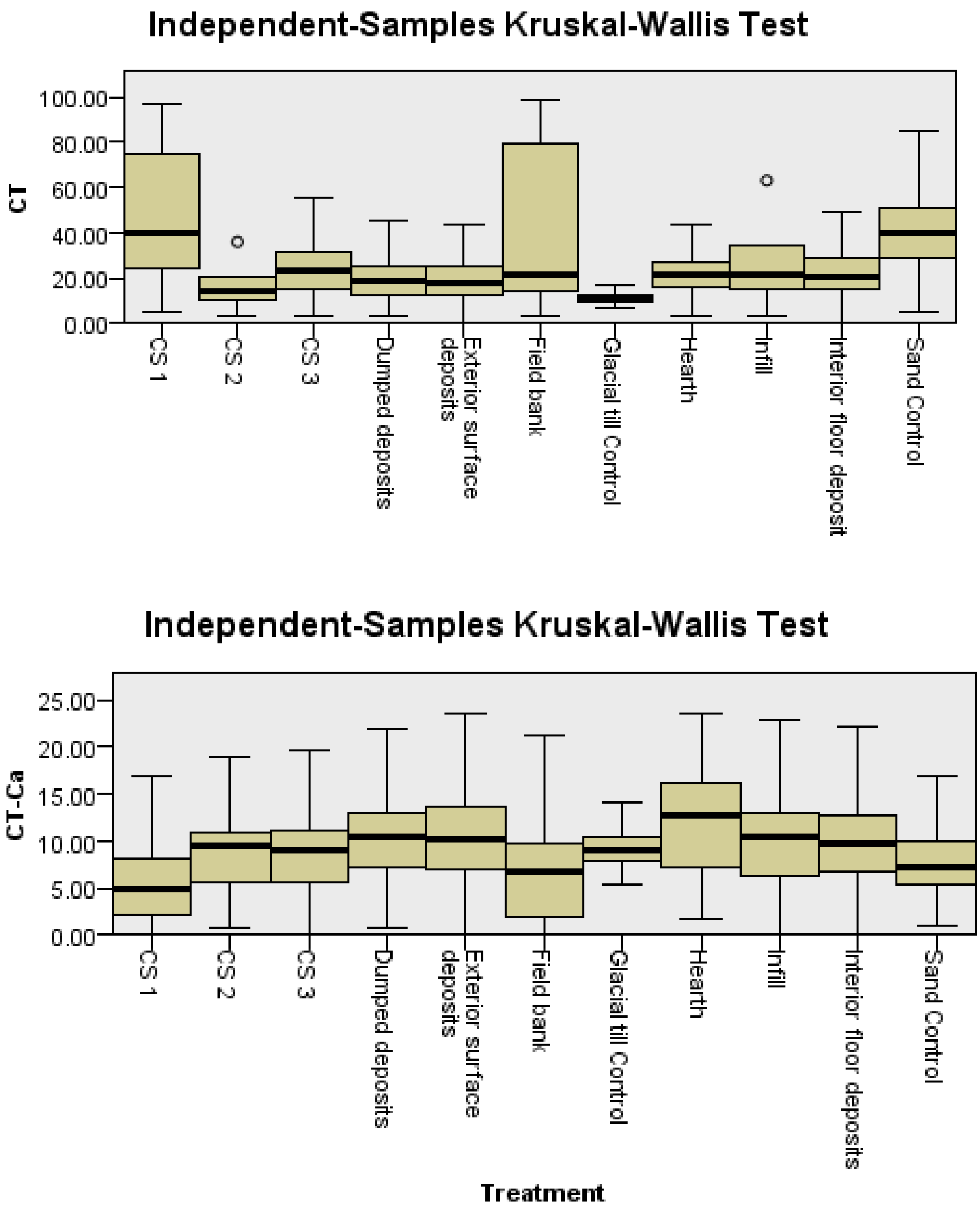


Figure 5.91: Visualisation of Kruskal Wallis tests, top = including Ca bottom = excluding Ca

5.6.4 *Summary of anthrosol formation*

Type 1 cultivation, the amendment of aeolian sand with anthropic material led to an increase in the cumulative nutrient content of aeolian sand. However this must be treated with caution as removal of the Ca element from analysis demonstrates that the cumulative content of other nutrients places CS1 in the lowest position, below the glacial till and aeolian sand controls.

Anthropic activities involving the tillage of the brown earths formed upon glacial till have led to a slight, non-significant depletion in cumulative nutrient content which has been improved by mixing in calcium rich aeolian sand and anthropic material (type 2 cultivation). This has successfully raised the cumulative nutrient content slightly above the level of the glacial till control (this is not a statistically significant difference).

Tillage of the in situ anthropic sediments (type 3 cultivation) successfully raised the cumulative nutrient content of the cultivated soil significantly above the levels of the GTC and type 2 cultivation and may represent the most efficient use of nutrients for cultivation at the Links of Noltland.

The tillage of brown earths, the strata upon which type 2 cultivation was carried out, has been related to the Area 5 settlement using auger survey data and so it is suggested that this may be the earliest form of tillage carried out at the Links of Noltland. The sediment was buried beneath aeolian sand evidenced by the clear boundary between the Ap horizon and overlying aeolian sand. The date at which this occurred has not been resolved but significant sand blow events are acknowledged toward the end of the Neolithic on Westray (Sharples 1984) and at Toftsness (Sommerville et al 2007). Sand blow events have been subject to higher resolution analyses at Mill Bay, Stronsay where periods of increased storminess between 3400-3100 cal. BP and c.2800-2260 cal. BP are acknowledged (Tisdall et al 2013).

Following sand accretion at the Links of Noltland, type 1 cultivation was carried out, the anthropic inclusions recorded in these deposits indicate a diversification of management methods including the addition of animal manure designed to stabilise aeolian sand for cultivation (also described by McKenna and Simpson 2011). The mean percentage of fine material present (figure 5.92) and cumulative nutrient content within these deposits indicates success was limited with loss of fines resulting in loss of soil structure and nutrients. It should be noted that both type 1 and type 2 cultivation are evidenced in the area known as the 'Area 5 field system' (Moore & Wilson 2011a).

The period between deposition of anthropic material into Area 5 structures and the tillage of the resultant sediment (type 3 cultivation) was short, with minimal sand accumulation evidenced. This was the most effective method of preserving nutrient content, fine material and soil structure. The difficulties presented by structural masonry to ard tillage may have been offset by the productivity of this type of cultivation. It seems likely that buildings may have been deliberately in-filled with anthropic material to create a more level surface and as an alternative to 'loosing' it by manuring aeolian sands.

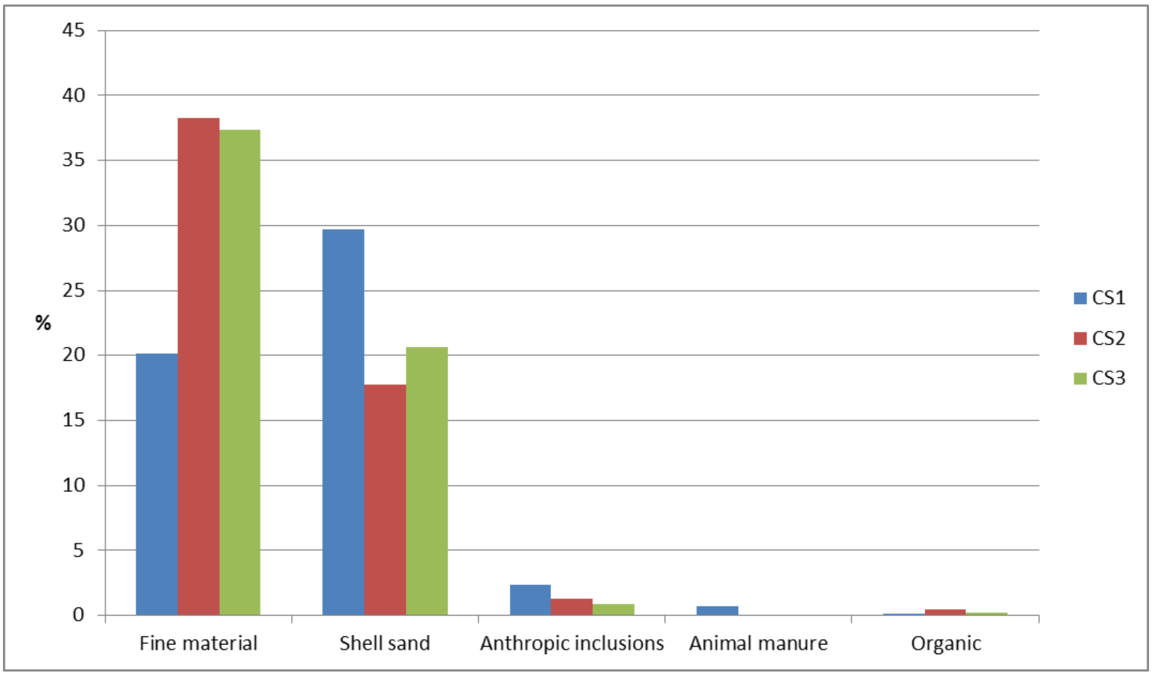


Figure 5.92: Point count results for samples grouped by cultivation type. Results expressed as mean percent ratio.

5.7 Summarizing thin section micromorphologiocal analyses of anthropic sediments and anthrosols at the Links of Notland

Anthropic sediments were split into six distinct contexts; foundations, interior floors, hearth deposits, exterior occupational desposits, dumped deposits and building infill. Thin section micromorphology has indicated that no clear distinction in the composition of midden material can be made between these contexts. However, activities within the midden can be described and in themselves form distinctive formation pathways. Activities observed include 'dumping' of material, in situ burning, animal stalling and maintanence tasks such as burning bedding and sweeping out hearths. In addition, the manufacture of yellow clay through puddling of natural boulder clay was identified. Primary, secondary and tertiary deposition can be described and evidence of this will be input into a revised flow model in chapter six.

Investigation of anthrosols lead to the discovery of three distinctive land management strategies at the Links of Noltland; vegetation clearance through burning prior to tillage (type 2), in situ tillage of archaic midden associated with earlier settlement (type 3) and manuring of aeolian sand using midden material and animal dung to combat sand accretion (type 1).

Chapter Six

Chapter 6 Significance of anthropic sediments on the Scottish North Atlantic seaboard: nature, versatility and value of midden

6.1 Introduction

Geoarchaeological research has characterized anthropic sediments and anthrosols at the Links of Noltland, providing an environmental and archaeological context for their formation and documenting the present day range and extent of anthrosols in the landscape.

The following chapter will draw together evidence from the Links of Noltland to address the broad aims of this research and discuss this with reference to published findings and ongoing research in the Scottish North Atlantic seaboard.

To do this the objectives and multiple-working hypothesis model formulated in chapter two is revisited and suggestions are made as to the nature, value and versatility of anthropic sediments on the Scottish North Atlantic seaboard based upon a human ecodynamics framework.

6.2 Nature

Anthrosols are widespread in the Links of Noltland landscape and represent the amendment of glacial till, brown earth and aeolian sand parent materials through the addition of cultural materials through cultivation, trampling and colluvial/aeolian action. Anthropic sediments have largely formed as gradual accumulations of organic matter and cultural materials intimately mixed with local geological parent materials imported with and without intent. Within these sediments occasional preservation of burning and dumping activities were observed under the microscope. Archaeological interpretations for anthropic sediment contexts were confirmed through microscope based analyses with a number of modifications suggested. The following presence/absence chart is constructed through point count, micromorphological and SEM EDX analyses (figure 6.1) and demonstrates the cultural inclusions and environmental indicators observed in each archaeological or geoarchaeological context with refinements based upon post-excavation analytical interpretations.

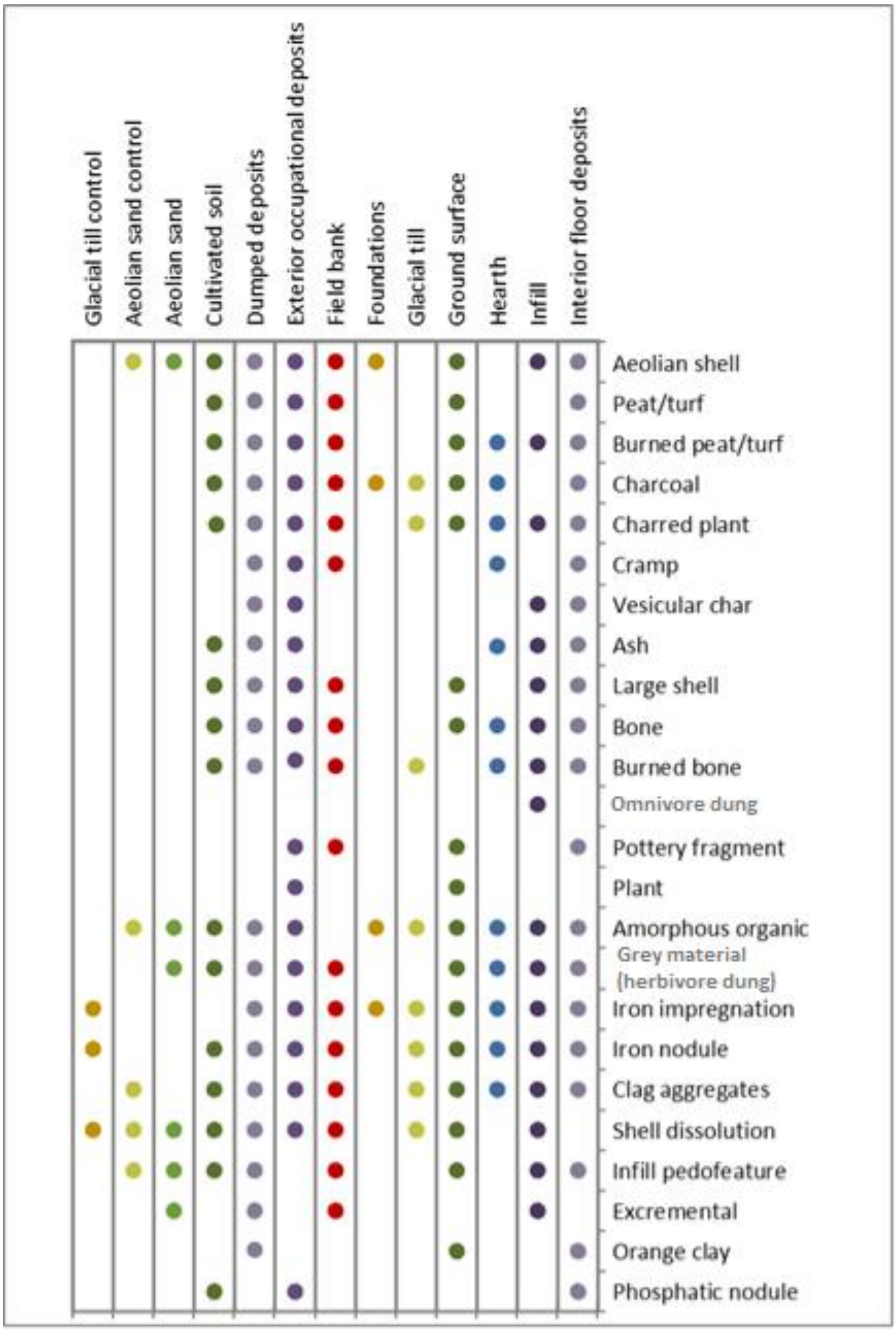


Figure 6.1 Final presence/absence chart drawing upon the interpretations of point count, micromorphological and SEM EDX analyses. This demonstrates the cultural inclusions and environmental indicators observed in each context group.

The presence/ absence chart indicates the composition of each ‘system output’ (figure 6.2) reached by the human ecodynamics flow model. The significance of each inclusion is presented in table 6.1.

Table 6.1: Summary of anthropic/natural inclusions observed in anthropic sediments at the Links of Noltland, their possible origins and significance for interpreting activities based upon the depositional context, micromorphological/ SEM EDX interpretations and human ecodynamics framework (after Shillito et al 2011).

Inclusion		Significance
Bone		
Unburned		Animal slaughter Food preparation Carnivore activity
Burned		Fragmented and randomly oriented: pre-deposition burning for cooking, ritual, cremation etc. Intimately associated with fuel residues or horizontally oriented; in situ burning
Plant Material		
Charcoal		Collection and burning of woody material Pre-deposition burning: cooking, heating, lighting, warmth, ritual, cremation, maintenance, fuel for other activities, accidental damage, deliberate destruction In situ burning: maintenance/hygiene, symbolism, accidental fires, vegetation clearance
Char		Collection and burning of grass, leaf or heath plants Pre-deposition burning: cooking, heating, lighting, warmth, ritual, cremation, maintenance, fuel for other activities Short duration/low temperatures
Punctuations/amorphous		Decay in situ: buried land surface or matting, hurdles (especially if articulated phytoliths are present) Decomposition post deposition: food waste, spoil discarded artefacts such as rope
Peat/turf		
Unburned		Cutting and importation for floor covering and the tertiary movement into dumped deposits. Fertiliser/stabliliser
Burned		Cutting and importation for fuel Maintenance of floor coverings Fertiliser
Coprolites		
Herbivore	Burned	Dung collected and burned as fuel Maintenance of stabling/ holding deposits Production of ash fertilizer
	Unburned	Cow/sheep grazing Manuring
Omnivore		Dog/pig foraging Management of dog/human waste
Ash		
Plant		High temperature/long duration burning
Peat/Turf		In situ accumulation/ mixing with clay for heath maintenance
Dung		Ex situ mixing as secondary or tertiary deposits
Clay aggregates		
Hearth-rake out		Maintenance / Fertiliser
Cultivation		Ripping up and mixing of underlying sediment
From glacial till		(Orange or yellow clay). Pottery production, manufacture and use of constructional materials

Inclusion	**Significance**
Large shell fragments	Food waste, artefact production, fertiliser
Pottery fragments	Ceramics use Broken artefacts, discard or deliberate deposition
Vesicular char	Still enigmatic; possibly burning driftwood or 'jetification' of carboniferous material.
Cramp	Funerary activity Deliberate scattering around the settlement /accidental incorporation
Fe/Mn movement	
Accumulation/depletion	Redoxification, periodic wetting and drying Acidification Pyrite framboids in extremely wet anoxic conditions
Nodules	Orthic – Addition of turf or peat from a wet, acid area to the situation where found Disorthic – Mixing of an acid soil Anorthic – Redoxification in situ, periodic wetting and drying Acidification
Shell dissolution	Acidification through the addition of anthropic materials
Non-laminated isotropic dusty clay pedofeatures	Cultivation higher up the soil profile
Excremental fabric/ pedofeatures	Biological activity in the presence of organic matter and oxygen
Minerals	
Marine shell sand	Aeolian/colluvial transport Increasing storminess Preparing a floor Cultivation
Flag stone geology	Colluvium Accidental incorporation (kicking, attached to turf) Mixing through cultivation Prepared gravel surfaces Cultivation Turf importation for floor preparation, fuel or fertilizer Artefact production Cooking (pot boilers)
Glacial till	Mixing through cultivation Trampling Digging

6.2.1 *Range and extent*

The first objective of this study was to identify the range and extent of anthrosols and anthropic sediments associated with both Neolithic and Bronze Age settlements and their wider landscapes. Typically anthropic sediments form a halo around Neolithic structures but it was found that they extended further into the landscape than expected as material related to the Area 5 settlement worked its way down slope through a combination of colluvial and aeolian action and tillage. This may indicate the deliberate situation of the settlement to allow easier transport of fertilisers or an accidental discovery. A discrete pocket of organic-rich material containing anthropic inclusions was also recorded 70m west of the main settlement area but not investigated further. Parallels may be drawn with Allt Chrisal (Foster et al 2005) where discrete anthropic activities are dotted around the landscape and may represent specialized work zones. Alternatively this may represent another discrete plough-pan as described for type 1 cultivation at the Links of Noltland.

6.2.2 *Environmental and cultural context*

Glacial till or boulder clay is found across Westray, having been carried by ice from Scandinavia and Scotland as it scoured red and yellow sandstone from Eday (Leather, 2006). Rock fragments and boulders are found in a bright orange - yellow clay matrix which is spread across the Links of Noltland in varying thickness. The glacial till appears to have been colonized by light vegetation post-glaciation and this progressed to deciduous woodland and the formation of brown earths progressing to sub-podsolisation. Vegetation was cleared down-slope of the Area 5 settlement through burning and subsequently subject to tillage until the soil was buried by aeolian sand. Although Neolithic sediments encountered in Area 5 and structure 7 were shell-sand free, aeolian sand was characteristic of anthrosols and sediments related to Bronze Age structures 13 and 17. These findings correlate with the accepted increased North Atlantic storminess during the Bronze Age.

Desk-based review and archaeological excavation have placed these sediments within a general cultural period. Micromorphology has provided a description of the 'output' of activities, recognizing areas of primary, secondary and tertiary discard.

Cultural behavior in the Neolithic at the Links of Noltland led to the formation of 'interior floors' in which different areas of activity are expected given findings of differential levels of anthropic inclusions and soil chemistry. Hearth sediments were free from coarse fuel residues but ash was mixed with clayey material indicating some degree of maintenance and an inferred decision process which removed residues from the immediate vicinity. Fine residues from burning, cooking and butchery and animal penning activities accumulated within deposits which were interpreted as exterior occupation surfaces and these were found to be analogous to 'dumped deposits' or areas of secondary and tertiary discard. An intimate and changeable relationship is hypothesized between exterior occupational surfaces and dumped deposits as surfaces and in situ burning was evidenced in both as well as periods of accumulation, trampling and biological reworking. This interwoven relationship extends to infill deposits. Where in situ burning, gradual and rapid accumulations of both organo-mineral and anthropic materials are evidenced along with biological reworking.

Cultural responses to a changing environment are evident in anthrosols and anthropic sediments at the Links of Noltland. As sand accretion began to affect activity areas anthropic materials and clay were added to aeolian deposits creating a more stable soil structure for tillage. This method achieved limited success and may have been the precursor to in situ tillage of anthropic sediments. The eventual abandonment of the area after the second millennium BC has been attributed to the instability of the landscape (Moore & Wilson 2011a).

The fuel residues in Area 5 are abundant and diverse. Of the twenty four samples recovered twenty three contain some form of fuel residue. Fuel residues give insight into the environmental resources available to the community and so consideration is given to this. The main fuel residues can be broken down as follows:

6.2.2.1 *Wood charcoal*

Evidence from West Mainland and Rousay indicates local woodland was in decline (Farrell 2009) by the time settlement was established at the Links of Noltland. However this does not rule out a locally accessible source on Westray as birch, hazel and alder were available on Sanday into the Bronze Age (Alldritt 2008). Driftwood is a further possible fuel source. Although anthropological evidence from Hebridean island communities who experience a lack of locally available timber indicates that when wood is scarce, driftwood is thought too precious to burn (Barber 2003). Driftwood exploitation as a fuel resource is known to have been carried out during the Bronze Age on Sanday (Alldritt 2008). An explanation which takes into account both arguments would be selective use of larger pieces of driftwood for building materials and smaller fragments as a fuel source. Drift wood or submerged forest are plausible sources for wood fuel on Westray - ethnographic evidence was collected by Leather (2006) indicating that children were playing around tree stumps and roots at low tide on the south side of the bay of Tuquoy in the 1940s.

6.2.2.2 *Peat and turf*

Davidson and Jones demonstrated that blanket peat formation began in Orkney 3000BC, coinciding with a decline in scrub cover. However, with a few unremarkable exceptions, peat has since been shown to occur around the coast of Westray only in very small patches often eroding into or being submerged by the sea (Stapf 1998, Leather 2006).

6.2.2.3 *Animal dung*

Decayed organic remains were identified as coprolites where they contained concentrations of spherulites and articulated phytoliths and matched with chemical analysis, comparison with published literature and the other sediments at Links of Noltland. The presence of herbivore dung ash in all context groups examined indicates its importance as a fuel. Dried dung was stored around the settlement at Eilean Domhuill and was interpreted as a potential fuel store (Mills et al 2004). Dung as a fuel residue was mobile amongst anthropic sediments and is found in dumped deposits, the hearth and in type 1 cultivation anthrosols. However in at least one area it was burned in situ cyclically. The utilisation of dung as a fuel is a secondary product, akin to milk/ wool etc. (Shahack-gross 2011) indicating a more complex social relationship between people and animals than their primary consumption for meat and hints at the secondary products revolution discussed by Sherratt (1981). The earliest evidence for the use of dung as a fuel was found at Neolithic Çatalhöyük (ibid.), where cattle were so venerated that some authors have postulated a 'cattle cult' (Ray and Thomas 2003: 35, Twiss and Russell 2010).

The relative lack of good fuel sources compared with Skara Brae and Tofts Ness indicate that it was the 'place' that was important to the community at the Links of Noltland rather than the set of resources, implying that cultural motivation rather than environment influenced the choice of settlement location.

6.2.3 *Formation pathways*

The complexities of formation evidenced at the Links of Noltland have necessitated a revision to the rather simplistic flow model proposed in chapter two. Figure 6.2 describes the flow of materials around the settlement based upon micromorphological interpretations and significance (table 6.1). The anthropic sediments are particularly complex and were excavated using a grid system for post-excavation interpretation of the spatial distribution of macro-remains which will provide a more accurate characterisation of the flow of materials than can be achieved by microscope based analyses. However the model presented below based upon the flow of fine material may aid future interpretation.

Working through figure 6.2, the flow of materials results in a diverse range of 'system outputs' which are all under the influence of post-depositional processes but most notably biological reworking which affects stratification. The flow of materials which result in the hearth deposit output indicates that fuel was collected predominantly in the form of animal manure but also wood and peat or turf. These materials are no longer present in the hearth in abundance but their presence in adjacent contexts indicates this is not a symptom of decomposition, nor is stratification observed or any significant overflow of materials.

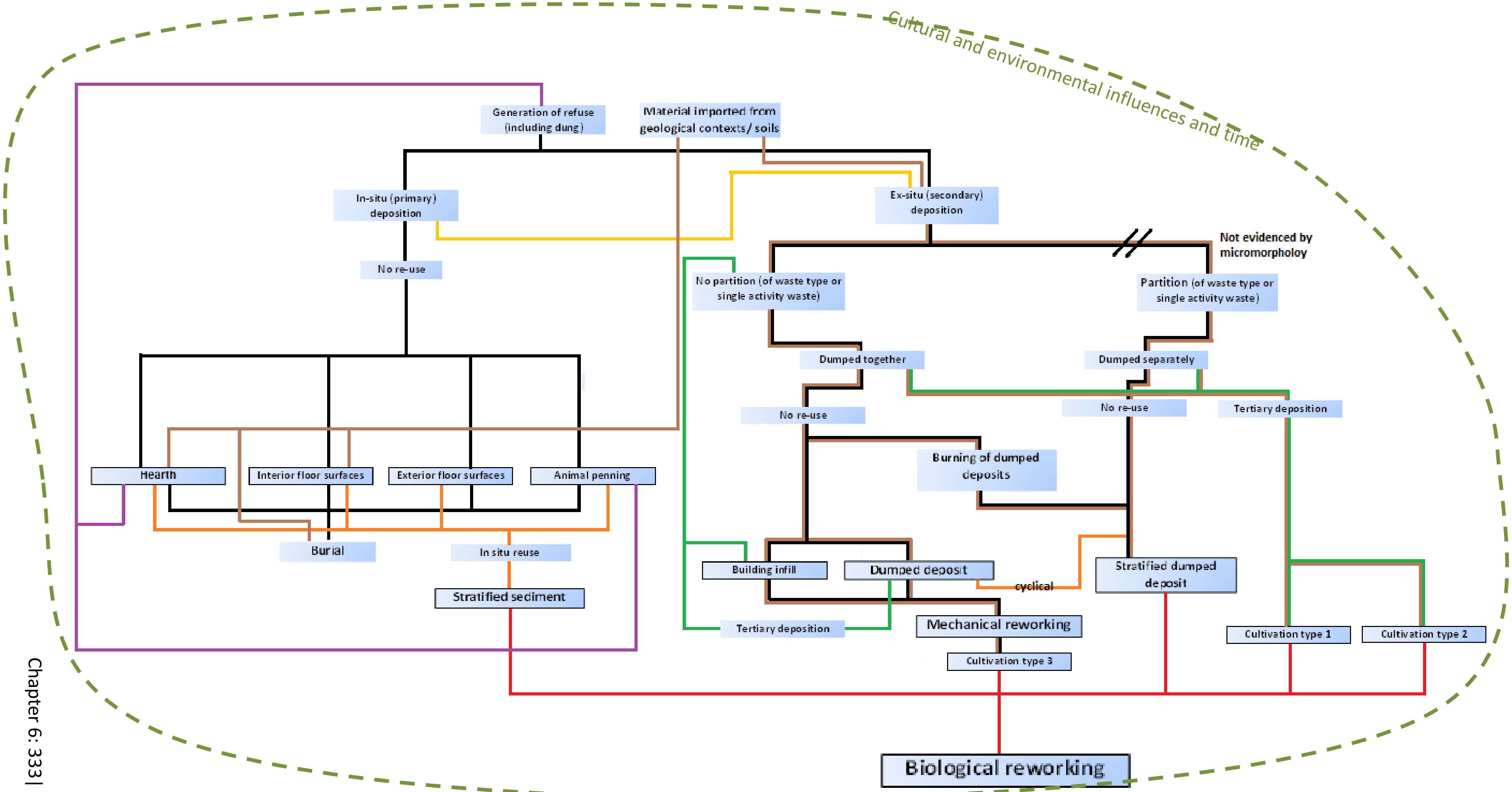


Figure 6.2: Revised flow model describing the types of deposition which led to the formation of archaeological contexts defined in this research. Boxes outlined in black are 'system outputs'. It is assumed that at any formation stage human agency or environmental influence can reverse, side-step or bury the flows.

Therefore unless occupation was short-lived (unlikely given the robust construction of structure 9), ex situ deposition must have occurred. This implies that hearths are places where both generation and deposition of materials take place. Theoretically, cultivation contexts also link to hearths as the products of this (vegetation/animals sustained by fodder) are collected and cooked. Traces of burned bone in the hearth sediment of structure 9 demonstrate this is in progress. Animal stalling is also a context type which is a potential generation zone as it provides a way of producing fuel or fertilizer which is easily collected. Parallels in later prehistory up to the pre-modern era are known on the Scottish North Atlantic seaboard (Simpson & Guttmann 2002, Davidson & Carter 1998, Fenton 1997, Davidson & Simpson 1994). In the North Atlantic animal stalling associated with Neolithic habitation is unprecedented and hints at the 'secondary products revolution' where animals were exploited for secondary products such as milk or wool (Shahack-Gross 2011, Bakels 1997, Sherratt 1981). This evidence marks a sophisticated farming method, with animals exploited not just for meat or skins. Collection of animal dung without stalling would be laborious and Bakels (1997) argues that this method is a direct consequence of keeping draught or milk animals. The faunal and archaeological evidence from the Links of Noltland excavation is expected to support this interpretation, but geoarchaeological investigation has provided a strong body of evidence for the methodical collection of animal dung for use in heating, lighting and as fertiliser. The scarcity of other fuels in the Links of Noltland landscape seems a likely impetus for the adoption of animal stalling here, enabling the inhabitants to have a ready supply of fuel when necessary.

Interior floor surfaces do not demonstrate any evidence of deliberately constructed surfaces such as ash deposition, thresh or peat covering as is the case in Neolithic, Iron Age and later settlements in the study area (Dixon 1989, Guttmann et al 2003, Milek 2005). Instead, they are more in keeping with 'stamped floors' described at Skara Brae and Rinyo (Childe 1930, Childe and Grant 1938) and have accumulated through the gradual buildup of geologically and anthropically derived materials with occupation. This implies that materials were not imported into the structure to create floors and so the proximity of the roof would not have become problematic necessitating digging out and removal of floor strata (Milek 2012). Thus floors can be considered primary deposits in both the Neolithic and Bronze Age interiors studied. If any maintenance was carried out it was not vigorous as excavation encountered macro deposits of bone, shell and fuel residues (Moore & Wilson 2011b).

Exterior floor surfaces, infill and dumped deposits are areas of secondary and primary deposition. With in situ activities, stand still and accumulation are interwoven, forming stratified and unstratified sediments. Aeolian and biological transport of materials seemed to have occurred with fine fuel, bone and artefact residues becoming incorporated into sediments through deliberate acts of deposition and probably accidental trampling from inside structures to outside surfaces (potentially by humans and animals). The in situ burned dung layers indicate that a degree of maintenance was carried out within animal pens. Very little microscopic evidence for partitioning of residues was observed with only the distribution of large shell fragments flagged up as statistically significant between dumped deposits and infill, exterior occupation surfaces and the hearth. Therefore based upon fine materials, all secondary deposits are spatially unpartitioned indicating no communal effort to save specific materials for specific purposes unless later reworking or tertiary deposition has obliterated this. Statistical testing of chemical data produced many more significant results but much more involved sampling would be needed to build a robust argument for partitioning. Spatial partitioning of activities within areas of secondary and tertiary deposition may have occurred and this is being addressed post-excavation by EASE.

Exterior floors evidence in situ or secondary re-use. Midden was a place in which the daily rituals of a working settlement were played out. Stratified sediments developed through repeated activities and continuous occupation. Activities evidence animal husbandry and home comforts like fresh bedding and clean floors. The evidence of cooking and eating is abundant everywhere, the inhabitants were 'at home' and during earlier phases of settlement, before sand accretion became a problem, were confident in their environment.

Secondary or tertiary deposition of mixed dumped deposits is evidenced within type 1 and type 2 cultivation (see table 6.2) indicating that a communal decision was taken to collect and redistribute material for tillage. Burned material including cooking debris and hearth rake-out, was redistributed either directly or indirectly into agricultural contexts. Type 3 cultivation may or may not have occurred at the same time or later than type 1 cultivation but, either way, an innovative step in resource management is evidenced and the Links of Noltland sediments have pushed back the known use of animal dung as fertilizer to the Neolithic period.

Table 6.2: Reminder of cultivation types identified at the Links of Noltland.

Cultivation type	Description
1	Application of midden material to windblown sand deposits
2	Tillage of brown earth
3	Tillage of insitu midden deposits

Wall core was not sampled at the Links of Noltland as the opportunity did not arise during the time-frame of this research. However, the placement of cattle skulls into wall core is worthy of remark. This has been hypothesised as evidence for a special significance afforded to cattle at the Links of Noltland (Fraser 2011, Moore and Wilson 2011b). Detailed analysis of these skulls is ongoing.

There are many possible pathways leading to the system outputs described in figure 6.2 and these are subject to revision, cessation, repetition and reappearance over time within the cultural and environmental spheres of influence. The flow model demonstrates some of these pathways. It shows that 'midden' is very much an entrenched part of communal living during prehistory. The use of local geological materials in building the distinctive stone structures characteristic of the prehistoric era on the Scottish North Atlantic seaboard together with the development of a particular method of animal husbandry linked with the secondary products revolution alludes to the intrinsic relationship between people, animals, anthropic materials and resources in the landscape. Within the human ecodynamics framework, this demonstrates that the distinctive culture which developed here was very much influenced by available landscape resources and the opportunity to manufacture midden from these.

Whether they liked it or not, Neolithic and Bronze Age communities were surrounded by midden. Whereas the more modern concept of 'midden' might refer to material described throughout this thesis as 'dumped-deposits', it has been shown to be a very versatile resource for prehistoric cultures. Prehistoric communities had an intrinsic relationship with midden. It was an unavoidable by-product of their very existence. It contained geological and organic material but also fuel residues, pieces of material culture, animal excrement (and likely human too – Simpson et al 1999b), bones and shells. This doesn't reflect a haphazard existence where individuals were either disorganised or lazy. Instead it seems to point to a reasonably pragmatic lifestyle with an acceptance of organic material composting freely and small inclusions allowed to remain on the living floor. Deep accumulations do indicate a concerted effort to pile composting materials together regularly though, so at least some of the community considered maintenance or management of decaying organics a worthwhile task. Certainly the inhabitants of prehistoric settlements did not suffer from the squeamishness felt by some towards rotting material, indeed the smell was probably quite 'homely' for them. Places to live and work were one and the same as midden.

6.2.3.1 *Summary*

The presence or absence of cultural inclusions has been documented through point count, micromorphology and SEM EDX analyses to fulfil thesis objective 3 for archaeological context groups at the Links of Noltland (figure 6.2). The functions of these anthrosols and anthropic sediments can be disentangled through consideration of the significance of cultural and natural inclusions, anthropic amendment and environmental processes (table 6.1). Set within a human ecodynamics framework the flows of materials leading to the formation of anthrosols and anthropic sediments together with intensity of use can be hypothesised (figure 6.2). The nature, range and extent, function and formation of anthropic sediments and anthrosols at the Links of Noltland has therefore been presented together with cultural and environmental contexts fulfilling objectives 1, 2 and 4. The next step is to characterise and understand these deposits in relation to the cultural diversity of communities across the Scottish North Atlantic seaboard by consideration of their versatility.

6.3 Versatility

Analysis of anthropic sediments at the Links of Noltland demonstrates that they are the product of many cultural activities and environmental influences and that they were also the setting in which these activities took place. Anthropic inclusions are ubiquitous across the Links of Noltland and are thus ingrained in cultural activity. Although no partitioning has yet been evidenced at this site, the versatility of anthropic sediments as an assemblage is demonstrated by their employment in a variety of activities manifested across the Scottish North Atlantic seaboard.

6.3.1 *Discussion of groups*

6.3.1.1 *Wall cores*

Wall core which incorporates anthropic materials is described across the Scottish North Atlantic seaboard as having a clay component. Yellow clay seems to have been an important constructional material and was observed lining hearths and stone boxes and bonding paving slabs and building masonry (Moore and Wilson 2012). Yellow clay was also observed bonding paving at Neolithic Tofts Ness (Dockrill et al 2007), in Bronze Age floors at Jarlshof (Hamilton

1957), Sumburgh Runway (Downes and Lamb 2000), Tougs (Hedges 1986) and Kebister (Owen & Lowe 1999) and in wall core at Skara Brae (Simpson et al 2006). It appears to have been particularly important at the prehistoric (but undated) settlement at Sand Wick, Unst, Shetland (Lelong 2006). At the Links of Noltland yellow clay found in anthropic sediments was analysed using SEM EDX and interpreted as derived from local glacial till. The glacial till at the Links of Noltland is stony and the extraction of clay would have taken some effort. The use of this material indicates a close relationship between people and the landscape. It often is found mixed with ash and other fuel residues which implies a deliberate act. Perhaps this was important for practical reasons (for example to make it more pliable) or perhaps this is a symbolic act as natural resources are brought into the domestic setting. In this way, anthropic material is employed to manufacture a functional material which is a popular or important part of Neolithic and Bronze Age settlement.

6.3.1.2 *Foundations*

Literature review found that foundations are occupational deposits, similar to floors and included bone, cereal grains, plant remains and fuel residues. These types of deposit beneath Neolithic structures had not yet been excavated as fieldwork was undertaken at the Links of Noltland and so no microscope based comparison can be made. The sediment beneath the Bronze Age building was analysed and has been observed to be very similar to the aeolian sand control and is therefore not considered an anthropic sediment. Structure 18 (also known as the Grobust building) which was partially excavated in 1979 and 1981 was found to be built into a pit cut into a sand dune creating a 'semi-subterranean building' (Moore and Wilson 2012) without any anthropic sediment present in the foundations. This might indicate that this was not culturally important at the Links of Noltland. However, later work revealed a 'platform' composed of shell midden beneath structure 13 (Moore and Wilson 2012). A review of sites on the Scottish North Atlantic seaboard and the work undertaken at the Links of

Noltland indicates that, although occupational debris was incorporated into foundations for some settlements, this was not always the case even within the same landscape.

6.3.1.3 *Interior floors*

Two types of floors were identified in the literature; earth and paved. Floors encountered at the Links of Noltland followed this pattern with both occurring in the same landscape. Micromorphological analysis of interior floors demonstrated that 'living floors' were preserved in structure 9 and fine anthropic materials, including burned and unburned bone, charcoal, charred plant remains and possibly herbivore dung became incorporated into the floor through occupation. Micro-inclusions were on average fairly light (<8% ± 11 %) but this is consistent with other recorded food cooking contexts (Matthews et al 1997). Macro remains included charcoal, shell, burnt bone and peat ash (Moore and Wilson 2011b). At least one 'prepared' floor surface was recognised. This involved spreading fuel residues across the floor. Whether this was for hygienic purposes can only be hypothesised but fuel residue based prepared floor surfaces are known across the North Atlantic seaboard and ethnographic research has demonstrated that ash was considered a hygienic resource by some communities (Milek 2012). The presence of amorphous organic fine material may indicate that vegetation (bracken, ferns, twigs etc.) or peat was imported into the structure, perhaps as thresh flooring as was observed at Eilean Domhuill (Dixon 1989). Microlaminations in the dumped deposits consistent with the burning of bedding (Miller & Sievers 2012) may hint at maintenance activities associated with interior floors.

The interior floor in structure 13 was much sandier than structure 9. The anthropic inclusions are intermixed with shell sand demonstrating that sand was allowed into the interior of structure 13 as it was occupied rather than as an aeolian event sealing a sand-free occupational floor. No evidence of stratification of floor deposits or the 'zones' described by Gé et al (1993) was found in structure 13. Macphail & Goldberg have found that when deposits expected to be floors do not exhibit fine laminations they may 'result from "disuse", squatter occupation or building decay' (2010: 595). Sandy floors were also reported at Cladh Hallan. These are deeply stratified and accumulated over a 700 year period (Parker-Pearson et al 2004) with many 'beaten floors' evidenced. A chronology based upon hierarchical relationships between sediment features was proposed and indicated an initial construction of domestic beaten floors upon clean quartz sand followed by a cyclical buildup of occupational debris and turf/sand/hearth deposition (Hamlet and Simpson 2013). The floors appear comparable to those recorded at the post-medieval sea stack site of Dùn Èistean (McKenna & Simpson 2009) where peat and hearth materials were laid down as rough floor coverings within stone and turf built structures. Although floors from Cladh Hallan and Eilean Domhuill are beginning to evidence the use of vegetation, turf and fuel residues to construct floor surfaces, the widespread intentional use of these materials in prehistoric floor construction on the Scottish North Atlantic seaboard has not yet been confirmed. The floors at the Links of Noltland demonstrated the incorporation of vegetative matter but if this was related to deliberate floor construction, bioturbation has erased the evidence. Nevertheless as soil micromorphological analysis is increasingly applied to these contexts a more thorough understanding will be achieved.

6.3.1.4 *Hearths*

Hearths are described as containing ashy deposits throughout the literature. This probably represents the final abandonment deposit as regular maintenance is evidenced by the accumulation of fuel residues, hearth rake-out clay and cooking debris in other contexts. Hearth sediments were analysed in chapter four and demonstrated the presence of a burnt layer containing burned and unburned bone, charcoal, burned peat and turf, charred plant remains and rake-out aggregates. This confirms that hearths are one of the generation areas of these materials. Sterile silt was described covering this layer in the field and this was confirmed microscopically. Thus, natural clays tempered with household waste seem also to have been employed in hearth construction. Comparison of this material in the hearth context, and in situ burned herbivore dung implied this layer may also contain a dung ash component. In pre-modern Orkney turf mixed with gritty clay was burned in house fires to increase the quantity of ashes for fertilizer (Fenton 1997) and it seems plausible this practice may have a prehistoric origin.

6.3.1.5 *Exterior occupational deposits*

The exterior occupational surface deposit sample set share a common microstructure characterized by soil faunal reworking. Despite this, a range of activities have been reconstructed within this group of samples. This demands a more detailed analysis of these deposits than has been allowed by the number of samples analysed by this research. Nevertheless, anthropic materials in the form of allochthonous fresh and burned peat/turf fragments, charcoal, charred plant, cramp, vesicular char, ash, large shell, burned and unburned bone, hearth rake-out clay aggregates and fragmented pottery have been demonstrated as incorporated into these contexts. For many of the samples, the same formation process as leads to occupational, living floors is interpreted as anthropic and natural colluvial and aeolian material was accumulated gradually over a long period of time. At the same time, greater disturbance is noted in the exterior deposits and discrete activities are evidenced, such as in situ burning or dumping of materials, which was not observed in the interior floor sample set.

Laminated layers overlying paving investigated within the structure 8 complex in Area 5 were interpreted as in situ burning of stabling deposits. This raises the possibility that the paved surface (Moore and Wilson 2011b) and associated walling (Moore & Wilson 2012) represent stabling. Cattle at the Links of Noltland were very large for domesticated breeds (Fraser 2011). The current RSPCA welfare standards recommend 3m^2 loafing space for each penned beef and dairy cow over >800kg (RSPCA 2010 & 2011). Guidelines for sheep recommend 1.5m^2 for each ewe with lambs and 2m² for rams (RSPCA 2013). This suggests that the internal dimensions of the buildings excavated associated with the paving would have been of an adequate size to house 1 or 2 cattle or a few sheep at any one time. Radiocarbon dates issued from sediments above these features have given a *terminus ante quem* of the 2870-2570 cal BC and 2630-2470 cal BC (Moore & Wilson 2011b). Cattle stalling was practiced by the Neolithic Pfyner culture in Switzerland as early as 3600 BC (Overgaard et akl 2000) but the earliest evidence in Britain comes from Bronze Age Jarlshof (Hamilton 1956). Ineed this practice does not become characteruistic of prehistoric culture until the Iron Age, with sites in the Western Isles (Parker-Pearson and Sharples 1999, Scott 1948, Young 1953 – all cited in Hunter & Carruthers 2012) and as part of the broader Iron Age 'Broch model' (Armit 2003). The Links of Noltland evidence may however push this relationship with livestock further into prehistory on the Scottish North Atlantic seaboard.

6.3.1.6 *Dumped deposits*

Desk-based review found that dumps or accumulations of mixed material and discrete dumps forming thick anthropic sediments containing bone, hearth residues and artefacts are regularly described in Neolithic and Bronze Age settlements in the study area. That this may be for deliberate ground-raising, composting or storage is a possibility. The potential storage of materials for later reuse or partitioning has been hypothesised in the past but no in depth analysis had been taken to elucidate formation processes or value.

The distinction between exterior occupational deposits, building infill and dumped deposits at the Links of Noltland was often slight. This supports archaeological interpretations for these types of sediments across the Scottish North Atlantic seaboard. Material dumped at the edge of the Noltland settlement areas contained burned peat/turf, charcoal, charred plant, ash, vesicular char, cramp, large shell, burned and unburned bone and hearth rake-out clay aggregates. The sediment was subject to faunal reworking and so, if the sediment was formed through many discrete dumping events, these had been mostly obliterated. This does however indicate these deposits were once highly organic. Weakly expressed severely truncated microlaminations may represent relict surfaces and surface deposits but others were clearly in situ burning activities. Planar cracks and the compact nature of the dumped deposits indicate they were areas of movement and activity.

6.3.1.7 *Building infill*

Prehistoric buildings across the Scottish North Atlantic seaboard are observed filled with mixed occupational deposits including feacal waste and occasional 'special deposits' such as articulated skeletons and figurines. This was confirmed through microscope based analysis at the Links of Noltland where burned peat/turf, charred plant, vesicular char, ash, large shell fragments, burned and unburned bone, feacal material, organic matter, dung ash and hearth rake-out were observed in the 'infill' sample group. The infill of Neolithic buildings was similar to the dumped deposits and exterior occupational surfaces examined, with in situ burning evidenced indicating that, as buildings which were no longer occupied became filled with cultural materials, organic matter and geologically derived material, fires were also set. Biological activity evidenced by microstructure and excrements demonstrates the gradual accumulation of material which formed a humic top soil before and during later cultivation or burial through aeolian sand deposition.

The Bronze Age buildings had filled up gradually with a mixture of aeolian sand, cultural inclusions, organic material and omnivore excrement. This was anticipated through literature review which demonstrated that upon abandonment, midden material was allowed to accumulate within structures across the study area. The randomly distributed and oriented inclusions mixed with dominant aeolian sand were typical of either 'squatter occupation' of roofed or partially roofed buildings, occasional deposition of waste into unroofed buildings or the trapping of windblown materials within an unroofed structure (Milek 2012).

6.3.1.8 *Ground surfaces and cultivated soil*

The ground surfaces group were amalgamated with the cultivated soil group as all old ground surfaces out-with the immediate settlement area sampled exhibited evidence of tillage or mixing. This is probably due to a sampling bias as soil test pits and archaeological test trenches were targeted at archaeological features or anthrosols. Future machine clearance of aeolian sand is anticipated at the Links of Noltland and this may elucidate areas of untilled ground surface.

The three distinct types of land management observed within the cultivated soils group are paralleled across the Scottish North Atlantic seaboard. The emerging chronological sequence begins with clearance followed by tillage of ground surfaces and the application of cultural material (type 2 cultivation at Noltland) and shifts to in situ cultivation of anthropic sediments (type 3) before progressing to larger scale re-deposition of anthropic material onto sand-inundated landscapes to improve structure and fertility for agriculture (type 1). This is not however a comprehensive model. For example, subsoil cultivation has not yet been described at Jarlshof, the literature does not describe the in situ cultivation of midden at Scourd of Brouster. At Northton boulder clay and Mesolithic anthropic sediments were tilled contemporaneously whilst at Rosinish subsoil tillage was closely followed on by anthrosol formation as sand accretion buried the subsoil and anthropic materials were added to counteract this. This indicates that all three types of land and resource management were available to communities across the Scottish North Atlantic seaboard in prehistory but were practiced in different orders at different times depending on environmental and/or cultural influences. The application of anthropic sediments to all three land management types does however evidence the versatility of this material; despite changing practices midden application continued.

Cultivation types 1 and 2 identified at the Links of Noltland have particular parallels with those at Rosinish where ard and spade cultivation are evidenced in both windblown sand with added anthropic material and the underlying subsoil. These remains were stratified and dated demonstrating that ploughing of the subsoil occurred 1970 BC ± 55 with the addition of limpet shells and the 'midden enhanced' sand cultivation occurred at 1900 BC ± 75.

Dating of different land management types at the Links of Noltland has proven more complex. There is potential to use auger survey grid 2 and test pit data to reconstruct buried land surfaces using GSI3D to begin to untangle the stratigraphic relationships between cultivated areas near to structures 1-3. The radiocarbon dating program should elucidate the period during which different areas of the site were occupied. Given that grass turves buried less than 2cm can make a full recovery within days (Kent et al 2005), it is possible that aeolian sand accretion had already begun as vegetation was cleared and so the provision of a robust chronology for the three types of cultivation encountered at the Links of Noltand is challenging. 3D analysis of stratigraphic relationships between the field system and the settlement in Area 5 alludes to a relationship between Neolithic sediments and the type 2 cultivation evidenced in soil test pit 3, but closer scrutiny of fine strata at the edge of the settlement is required to confirm this. The earliest occupation at the Scord of Brouster occurred whilst scrub clearance was carried out but at Tofts Ness the settlement hinterland was not brought into cultivation until the Bronze Age. The earliest buildings (once resolved) at the Links of Noltland should be examined with reference to the findings of auger survey 1 to elucidate this matter. Therefore, future work is anticipated to identify the chronological order of cultivation types and thus the land management changes over time.

6.3.1.9 *Summary*

Detailed consideration and microscopic analysis of the many contexts of anthropic sediments and anthrosols at the Links of Noltland has demonstrated the versatility of this material across the Scottish North Atlantic seaboard. It was incorporated into every facet of life originating in the home, forming the constructional materials of the home and spreading out into the landscape. The landscape itself was brought into the home in the form of glacial till and mixed with materials generated in the hearth for the manufacture of building clay and ceramics. People enacted their lives upon and within anthropic sediments and, when environmental pressures grew, communities responded by finding new ways of employing anthropic sediments. When building materials were needed, anthropic sediments were incorporated and there does not seem to have been any effort made to confine these materials and prevent them from circulating around the settlement, implying a communal acceptance of their presence. The versatility of anthropic sediments hints at an intrinsic relationship between people, the resources in the landscape and a 'secondary products revolution'. Not only were animals and crops domesticated and exploited for their productive qualities but the products of human occupation were equally exploited as necessary. These sediments were an intrinsic part of human existence and formed a valuable resource.

6.4 Value

Without the presence of anthropic sediments prehistoric settlements on the Scottish North Atlantic seaboard would seem bare and uninhabited. An archaeologist would become highly suspicious if this material was missing entirely from an otherwise well-preserved archaeological site in this area. Therefore, anthropic sediments are one of the defining features of Neolithic and Bronze Age culture. The value of this material to prehistoric communities may have taken many forms and this may have changed with cultural or environmental circumstances. Anthropic sediments were recognised in prehistory as a suitable material for stabilising or fertilising soil for tillage but at the same time some of these materials were being left to compost in situ around the settlement. Statistical analysis of the inherent chemical concentrations of these deposits has demonstrated that material composting in situ (e.g. dumped deposits, exterior surfaces etc.) was enriched in nutrients essential for crop growth compared with tilled soils and so essentially represents a wasted resource if maximising yield was the priority. This leads to a range of possible interpretations; communities may have been unaware of the potential of anthropic sediments, or they may have deemed it unnecessary to further fertilise or stabilise soils for cultivation. Another possibility is that the Area 5 settlement at Links of Noltland was deliberately situated at the top of a slope so that anthropic material would be easier to drag or would naturally creep downhill for fertiliser. Field systems across Shetland have been repeatedly observed as oriented downhill (Turner 2013) and ethnographic evidence from Shetland indicates that manure was dumped at the top of a sloping cultivated field to make it easier to till with a spade (McKenzie 2006, also cited in Turner 2013). This would account for the bank or lynchet feature containing anthropic inclusions investigated in soil test pit 5 and would fit with archaeological findings. Midden 'peters out' gradually at the downslope edge of the settlement (Moore & Wilson 2009c).

Given that anthropic sediments were routinely tilled for cultivation at Tofts Ness and Northton during the Neolithic it seems likely that communities were well aware of their nutrient properties. Perhaps the investment of time and energy into redepositing this material onto arable soils may have simply not been economical before sand accretion became a problem.

The input of anthropic materials into each type of land management technique at the Links of Noltland is evidenced by the inclusions observed in thin sections (table 6.3). Although fresh or charred peat and hearth rake-out aggregates were not observed in type 2 cultivation (see table 6.2) and artefacts were not observed in type 1, no obvious demonstrable difference could be made between the fine anthropic inclusions which would define land management based upon a recipe. Nutrient enrichment was highest in type 1, and analysis concluded that, statistically, cultivation type 1 was the most successful enrichment strategy followed by type 3 and then type 2. However high levels of Ca derived from shell sand may have obscured these results as the removal of this element from the analysis demonstrated that management types 2 and 3 were more successful. Anthropic material left to accumulate in situ by early inhabitants at Noltland was a fortuitous inheritance for the community affected by sand blow.

Table 6.3: Economic and nutrient comparison between the three management strategies evidenced at Links of Noltland.

Cultivation type	Fuel residues	Ash	Unburned bone	Burned Bone	Peat/turf	Charred peat/turf	Large shells	Artefacts	Herbivore manure	Hearth rake-out	Nutrient loadings (mean)				
											Mg	P	S	K	Ca
1	X	X	X	X	X	X	X		X	X	1.49	1.01	0.20	2.8	42.02
2	X		X	X			X		?		1.52	1.06	0.04	6.56	8.46
3	X		X	X	X	X	X	X	X	X	1.29	1.63	0.08	5.87	17.67

Homeliness

Homeliness from an anthropological perspective describes the state of ‘dwelling’ within a built environment (Ingold, 2000). Children who grow up surrounded by the furnishings and ideas on building construction of past generations (Ingold, 2000) will come to feel a sense of homeliness invoked by the sights, smells, orientations and edifices of their homes.

In the review of the midden recorded by archaeological research in the Western and Northern Isles of Scotland, Chapter One demonstrated that midden of some form is found at almost every prehistoric settlement or camp/ temporary worksite. Therefore, although midden might mark seasonal campsites, the scale, sensory perception and usefulness of midden achieved at settlement sites was new and integral to Neolithic culture. The value of midden to cultural security, sense of homeliness and utilitarian purpose cannot be understated.

Creation of islands

In the Western Isles Neolithic and Bronze Age sites are often found on Islets. The reason for this has not yet been resolved but it is thought unlikely to have been for defence purposes

(Armit 1996). The view that a desire for control over nature and a separation of domestic versus wild (Whittle 1996, Hodder 1990) is the most recently held hypothesis for this phenomenon (Armit 1996). If anthropic sediments today are a dominant feature in prehistoric archaeology on the Scottish North Atlantic seaboard then they are unlikely to have been inconspicuous during the Neolithic and Bronze Age. The accumulation of materials around settlements is increasingly discussed using the framework of 'conspicuous consumption' in Bronze Age and Iron-Age archaeology. Midden accumulations directly outside the home were therefore a 'positive social medium' according to D.D.A Simpson (2006). That prehistoric communities were making a lasting stamp on the landscape with these accumulations is undisputed regardless of the reasons why. Given the current trajectories of archaeological theory, the creation of an 'island of midden', similar to those which were deliberately constructed in the Western Isles and as Crannogs in later prehistory may have been the intended accomplishment. The use of anthropic debris to create a distinction between the 'domestic and the other' may be manifested in the Scottish North Atlantic seaboard in the transformation of natural resources into cultural ones (Hodder 1990).

Significance of animals

The domestication of animals and the secondary products revolution has already been alluded to above and the widespread inclusion of herbivore dung ash in the Links of Noltland samples was surprising but not unexpected. That animal dung may have been burned for fuel in Neolithic Orkney has been hypothesised for some time (Guttmann 2001). Findings from the Links of Noltland indicate that this material was an important fuel source and similar but unconfirmed material has been found at Rinyo. The penning of animals was also surprising and demonstrates management of livestock and also the in situ burning of dung. This destruction of a valuable fertiliser resource is intriguing. Animal dung is a much more effective fertiliser than the other options open to the community at the Links of Noltland (Guttmann 2005) but at least some of this material was indirectly applied to cultivated soil as ash.

6.5 Future work

Implications of research

In Chapter One, review established that although midden was a well-documented part of the archaeological record on the Scottish North Atlantic seaboard, archaeologists have yet to be supplied with a comprehensive geoarchaeological investigation of its nature, versatility and value. Within the Orcadian context, this work provides a thorough explanation of the fine-resolution characteristics of midden and its possible formation pathways and subsequent uses. The identification of specific features by thin section micromorphology and SEM EDX analysis will contribute to the body of evidence for anthropic inclusions and diagenic processes. SEM EDX has been shown to be a useful tool to corroborate and support thin section micromorphology results. The elemental information provided by SEM EDX results have demonstrated that a comparison of Mg, P, K, S and Ca can be successfully applied to understand the artificial nutrient enhancement of relict soils. It is hoped that this contribution will give greater insight into how midden was utilised in prehistory. The broader implications of this work are to support anthropic sediment and anthrosol studies everywhere. Both micromorphological interpretations and detecting stratigraphic relationships through sub-surface modelling may benefit complex midden sites in the future. Work ongoing at complex midden sites such as Çatalhöyük, Turkey or Ness of Brodgar, Orkney will in turn contribute to a greater awareness of cultural evolution driven by available resources and ingenuity in the context of human ecodynamics.

Beyond the World Heritage Site

The geoarchaeological toolkit has been successfully applied in the study of anthrosols and anthropic sediments in the Orcadian context for more than a decade and is anticipated to continue alongside archaeological excavation in the globally significant centre of prehistoric archaeology. The present study has brought together the body of evidence extending across the Scottish North Atlantic seaboard which has highlighted a strong bias toward Orcadian sites. Relatively few Neolithic sites have been investigated in Shetland despite a wealth of anthropic sediments and anthrosols related to oval-houses recorded in the literature. The Western Isles of Scotland have also been neglected by geoarchaeological endeavors although forthcoming publication of Cladh Hallan is anticipated. The archaeology of the Northern Scottish mainland demonstrates a wealth of Neolithic funerary architecture (Henshall 1972) but surprisingly little research has been carried out into the landscapes and settlements which must relate to these monuments (Cavers and Hudson 2010). Recent research in the North West Highlands of mainland Scotland (Assynt community council area) has led to the hypothesis that a proportion of the funerary monuments described as 'round cairns' (Henshall 1972) might in fact represent inward collapse of oval houses similar to the Shetland style (Cavers and Hudson 2010). Given the findings of this thesis, a simple program of auger survey would be a useful method to prospect for the midden expected through occupation to begin to address this hypothesis. A research strategy reflecting this is currently being formulated by the North West Highlands UNESCO Global Geopark.

6.6 Summary of research

Geoarchaeological research at the Links of Noltland has placed the settlement in its wider regional context and used anthropic sediments and anthrosols to provide a narrative for human relationships with resources, animals and the environment. The range and extent of anthropic materials in the landscape has been investigated through auger survey and spatial analysis, experimentally applying geoarchaeological data to geological sub surface modelling software developed by the British Geological Survey. An environmental and cultural context for anthrosols and anthropic sediments has been provided by a combination of desk-based research, fieldwork, laboratory analyses and access to post-excavation analysis provided by EASE on behalf of Historic Scotland. Anthrosols and anthropic sediments have been described in detail though micromorphological analysis and chemical properties explored through SEM EDX. Setting these results within a human ecodynamics flow model has allowed interpretation of the functions of anthrosols and anthropic sediments in relation to the Scottish North Atlantic seaboard region. Although there is much left to learn about midden in prehistory, this work has been able to describe the nature of midden and its probable formation pathways in detail. It has revealed the details of the numerous ways in which prehistoric communities found solutions to cultural, practical and environmental challenges in midden. The value of this material to both its contemporary culture and geo-archaeology has been brought into sharper focus and cannot be understated. It is hoped that the findings on nature, versatility and value of midden will be taken on board to inform future research strategy. Midden is perhaps the most informative line of evidence in regions thought previously devoid of archaeological settlement in the Neolithic and Bronze Age especially on the Scottish North Atlantic seaboard where good building materials have been historically recycled again and again. The message for North Atlantic seaboard geoarchaeology is an encouraging one; where there is midden, there is life!

6.6.1 *Key findings*

- Vegetation clearance is evidenced within the underlying soils at the Links of Noltland.
- Spatial analyses of soils associated with Neolithic occupation demonstrate they are preserved over a wider area than anticipated.
- Early agricultural practice involved the tillage of cleared ground with the addition of hearth waste and incorporated aeolian sand and brown earth to create a fertile tilth.
- Animal manure was burned as fuel in domestic hearths during the Neolithic and Bronze Age.

- The potential nutrient value of both animal manure and anthropic sediments was not exploited to maximum potential by communities in the Late Neolithic/ Early Bronze Age at the Links of Noltland.
- The archaeological material known as cramp was incorporated into anthropic deposits around the settlement area.
- Yellow clay found at the Links of Noltland is processed glacial till.
- Interior floors were accumulated through occupation, organic residues may hint at thresh-like flooring.
- In situ burning activities in anthropic sediments alluded to maintenance activities including hearth rake-out and burning grassy material which may represent floor covings or bedding.
- Animal stalling and related maintenance is associated with the later Neolithic /Early Bronze Age part of the settlement.
- Sand accretion necessitated a change in land management activity.
- Anthropic sediments covering the Neolithic settlement were cultivated prior to sand inundation.
- Anthropic sediments were redirected into zones of windblown sand to establish cultivated zones.

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Appendix I: Point counting form

Slide ID___________ Context _______

	Void		Orange amorphous organic		Silty infill pedofeature
	Large shell fragment		Unburned bone		Charcoal
	Fine material		Grey material		Burned bone
	Coarse quartz/mineral		Iron accumulation		
	Burned peat/turf		Plant material		

Appendix II: Results of point count analysis

Table A1: Point count results for contexts with >1 sample. Extents expressed as mean percentage ratio and σ

	Fine material		Void		Mineral		Aeolian shell		Plant		Amorphous organic		Infill pedofeatures	
Context	**Mean**	**σ**	**Mean**	**σ**	**Mean**	**σ**	**Mean**	**σ**	**Mean**	**σ**	**Mean**	**σ**	**Mean**	**σ**
Aeolian sand	**10.66**	**4.20**	**40.74**	**5.90**	**11.78**	**9.64**	**35.18**	**8.85**	**0**	**0**	**0.12**	**0.18**	**0.72**	**1.02**
Cultivated soil	**18.97**	**13.09**	**31.44**	**15.35**	**11.56**	**4.92**	**32.33**	**9.89**	**0**	**0**	**0.11**	**0.15**	**2.28**	**2.94**
Dumped deposits	**41.46**	**16.37**	**16.87**	**12.14**	**10.70**	**9.38**	**1.24**	**2.89**	**0.00**	**0.00**	**7.20**	**15.53**	**1.47**	**2.47**
Exterior surface deposits	**42.14**	**10.00**	**24.82**	**10.62**	**11.11**	**8.12**	**9.84**	**15.06**	**0.07**	**0.15**	**0.77**	**0.82**	**5.15**	**11.31**
Field bank	**59.00**	**10.89**	**9.48**	**1.11**	**18.61**	**1.90**	**1.13**	**0.48**	**0.00**	**0.00**	**0.00**	**0.00**	**7.10**	**9.73**
Ground surface	**29.02**	**17.60**	**24.48**	**12.20**	**14.37**	**8.96**	**26.02**	**18.25**	**0.01**	**0.03**	**0.21**	**0.41**	**2.80**	**4.54**
Hearth	**30.61**	**17.42**	**24.06**	**15.80**	**18.68**	**8.82**	**12.26**	**17.45**	**0.00**	**0.00**	**1.98**	**3.96**	**0.00**	**0.00**
Infill	**31.06**	**21.31**	**25.87**	**18.83**	**18.39**	**10.78**	**15.64**	**19.70**	**0.00**	**0.00**	**0.00**	**0.00**	**6.02**	**10.12**
Interior floor deposits	**37.46**	**16.11**	**22.81**	**13.01**	**15.52**	**6.24**	**9.85**	**15.75**	**0.00**	**0.00**	**2.86**	**3.43**	**0.67**	**1.07**

Table A212: Point count results for contexts with <1 sample. Extents expressed as sample percentage ratio

Context	Fine material	Void	Mineral	Aeolian shell	Plant	Amorphous organic	Infill pedofeatures
Sand Control	**23.52**	**19.01**	**10.66**	**45.71**	**0.00**	**0.11**	**0.33**
Glacial till Control	**65.09**	**3.71**	**28.16**	**0.00**	**0.00**	**0.00**	**0.00**
Glacial till	**46.32**	**0.00**	**4.91**	**0.00**	**0.00**	**26.07**	**0.00**
Foundations	**6.94**	**37.37**	**10.04**	**45.34**	**0.00**	**0.10**	**0.00**

Table A3: Point count results for unburned peat/turf and fuel residues, (contexts with >1 sample). Extents expressed as mean percentage ratio and σ

	Peat/turf		Burned peat/turf		Charcoal		Charred plant		Cramp		Vesicular char		Ash	
Context	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ
Aeolian sand	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cultivated soil	0.34	0.61	0.03	0.06	0.27	0.28	0.30	0.30	0.00	0.00	0.00	0.00	0.16	0.31
Dumped deposits	0.00	0.00	2.57	3.76	0.28	0.23	2.82	3.31	0.00	0.00	0.02	0.05	0.00	0.00
Exterior surface deposits	0.02	0.07	0.16	0.24	0.41	0.88	0.77	1.62	0.04	0.12	0.05	0.08	0.02	0.07
Field bank	0.34	0.48	0.06	0.08	0.06	0.08	0.45	0.32	0.11	0.16	0.00	0.00	0.00	0.00
Ground surface	0.03	0.05	0.13	0.35	0.06	0.10	0.47	0.63	0.00	0.00	0.00	0.00	0.00	0.00
Hearth	0.00	0.00	11.01	1.43	0.05	0.07	0.73	0.49	0.10	0.14	0.00	0.00	0.00	0.00
Infill	0.00	0.00	0.13	0.25	0.00	0.00	1.06	0.77	0.00	0.00	0.03	0.06	0.00	0.00
Interior floor deposits	0.00	0.00	2.24	3.09	1.42	2.28	0.98	0.67	0.00	0.00	0.46	1.02	0.18	0.40

Table A4: Point count results for unburned peat/turf and fuel residues, (contexts with <1 sample). Extents expressed as sample percentage ratio

Context	Peat/turf	Burned peat/turf	Charcoal	Charred plant	Cramp	Vesicular char	Ash
Sand Control	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glacial till Control	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glacial till	0.00	0.00	0.92	10.74	0.00	0.00	0.00
Foundations	0.00	0.00	0.10	0.00	0.00	0.00	0.00

Table A5: Point count results for anthropic inclusions, (contexts with >1 sample). Extents expressed as mean percentage ratio and σ

	Large shell		Bone		Burned bone		Dung		Pottery fragment		Clag aggregates	
Context	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ
Aeolian sand	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cultivated soil	0.47	0.47	0.32	0.37	0.26	0.40	0.00	0.00	0.00	0.00	0.05	0.06
Dumped deposits	3.46	2.80	0.24	0.34	3.63	7.45	0.00	0.00	0.00	0.00	0.39	0.14
Exterior surface deposits	0.11	0.13	0.40	0.45	0.16	0.32	0.00	0.00	0.00	0.00	0.99	1.47
Field bank	0.06	0.08	0.51	0.72	0.79	0.96	0.00	0.00	0.23	0.32	0.45	0.64
Ground surface	0.43	1.18	0.23	0.31	0.00	0.00	0.00	0.00	0.02	0.07	0.06	0.10
Hearth	0.00	0.00	0.88	1.24	0.15	0.07	0.00	0.00	0.00	0.00	2.39	3.37
Infill	0.42	0.85	0.34	0.45	0.03	0.06	0.00	0.00	0.00	0.00	0.00	0.00
Interior floor deposits	0.28	0.35	1.16	1.72	0.03	0.05	0.02	0.04	0.02	0.04	0.89	0.71

Table A6: Point count results for anthropic inclusions, (contexts with <1 sample). Extents expressed as sample percentage ratio

Context	Large shell	Bone	Burned bone	Dung	Pottery fragment	Clag aggregates
Sand Control	0.00	0.00	0.00	0.00	0.00	0.11
Glacial till Control	0.00	0.00	0.00	0.00	0.00	0.00
Glacial till	0.00	0.00	0.61	0.00	0.00	0.31
Foundations	0.00	0.00	0.00	0.00	0.00	0.00

Table A7: Point count results for pedofeatures, (contexts with >1 sample). Extents expressed as mean percentage ratio and σ

	Grey material		Iron impregnation		Iron nodule		Shell dissolution		Excremental		Orange clay		Apatite nodule	
Context	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ
Aeolian sand	0.21	0.29	0.00	0.00	0.00	0.00	0.21	0.29	0.37	0.53	0.00	0.00	0.00	0.00
Cultivated soil	0.54	0.70	0.00	0.00	0.15	0.19	0.44	0.29	0.00	0.00	0.00	0.00	0.03	0.06
Dumped deposits	0.72	1.19	0.80	0.77	0.22	0.30	0.14	0.20	0.15	0.27	0.00	0.00	0.00	0.00
Exterior surface deposits	3.22	5.65	0.18	0.40	0.46	0.40	0.46	0.75	0.00	0.00	0.00	0.00	0.00	0.00
Field bank	1.19	1.68	0.06	0.08	0.11	0.00	0.06	0.08	0.23	0.32	0.00	0.00	0.00	0.00
Ground surface	0.03	0.05	0.15	0.34	0.13	0.19	0.75	1.14	0.00	0.00	0.01	0.03	0.00	0.00
Hearth	2.96	3.50	2.35	2.22	1.20	1.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Infill	1.39	1.93	0.85	1.55	0.91	0.93	2.65	4.67	0.03	0.05	0.00	0.00	0.00	0.00
Interior floor deposits	0.96	2.15	1.39	1.35	0.38	0.67	0.00	0.00	0.00	0.00	0.46	1.04	0.05	0.12

Table A8: Point count results for pedofeatures, (contexts with <1 sample). Extents expressed as sample percentage ratio

Context	Depletion	Iron impregnation	Iron nodule	Shell dissolution	Excremental	Orange clay	Apatite nodule
Sand Control	0.00	0.00	0.00	0.55	0.00	0.00	0.00
Glacial till Control	0.00	2.19	0.34	0.51	0.00	0.00	0.00
Glacial till	0.00	7.36	1.23	1.53	0.00	0.00	0.00
Foundations	0.00	0.10	0.00	0.00	0.00	0.00	0.00

Appendix III: Thin section description table, control samples Links of Noltland

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)							FINE MATERIAL (<63µm)							PEDOFEATURES						
						MINERAL COMPONENT					ORGANIC COMPONENT		MINERAL COMPONENT		ORGANIC COMPONENT											
Context	Thin section reference	Micro-stratigraphic unit (s)	Microstructure	Coarse/fine related distribution	Coarse mineral arrangement	Marine shell	Quartz	Quartzite	Mica/Garnet	Rock fragments	Lignified tissue	Charred Plant material or charcoal	Nature of fabric (PPL)	b-Fabric (XPL)	Punctuations	Amorphous reddish brown	Amorphous black	Yellow amorphous	Pigment	Fe/Mn impregnation	Fe/MN Nodule	Dusty clay coatings/infill	Laminated infill	Sandy infill	Fe depletion	Shell dissolution
Aeolian sand contol	116	B	Bridged grain-microaggregates, Single grain / complex packing chitonic grains voids and vughs	Monic and concave gefuric	Random, well sorted	5	1		1	3			Light brown dotted organo-mineral (PPL) yellowish brown (OIL)	Crystallitic	t	t	t					⦿⦿ ⦿				
		A		Concave gefuric and close porphyric	Random, w ell sorted	4	1		t	3		t	Light brown dotted organo-mineral, patches of white/ greyish (PPL) yellowish brown (OIL)	Stipple speckled, grano and porostriated crystallitic	t	1	1		1	t	t	>10 %				t
Windblown sand and natural glacial till	115	C	Complex, intergrain	Close porphyric	Random, well sorted	4	1			3			Light brownish grey organo-mineral (PPL) yellowish brown (OIL)	Stipple speckled, micro crystallitic							⦿	>10 %	⦿			
		B	Complex, cracked, vughs and chambers	Open and double spaced porphyric	Random, moderately sorted,	2	2	1	t	2			Light brown/ greyish organo-mineral (PPL) yellowish brown (OIL)	Stipple speckled micro crystallitic			t	t		t	⦿⦿			⦿	t	
		A	Cracked massive	Open and double spaced porphyric	Random, poorly sorted,		3	1	t	2	t		Light brown/ greyish organo-mineral (PPL) yellowish brown (OIL)	Speckled micro crystallitic				t	t	⦿⦿	⦿⦿ ⦿			⦿	⦿⦿	

Frequency class refers to the appropriate area of section (from Bullock et al. 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures: t = trace (<1%) ⦿ = Rare (1-2%) ⦿⦿ = Occasional (2 – 5%) ⦿⦿⦿ = Many (5 – 10%)

Appendix IV: Thin section description tables, anthropic sediments at the Links of Noltland

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)															FINE MATERIAL (<63µm)										PEDOFEATURES								
						MINERAL COMPONENT								ORGANIC COMPONENT							MINERAL COMPONENT				ORGANIC COMPONENT														
Context	Thin section reference	Microstratigraphic unit (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Turf fragments	Rubified minerals	Well decomposed plant material	Charcoal	Charred plant remains	Burned peat	Burned Turf	Unburned bone	Burned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Clay aggregates	Heat altered clay fragments	Punctuations	Amorphous orange	Amorphous black	Amorphous yellow	Amorphous pink	Fungal Tissue	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Fe/Mn Hypocoatings	Psuedomorphic ferruginous	Sandy coatings/infill	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
9252	113	Single	Bridged grain	Enaulic	Random, well sorted	5	4														Brown organo-mineral (PPL) Light yellowish brown (OIL)	Crystallitic					t				t								

Foundations sample. Frequency class refers to the appropriate area of section (from Bullock et al. 1985):

t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)

Frequency class for textual pedofeatures: t = trace (<1%) ⦿ = Rare (1-2%) ⦿⦿ = Occasional (2 – 5%) ⦿⦿⦿ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)																			FINE MATERIAL (<63µm)												PEDOFEATURES									
						MINERAL COMPONENT									ORGANIC COMPONENT										MINERAL COMPONENT						ORGANIC COMPONENT															
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Turf fragments	Rubified minerals	Large shell	Well decomposed plant material	Vesicular char	Charcoal	Charred plant remains	Burned peat	Burned Turf	Pottery	Unburned bone	Burned bone	Dung	Nature of fabric (PPL)	b-Fabric (XPL)	Diatoms/phytoliths	Ash	Clay aggregates	Heat altered clay fragments	Punctuations	Amorphous red/orange	Amorphous black	Amorphous yellow	Orange clay	Fungal Tissue	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Fe/Mn Hypocoatings	Psuedomorphic ferruginous	Phosphatic	Sandy coatings/infill	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
9118/9166	109	B	Channels, chambers & vughs	OP	Random, moderate/ poorly sorted		2	1	t	t	2	1	t			3	2	2	t	1		t			Very dark brown organo-mineral (PPL) Dark orangey brown (OIL)	Stipple speckled micro-crystallitic					t	t	1	t			t	t	⊙					⊙		
		A	Channels, chambers & vughs	OP	Random, poorly sorted		1	1	t	1	2				t	t	t	1	t			1	t		Dark brown organo-mineral (PPL) Dark orangey brown (OIL)	Stipple speckled micro-crystallitic					1	1	1			t	⊙⊙⊙	⊙	⊙⊙⊙				t	⊙⊙		

Structure 9 east recess interior floor. Frequency class refers to the appropriate area of section (from Bullock et al. 1985):

t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)

Frequency class for textual pedofeatures: t = trace (<1%) ⊙ = Rare (1-2%) ⊙⊙ = Occasional (2 – 5%) ⊙⊙⊙ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm) MINERAL COMPONENT									ORGANIC COMPONENT										FINE MATERIAL (<63µm) MINERAL COMPONENT						ORGANIC COMPONENT							PEDOFEATURES									
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Turf fragments	Rubified minerals	Large shell	Well decomposed plant	Vesicular char	Charcoal	Charred plant remains	Burned peat	Burned turf	Pottery	Unburned bone	Burned bone	Dung	Nature of fabric (PPL)	b-Fabric (XPL)	Diatoms/phytoliths	Ash	Clay aggregates	Heat altered clay fragments	Punctuations	Amorphous red/orange	Amorphous black	Amorphous yellow	Pigment	Orange clay	Fungal Tissue	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Fe/Mn Hypocoatings	Psuedomorphic ferruginous	Phosphatic	Sandy coatings/infill	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
9119	128	HORIZONTAL	Channels, vughs and cracks	OP	Random, poorly sorted		2	3			3					t	1	1	2				1		Greyish brown organo-mineral (PPL) Dark yellowish brown (OIL)	Stipple speckled micro-crystallitic				t	1	2						⦿⦿⦿	⦿⦿	⦿⦿							

Structure 9 west recess interior floor. Frequency class refers to the appropriate area of section (from Bullock et al. 1985):

t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)

Frequency class for textual pedofeatures: t = trace (<1%) ⦿ = Rare (1-2%) ⦿⦿ = Occasional (2 – 5%) ⦿⦿⦿ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)																			FINE MATERIAL (<63µm)												PEDOFEATURES									
						MINERAL COMPONENT									ORGANIC COMPONENT										MINERAL COMPONENT						ORGANIC COMPONENT															
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Turf fragments	Rubified minerals	Large shell	Well decomposed plant	Vesicular char	Charcoal	Charred plant remains	Burned peat	Burned turf	Pottery	Unburned bone	Burned bone	Dung	Nature of fabric (PPL)	b-Fabric (XPL)	Diatoms/phytoliths	Ash	Clay aggregates	Heat altered clay fragments	Punctuations	Amorphous red/orange	Amorphous black	Amorphous yellow	Orange clay	Fungal Tissue	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Fe/Mn Hypocoatings	Psuedomorphic ferruginous	Phosphatic	Sandy coatings/infill	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
9189 & 9173	110	B	Very compact with compressed channels and poly concave vughs	OP	Random, poorly sorted	t	3	1		1	2	t					t	t	t			t	1		Dark brown (PPL) Mottled dark brown and yellowish orange (OIL) Organo-mineral	Stipple speckled micro-crystallitic		1	t		1	2					⦿⦿	⦿	⦿⦿	t			⦿	t		t
		A	Compact with compressed channels and poly concave vughs	OP	Random, moderately sorted	1	1	t	t	1	2						t	t	t			t	t		Light brown/grey (PPL) Yellowish brown (OIL) Organo-mineral	Stipple speckled micro-crystallitic		2		t	t	1					⦿⦿⦿	⦿⦿	⦿			⦿⦿		⦿⦿		t

Structure 9 east central interior floor. Frequency class refers to the appropriate area of section (from Bullock et al. 1985):

t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)

Frequency class for textual pedofeatures: t = trace (<1%) ⦿ = Rare (1-2%) ⦿⦿ = Occasional (2 – 5%) ⦿⦿⦿ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)																			FINE MATERIAL (<63µm)													PEDOFEATURES									
						MINERAL COMPONENT									ORGANIC COMPONENT										MINERAL COMPONENT						ORGANIC COMPONENT															
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine Shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Turf fragments	Rubified minerals	Large shell	Well decomposed plant	Vesicular char	Charcoal	Charred plant remains	Burned peat	Burned turf	Unburned bone	Pottery	Burned bone	Dung	Nature of fabric (PPL)	b-Fabric (XPL)	Diatoms/phytoliths	Ash	Clay aggregates	Heat altered clay fragments	Punctuations	Amorphous red/orange	Amorphous black	Amorphous yellow	Pigment	Orange clay	Fungal Tissue	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Fe/Mn Hypocoatings	Psuedomorphic ferruginous	Phosphatic	Sandy coatings/infill	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
9189/9173	127	C	Compact with Compressed channels and poly concave vughs	OP/CP	Weak horizontal orientation, poorly sorted		3	2		1	2	1				t	2	1	3				1	t	Dark brown (PPL) Dark orangey/ yellowish brown (OIL) Organo-mineral	Stipple speckled micro-crystallitic					1		1					⦿⦿				t			t		
		B	Compact with compressed channels and poly concave vughs	OP	Weak horizontal orientation, poorly sorted	t	1	t	t	t	2						1	1	2		2		1		Dark brown (PPL) Dark yellowish brown (OIL) Organo-mineral	Stipple speckled micro-crystallitic			2	t	1	2	2	1				⦿⦿⦿		⦿					⦿⦿	⦿⦿	
		A	Compact with slight fissure	OP	Weak horizontal orientation, poorly sorted		1	t	t	1	1	t					1				t		1		Dark brown (PPL) Dark brown (OIL) Organo-mineral	Stipple speckled micro-crystallitic			3			1	2	1				⦿⦿⦿	⦿⦿⦿	⦿						⦿⦿⦿	

Structure 9 west central interior floor. Frequency class refers to the appropriate area of section (from Bullock et al. 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures: t = trace (<1%) ⦿ = Rare (1-2%) ⦿⦿ = Occasional (2 – 5%) ⦿⦿⦿ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL(>63µm)															FINE MATERIAL (<63µm)											PEDOFEATURES									
						MINERAL COMPONENT							ORGANIC COMPONENT								MINERAL COMPONENT					ORGANIC COMPONENT															
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Mica/Garnet	Rock fragments	Rubified minerals	Pottery	Well decomposed plant	Lignified tissue	Peat/ turf fragment	Charcoal	Charred plant	Burned peat/ turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Grey material	Phytoliths/ Diatoms	Heat altered clay fragments	Punctuations	Amorphous reddish orange	Amorphous black	Yellow amorphous	Pigment	Fungal tissue	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodule	Fe/Mn hypocoatings	Silty clay link capping	Laminated infill	Limpid clay coatings/infill	Sandy infill	Excremental	Phospatic
9610 / 9569	178	B	Complex packing voids / intergrain microaggregates	Enaulic/ chitonic /monic	Random, well sorted	4	t	1	t		t						t				Brown organo-mineral (PPL & OIL)	Stipple speckled micro crystallitic			t	t															
		A	Complex packing voids / intergrain microaggregates locally cracked	Enaulic	Random, well sorted	3		t	t	t	1	t				t	1	t		t	Dark brown organo-mineral (PPL) Brown and orange (OIL)	Stipple speckled micro crystallitic			1	1		1				⦿		⦿⦿		⦿				t	

Structure 13 interior floor. Frequency class refers to the appropriate area of section (from Bullock et al. 1985)

Frequency class refers to the appropriate area of section (from Bullock et al., 1985):

t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)

Frequency class for textual pedofeatures:

t = trace (<1%) ⦿ = Rare (1-2%) ⦿⦿ = Occasional (2 – 5%) ⦿⦿⦿ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL(>63µm)															FINE MATERIAL (<63µm)											PEDOFEATURES									
						MINERAL COMPONENT							ORGANIC COMPONENT								MINERAL COMPONENT					ORGANIC COMPONENT															
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMENT	Marine shell	Quartz	Quartzite	Mica/Garnet	Rock fragments	Rubified minerals	Pottery	Well decomposed plant	Lignified tissue	Peat/ turf fragment	Charcoal	Charred plant	Burned peat/ turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Grey material	Phytoliths/ Diatoms	Heat altered clay fragments	Punctuations	Amorphous reddish orange	Amorphous black	Yellow amorphous	Pigment	Fungal tissue	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodule	Fe/Mn hypocoatings	Silty clay link capping	Laminated infill	Limpid clay coatings/infill	Sandy infill	Excremental	Phospatic
9610 / 9569	179	B	Complex packing voids / microaggregates	Enaulic / chitonic/ monic	Random, well sorted	5	t	1	t								t				Brown organo-mineral (PPL & OIL)	Stipple speckled micro crystallic							t												
		A	Complex packing voids / intergrain microaggregates	Enaulic	Random, well sorted	2	1	1	t	1	t						t	t		t	Brown organo-mineral (PPL) Brown and orange (OIL)	Stipple speckled micro crystallic										⊙				⊙⊙⊙					

Structure 13 interior floor.. Frequency class refers to the appropriate area of section (from Bullock et al. 1985)

Frequency class refers to the appropriate area of section (from Bullock et al., 1985):

t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)

Frequency class for textual pedofeatures:

t = trace (<1%) ⊙ = Rare (1-2%) ⊙⊙ = Occasional (2 – 5%) ⊙⊙⊙ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)												FINE MATERIAL (<63µm)								PEDOFEATURES							
						MINERAL COMPONENT						ORGANIC COMPONENT						MINERAL COMPONENT				ORGANIC COMPONENT											
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Wood charcoal	Burned peat	Charred plant remains	Pottery	Unburned bone	Burned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Clay aggregates	Heat altered clay fragments	Punctuations	Amorphous orange	Amorphous black	Amorphous yellow	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Fe/Mn Hypocoatings	Sandy coatings/infill	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
9124/ 9117	125	B	Poly concave vughs	OP	Random, moderately sorted		2	1		t	t	1			t		1	Dark brown organo-mineral (PPL) Dark greyish brown (OIL)	Stipple speckled micro-crystallitic	t		1				⊙⊙⊙		t	⊙	⊙	⊙		
9124/ 9117	125	A	Poly concave vughs	OP	Random, moderately sorted	t	2	1		t	t							Dark greyish brown organo-mineral (PPL) Brownish yellow (OIL)	Stipple speckled micro-crystallitic			1		1		⊙⊙⊙	t	⊙⊙⊙					

Structure 9 hearth. Frequency class refers to the appropriate area of section (from Bullock et al. 1985)

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SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)												FINE MATERIAL (<63µm)								PEDOFEATURES							
						MINERAL COMPONENT						ORGANIC COMPONENT						MINERAL COMPONENT				ORGANIC COMPONENT											
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Wood charcoal	Burned peat/turf	Charred plant remains	Pottery	Unburned bone	Burned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Clay aggregates	Heat altered clay fragments	Punctuations	Amorphous orange	Amorphous black	Amorphous yellow	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Fe/Mn Hypocoatings	Sandy coatings/infill	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
9125/9124	126	C	Channels and vughs	OP	Random, Moderately sorted		2	1		t	t			t		t		Light-mid brown organo-mineral (PPL) Yellowish brown (OIL)	Stipple speckled micro-crystallitic						t	⊙		⊙⊙⊙			⊙		
		B	Crack structure with channels and vughs	OP	Random, poorly sorted		1	2	t	t		1	4	1			1	Dark reddish brown organo-mineral (PPL) Dark orangey brown/ black (OIL)	Stipple speckled micro-crystallitic		t		1			t		⊙			⊙⊙⊙	⊙	
		A	Channels and vughs	OP	Random, poorly sorted	t	2	2	t	t	1	1	2	t		t	2	Dark brown organo-mineral (PPL) Light olive brown (OIL)	Stipple speckled micro-crystallitic	1	t	1	1			⊙⊙⊙		⊙⊙			⊙		t

Structure 9 hearth. Frequency class refers to the appropriate area of section (from Bullock et al. 1985)

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Frequency class for textual pedofeatures:
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SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm) MINERAL COMPONENT							COARSE MATERIAL (>63µm) ORGANIC COMPONENT								FINE MATERIAL (<63µm) MINERAL COMPONENT						ORGANIC COMPONENT				PEDOFEATURES								
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMENT	Marine shell	Quartz/feldspar	Quartzite	Mica	Garnet	Rock fragments	Cramp	Well decomposed plant material	Unburned peat/turf	Woody charcoal	Charred plant	Burned peat/turf	Unburned bone	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Weathered ash/ grey material	Diatoms/phytoliths	Clay aggregates	Punctuations	Amorphous reddish orange	Amorphous black	Yellow amorphous	Fungal tissue	Fe/Mn accumulation	Fe depletion	Fe/MN Nodule	Fe/Mn Hypocoatings	Fe/Mn depletion hypocoatings	Sandy coatings/infill	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
8002	76	B	Channels, some slight fissures in open porphyric with no separate aggregates.	Open porphyric	Random, well sorted		1	t													Mixed light brown & grey organo-mineral (PPL) Light grey and yellowish brown (OIL)	Stipple-speckled Micro-crystallitic	6					1			⦿⦿⦿		⦿⦿				⦿⦿⦿		
		A	Channels, vughs in open porphyric with no separate aggregates.	Open porphyric	Random, well sorted		1				1				t	2			1		Mixed very dark brown & black organo-mineral (PPL) yellowish brown/black (OIL)	Speckled Micro-crystallitic	2					4			⦿		t				⦿⦿		

Exterior floor surfaces, Area 5. Frequency class refers to the appropriate area of section (from Bullock et al. 1985)

Frequency class refers to the appropriate area of section (from Bullock et al., 1985):

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Frequency class for textual pedofeatures:

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SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm) MINERAL COMPONENT							ORGANIC COMPONENT							FINE MATERIAL (<63µm) MINERAL COMPONENT						ORGANIC COMPONENT				SAMPLE								
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz/feldspar	Quartzite	Mica	Garnet	Rock fragments	Cramp	Well decomposed plant material	Unburned peat/turf	Woody charcoal	Charred plant	Burned peat/turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Weathered ash	Diatoms/phytoliths	Clay aggregates	Punctuations	Amorphous reddish orange	Amorphous black	Yellow amorphous	Fungal tissue	Fe/Mn accumulation	Fe/Mn depletion	Fe/MN Nodule	Fe/Mn Hypocoatings	Fe/Mn depletion hypocoatings	Sandy coatings/infill	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
8002	77	C	Channels & vughs	Open porphyric	Random, poorly sorted		1	t	t		t									Light brown and grey (PPL) yellowish brown and white (OIL)	Stipple-speckled Micro-crystallitic				1		2	t		⊙	⊙	⊙				⊙⊙⊙		
		B	Channels & vughs	Open porphyric	Random, moderately sorted		1	t			1				t	1				Mixed black and mid brown (PPL & OIL)	Stipple-speckled Micro-crystallitic	1					6			⊙		⊙			⊙⊙	⊙⊙⊙		
		A	Channels, vughs and weakly developed blocky peds.	Open porphyric	Random, moderately sorted		2	1			1					t			t	Mid yellowish brown organo-mineral (PPL) mixed yellowish brown & dark brown (OIL)	Stipple-speckled Micro-crystallitic	3				1	2			⊙⊙		⊙				⊙⊙⊙		

Exterior floor surfaces, Area 5. Frequency class refers to the appropriate area of section (from Bullock et al. 1985)

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SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm) MINERAL COMPONENT							COARSE MATERIAL (>63µm) ORGANIC COMPONENT							FINE MATERIAL (<63µm) MINERAL COMPONENT						FINE MATERIAL (<63µm) ORGANIC COMPONENT				PEDOFEATURES								
CONTEXT	THIN SECTION REFERENCE	MICRO STRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz/feldspar	Quartzite	Mica	Garnet	Rock fragments	Cramp	Well decomposed plant material	Unburned peat/turf	Woody charcoal	Charred plant	Burnt peat/turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Weathered ash	Diatoms/phytoliths	Clay aggregates	Punctuations	Amorphous reddish orange	Amorphous black	Yellow amorphous	Fungal tissues	Fe/Mn accumulation	Fe depletion	Fe/MN Nodule	Fe/Mn Hypocoatings	Fe/Mn depletion hypocoatings	Sandy coatings/infill	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
		E	Channels & vughs	Open porphyric	Random, poorly sorted		2	1									1		t	Dark brown (PPL) Orangey yellow (OIL)	Speckled micro-crystallitic						1			⊙⊙⊙		⊙⊙	⊙⊙	t		⊙		
		D	Channels & vughs	Open porphyric	Random, poorly sorted		1	t	t			t				1				Mixed grey & dark brown organo-mineral (PPL) Mixed white and mid brown (OIL)	Stipple-speckled micro-crystallitic	1				t	3	t		⊙⊙⊙	⊙⊙	⊙⊙⊙	⊙⊙			⊙⊙	⊙	
9157	106	C	Channels & vughs	Open porphyric	Random, moderately sorted	t	2	1			1					2				Mixed brown & dark brown organo-mineral (PPL) white & yellowish brown (OIL)	Speckled micro-crystallitic					1	4		1	⊙⊙⊙	⊙	⊙⊙⊙	⊙	⊙	⊙	⊙⊙	⊙	
		B	Channels & vughs	Open porphyric	Random, poorly sorted		1	t						t		2				Mixed black and dark brown organo-mineral (PPL) Grey & yellowish brown (OIL)	Speckled micro-crystallitic	t			1	t	4			t	t	⊙			⊙	⊙⊙⊙	⊙⊙	
		A	Channels & vughs	Open porphyric	Random, moderately sorted		2	t	t	t						t				Grey organo-mineral (PPL) white/grey (OIL)	Speckled micro-crystallitic		t			t	1			⊙⊙⊙	⊙⊙⊙	⊙⊙	t		⊙	t		

Exterior floor surfaces, Area 5. Frequency class refers to the appropriate area of section (from Bullock et al. 1985)

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SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm) MINERAL COMPONENT							ORGANIC COMPONENT							FINE MATERIAL (<63µm) MINERAL COMPONENT						ORGANIC COMPONENT				PEDOFEATURES								
CONTEXT	THIN SECTION REFERENCE	MICRO -STRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz/Feldspar	Quartzite	Mica	Garnet	Rock fragments	Cramp	Well decomposed plant material	Peat/turf fragments	Charcoal	Charred plant	Burned peat/turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Ash	Diatoms	Clay aggregates	Punctuations	Amorphous reddish orange	Amorphous black	Amorphous yellow	Fungal tissue	Fe/Mn accumulation	Fe depletion	Fe/MN Nodule	Fe/Mn Hypocoatings	Fe/Mn depletion hypocoatings	Sandy coatings/infill	Silty clay coatings/infill	Limpid clay coatings/infill	Excremental
9171	100	B	Channels & vughs	Open porphyric	Weak striations, mostly random, poorly sorted		1	1	t						t		t	1	t	Light brown organo-mineral (PPL) Grey (OIL)	Stipple speckled micro-crystallitic	1	t			t	1	2		⦿⦿⦿	⦿⦿⦿	⦿⦿				⦿		
		A	Channels & vughs	Open porphyric	Random, unsorted	t	2	1	t	t	2			t	1	1		t	t	Dark brown organo-mineral (PPL) Yellowish brown (OIL)	Stipple speckled micro-crystallitic					1	1			⦿	⦿⦿	⦿⦿⦿				⦿		t

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SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)																FINE MATERIAL (<63µm)								PEDOFEATURES								
						MINERAL COMPONENT								ORGANIC COMPONENT								MINERAL COMPONENT					ORGANIC COMPONENT											
THIN SECTION REFERENCE	CONTEXT	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMENT	Marine shell	Quartz/feldspar	Quartzite	Rock fragments	Cramp	Large shell fragments	Rubified mineral	Pottery	Well decomposed plant material	Unburned peat/turf	Woody charcoal	Charred plant remains	Burned peat/turf	Vesicular char	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Peat ash	Clay aggregates	Punctuations	Amorphous reddish orange	Amorphous black	Amorphous yellow	Fe/Mn accumulation	Fe/ Mn nodule	Fe/Mn coatings	Void coatings	Silty/dusty clay /infill	Limpid clay coatings/infill	Excremental	Phosphatic	$CaCO^3$
85	9105/ 9103	B	Channels and chambers	OP	Random, poorly sorted	1	2	t	1	t	1	t				t	1		t	t	t	Dark brown organo-mineral (PPL) brown (OIL)	Stipple speckled micro-crystallitic		t	1		1									t	
		A	Channels chambers and vughs	OP	Random, poorly sorted	2	2		2	1	1	1				1					t	Brown organo-mineral (PPL) brown (OIL)	Stipple speckled micro-crystallitic			1		1			t							
86	9103	SINGLE	Channels chambers and vughs	OP	Random, poorly sorted	t	1	2	2		1	t	t			t	1		t	1	1	Dark brown organo-mineral (PPL & OIL)	Stipple speckled micro-crystallitic		t	1	t							⦿ ⦿				
87	9100/9103	B	Bridged grain	Enaulic	Random, well sorted	4	3											1	t			Dark brown organo-mineral (PPL) Mid brown (OIL)	Stipple speckled micro-crystallitic					t						⦿ ⦿				
		A	Channels & Vughs	OP	Random, moderately sorted	2	2	1	1											1		Orangey brown organo-mineral (PPL) Mid orangey brown (OIL)	Speckled micro-crystallitic				t			⦿				⦿ ⦿				

Exterior floor surfaces, soil test pit 2. Frequency class refers to the appropriate area of section (from Bullock et al. 1985)

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SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm) MINERAL COMPONENT								COARSE MATERIAL (>63µm) ORGANIC COMPONENT								FINE MATERIAL (<63µm) MINERAL COMPONENT					FINE MATERIAL (<63µm) ORGANIC COMPONENT			PEDOFEATURES								
THIN SECTION REFERENCE	CONTEXT	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz/feldspar	Quartzite	Rock fragments	Cramp	Large shell fragments	Rubified mineral	Pottery	Well decomposed plant material	Unburned peat/turf	Woody charcoal	Charred plant remains	Burned peat/turf	Vesicular char	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Peat ash	Clay aggregates	Punctuations	Amorphous reddish orange	Amorphous black	Amorphous yellow	Fe/Mn accumulation	Fe/ Mn nodule	Fe/Mn coatings	Void coatings	Silty/dusty clay /infill	Limpid clay coatings/infill	Excremental	Phosphatic	CaCO³
88	9100 /9103	B	Channels chambers and vughs	OP	Random, poorly sorted	t	2	1	1		1						1	t	t		t	Brown organo-mineral (PPL) Dark reddish brown (OIL)	Stipple speckled micro-crystallitic			1		t		⊙				⊙⊙				
		A	Channels chambers and vughs	OP	Random, moderately sorted	3	1	1	1		t						t				t	Brown organo-mineral (PPL & OIL)	Stipple speckled micro-crystallitic	t		1					t			⊙				
89	9103 /9102	B	Cracked massive	OP	Random, poorly sorted	t	2		2							t				t		Greyish brown organo-mineral (PPL) Yellowish brown (OIL)	Stipple speckled micro-crystallitic								⊙⊙⊙				⊙			
		A	Sub angular blocky with channels chambers and vughs	OP	Random, poorly sorted	t	1	t	1								1				1	Brown organo-mineral (PPL) Dark reddish brown (OIL	Stipple speckled micro-crystallitic				t				⊙⊙⊙			⊙				

Exterior floor surfaces, soil test pit 2. Frequency class refers to the appropriate area of section (from Bullock et al. 1985)

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SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm) MINERAL COMPONENT								COARSE MATERIAL (>63µm) ORGANIC COMPONENT								FINE MATERIAL (<63µm) MINERAL COMPONENT					FINE MATERIAL (<63µm) ORGANIC COMPONENT			PEDOFEATURES								
THIN SECTION REFERENCE	CONTEXT	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz/feldspar	Quartzite	Rock fragments	Cramp	Large shell fragments	Rubified mineral	Pottery	Well decomposed plant material	Unburned peat/turf	Woody charcoal	Charred plant remains	Burned peat/turf	Vesicular char	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Peat ash	Clay aggregates	Punctuations	Amorphous reddish orange	Amorphous black	Amorphous yellow	Fe/Mn accumulation/ depletion	Fe/ Mn nodule	Fe/Mn coatings	Void coatings	Silty/dusty clay /infill	Limpid clay coatings/infill	Excremental	Phosphatic	$CaCO^3$
90	9100 /9103/9102	B	Inter/ bridged grain micro aggregate	Enaulic/CP	Random well sorted	4	3		t								t					Brown organo-mineral (PPL & OIL)	Stipple speckled micro-crystallitic			t		t					⊙⊙⊙	⊙⊙				⊙
		A	Crack, channels. Chambers & grain micro vughs	OP	Random, poorly sorted	t	2		2													Brownish yellow organo-mineral (PPL) Brown (OIL)	Stipple speckled micro-crystallitic			t	t	t	t	⊙	⊙⊙⊙	⊙	⊙	⊙⊙				
91	9103 / 9101	B	Channels chambers and vughs	OP	Random, moderately sorted	t	2	3	t													Yellowish brown organo-mineral (PPL) Greenish yellow brown (OIL)	Stipple speckled micro-crystallitic					t		⊙								
		A	Inter/ bridged grain micro aggregate/ crumb	Enaulic/CP	Random, poorly sorted	2	1	2	2													Brown organo-mineral (PPL) Yellowish brown (OIL)	Stipple speckled micro-crystallitic		1			t		⊙			⊙⊙⊙	⊙⊙⊙				

Exterior floor surfaces, soil test pit 2. Frequency class refers to the appropriate area of section (from Bullock et al. 1985)

Frequency class refers to the appropriate area of section (from Bullock et al., 1985):

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SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm) MINERAL COMPONENT							COARSE MATERIAL (>63µm) ORGANIC COMPONENT								FINE MATERIAL (<63µm) MINERAL COMPONENT					FINE MATERIAL (<63µm) ORGANIC COMPONENT						PEDOFEATURES								
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMENT	Marine shell	Quartz	Quartzite	Mica/Garnet	Rock fragments	Cramp	Pottery	Well decomposed plant	Lignified tissue	Peat fragment	Woody charcoal	Charred plant	Burned peat/ turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Grey material	Phytoliths/ Diatoms	Heat altered clay	Punctuations	Amorphous reddish orange	Amorphous black	Yellow amorphous	Pigment	Fungal spore	Fe/Mn accumulation	Fe depletion	Fe/MN Nodule	Fe/Mn Hypocoatings	Dusty clay coatings/infill	Laminated infill	Limpid clay coatings/infill	Sandy infill	Excremental Phosphatic
9136 & dark shell midden	134	single	Channels, chambers & vughs	Open porphyric	Random, unsorted	1	2	1		1						t	t	t	1		Dark brown – grey organo-mineral (PPL) Brown – yellowish brown (OIL)	Speckled micro-crystallitic	4	t	t	1	2	2	1		t	⦿ ⦿				t				⦿

Deep sondage, 'dumped deposits'. Frequency class refers to the appropriate area of section (from Bullock et al. 1985)

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t = trace (<1%) ⦿ = Rare (1-2%) ⦿⦿ = Occasional (2 – 5%) ⦿⦿⦿ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm) MINERAL COMPONENT							COARSE MATERIAL (>63µm) ORGANIC COMPONENT								FINE MATERIAL (<63µm) MINERAL COMPONENT					FINE MATERIAL (<63µm) ORGANIC COMPONENT						PEDOFEATURES								
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMENT	Marine shell	Quartz	Quartzite	Mica/Garnet	Rock fragments	Cramp	Pottery	Well decomposed plant	Lignified tissue	Peat fragment	Woody charcoal	Charred plant	Burned peat/ turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Grey material	Phytoliths/ Diatoms	Heat altered clay	Punctuations	Amorphous reddish orange	Amorphous black	Yellow amorphous	Pigment	Fungal spore	Fe/Mn accumulation	Fe depletion	Fe/MN Nodule	Fe/Mn Hypocoatings	Dusty clay coatings/infill	Laminated infill	Limpid clay coatings/infill	Sandy infill	Excremental Phosphatic
Dark shell midden	135	B	Channels, chambers & vughs /platy	Open porphyric	Random,, poorly sorted	1	t		t	t			t			1					Grey and orangey brown / light brown organo-mineral (PPL) White and light brown (OIL)	Speckled micro-crystallitic	4			1	2	1	t	t		⊙			t			⊙⊙		
		A	Channels, chambers & vughs /platy	Open porphyric	Random,, poorly sorted	2	2	t		t	t					2			1		Dark brown – grey organo-mineral (PPL) Mid brown – yellowish brown (OIL)	Speckled micro-crystallitic	2		t	1	2	2	2	t		t	t		t			t		

Deep sondage, ‘dumped deposits’. Frequency class refers to the appropriate area of section (from Bullock et al. 1985)

Frequency class refers to the appropriate area of section (from Bullock et al., 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures:
t = trace (<1%) ⊙ = Rare (1-2%) ⊙⊙ = Occasional (2 – 5%) ⊙⊙⊙ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)															FINE MATERIAL(<63µm)											PEDOFEATURES									
						MINERAL COMPONENT							ORGANIC COMPONENT								MINERAL COMPONENT					ORGANIC COMPONENT															
CONTEXT	THIN SECTION REFERENCE	MICRO-STRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Mica/Garnet	Rock fragments	Cramp	Pottery	Well decomposed plant	Lignified tissue	Peat fragment	Woody charcoal	Charred plant	Burned peat / turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Grey material	Phytoliths/diatoms	Heat altered clay fragments	Punctuations	Amorphous reddish orange	Amorphous black	Yellow amorphous	Pigment	Fungal Spore	Fe/Mn accumulation	Fe/Mn depletion	Fe/Mn nodule	Fe/Mn Hypocoatings	Dusty clay coatings/infill	Laminated infill	Limpid clay coatings/infill	Sandy infill	Excremental	Phosphatic
9174	136	E	Channels, chambers & vughs	Open porphyric	Random, some weak striations. poorly sorted.	t	2	t		t		t				2		2	t	1	Dark brown organo-mineral (PPL) Light brown (OIL)	Speckled micro-crystallitic	4	t			1	1	1							⦿					
		D	Channels, chambers & vughs	Open porphyric	Random, some weak striations. poorly sorted.	2	2	t	t	1	t	t				2		1		1	Mid-brown and grey organo-mineral (PPL) Light brown & white (OIL)	Speckled micro-crystallitic	2	t			1	1	1		t	⦿				⦿					
		C	Chambers & vughs	Open porphyric	Random, some. Poorly sorted.	1	1	1		1						1		1		t	Light brown and grey organo-mineral (PPL) very light brown (OIL)	Speckled micro-crystallitic	2				2	2	1	t		⦿⦿		⦿⦿							
		B	Channels, chambers & vughs	Open porphyric	Random, some weak striations. Poorly sorted.	t	2		1	1						t				t	Mid brown, yellow, orange and grey organo-mineral (PPL) mid-light brown (OIL)	Speckled micro-crystallitic	2				2	1	1			⦿⦿		⦿		⦿	⦿		⦿		
		A	Channels, chambers & vughs	Open porphyric	Random, poorly sorted.	t	2		1	1								t			Very light brown, yellow and grey organo-mineral (PPL) Light brown (OIL)	Speckled micro-crystallitic	3			1	1	1	1	t											

Deep sondage, 'dumped deposits'. Frequency class refers to the appropriate area of section (from Bullock et al. 1985)

Frequency class refers to the appropriate area of section (from Bullock et al., 1985):

t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)

Frequency class for textual pedofeatures:

t = trace (<1%) ⦿ = Rare (1-2%) ⦿⦿ = Occasional (2 – 5%) ⦿⦿⦿ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm) – MINERAL COMPONENT							COARSE MATERIAL (>63µm) – ORGANIC COMPONENT								FINE MATERIAL(<63µm) – MINERAL COMPONENT					FINE MATERIAL(<63µm) – ORGANIC COMPONENT						PEDOFEATURES									
CONTEXT	THIN SECTION REFERENCE	MICRO-STRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Mica/Garnet	Rock fragments	Cramp	Pottery	Well decomposed plant	Lignified tissue	Peat fragment	Woody charcoal	Charred plant	Burned peat / turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Grey material	Phytoliths/diatoms	Heat altered clay fragments	Punctuations	Amorphous reddish orange	Amorphous black	Yellow amorphous	Pigment	Fungal Spore	Fe/Mn accumulation	Fe/Mn depletion	Fe/Mn nodule	Fe/Mn Hypocoatings	Dusty clay coatings/infill	Laminated infill	Limpid clay coatings/infill	Sandy infill	Excremental	Phosphatic
9185	138	B	Channels, chambers & vughs	Open Porphyric	Random, poorly sorted		1	t	t	1	t					2		1		t	Dark-mid brown organo-mineral (PPL) Yellowish-reddish brown (OIL)	Speckled micro-crystallitic	2			1	1	1	1					t							
		A	Channels, chambers & vughs	Open Porphyric	Random, poorly sorted	t	1		t	1				t		2			2	t	Yellowish orange organo-mineral (PPL) Mid brown (OIL)	Speckled micro-crystallitic	4					1	1		t			t							

Deep sondage, 'dumped deposits'. Frequency class refers to the appropriate area of section (from Bullock et al. 1985)

Frequency class refers to the appropriate area of section (from Bullock et al., 1985):

t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)

Frequency class for textual pedofeatures:

t = trace (<1%) ⦿ = Rare (1-2%) ⦿⦿ = Occasional (2 – 5%) ⦿⦿⦿ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL(>63µm) MINERAL COMPONENT						ORGANIC COMPONENT								FINE MATERIAL (<63µm) MINERAL COMPONENT					ORGANIC COMPONENT						PEDOFEATURES									
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Mica/Garnet	Rock fragments	Pottery	Well decomposed plant	Lignified tissue	Peat/ turf fragment	Charcoal	Charred plant	Burned peat/ turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Grey material	Phytoliths/ Diatoms	Heat altered clay fragments	Punctuations	Amorphous reddish orange	Amorphous black	Yellow amorphous	Pigment	Fungal tissue	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodule	Fe/Mn hypocoatings	Dusty clay coatings/infill	Laminated infill	Limpid clay coatings/infill	Sandy infill	Excremental	Phosphatic
9192/natural	188	B	Channels, chambers & vughs	Close Porphyric	Random, unsorted		3	t	t	2					1			1	1	Dark brown/grey organo-mineral (PPL) Light brown/orange (PPL)	Speckled micro-crystallitic	1			1			2		t	⦿⦿		⦿				t		t	
		A	Complex massive	Close Porphyric	Random, unsorted		2	1	t	4										Dark brown/light brown/ greyish organo-mineral (PPL) yellowish brown (OIL)	Stipple speckled micro-crystallitic							1			⦿⦿⦿ +	⦿⦿⦿	⦿⦿	⦿⦿			⦿			

Deep sondage, 'dumped deposits'. Frequency class refers to the appropriate area of section (from Bullock et al. 1985)

Frequency class refers to the appropriate area of section (from Bullock et al., 1985):

t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)

Frequency class for textual pedofeatures:

t = trace (<1%) ⦿ = Rare (1-2%) ⦿⦿ = Occasional (2 – 5%) ⦿⦿⦿ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm) MINERAL COMPONENT								ORGANIC COMPONENT								FINE MATERIAL (<63µm) MINERAL COMPONENT						ORGANIC COMPONENT						PEDOFEATURES								
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMENT	Marine shell	Quartz	Quartzite	Mica/Garnet	Rock fragments	Cramp	Pottery	Rubified minerals	Well decomposed plant	Lignified tissue	Peat fragment	Charcoal	Charred plant	Burned peat/ turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Peat ash	Grey material	Phytoliths/ Diatoms	Heat altered clay	Punctuations	Amorphous reddish orange	Amorphous black	Yellow amorphous	Pigment	Fungal spore	Fe/Mn accumulation	Fe depletion	Fe/MN Nodule	Fe/Mn Hypocoatings	Silty coatings/infill	Laminated infill	Limpid clay coatings/infill	Sandy infill	Excremental Phosphatic
195	9810 / 9811 / 9812/ 9813	D	Channels, chambers and vughs	OP	Random, unsorted	3	1	1		1			t				1		2			Brown organo-mineral (PPL & OIL)	Stipple speckled micro-crystallitic	t	1			1	t	t												⦿⦿
		C	Complex packing voids	Enaulic & CP	Random, Well sorted	3	1	1		1							t	t	1			Brown organo-mineral (PPL) Orangey brown (OIL)	Stipple speckled micro-crystallitic	t				t		1								⦿⦿⦿+				⦿⦿⦿+
		B	Channels, chambers and vughs	OP	Random, poorly sorted	2	1	1					1				t	1	1		t	Brown organo-mineral (PPL) Brown/yellow / orange (OIL)	Stipple speckled micro-crystallitic	1	2			1	1	2	t			⦿		⦿						⦿⦿
		A	Complex packing voids	Enaulic & CP	Random, Well sorted	4	1							t				1				Brown organo-mineral (PPL & OIL)	Stipple speckled micro-crystallitic					t		t								⦿⦿⦿				

Dumped deposits associated with structures 16 and 17. Frequency class refers to the appropriate area of section (from Bullock et al. 1985)

Frequency class refers to the appropriate area of section (from Bullock et al., 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures:
t = trace (<1%) ⦿ = Rare (1-2%) ⦿⦿ = Occasional (2 – 5%) ⦿⦿⦿ = Many (5 – 10%) ⦿⦿⦿+ = Common (>10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)																	FINE MATERIAL (<63µm)											PEDOFEATURES								
						MINERAL COMPONENT								ORGANIC COMPONENT									MINERAL COMPONENT					ORGANIC COMPONENT													
CONTEXT	THIN SECTION REFERENCE	MICRO -STRATIGRAPHIC UNITS	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Turf fragments	Rubified minerals	Well decomposed plant material	Vesicular char	Charcoal	Charred plant remains	Burned Peat	Burned turf	Pottery	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Diatoms/ phytoliths	Grey material	Clay aggregates	Punctuations	Amorphous orange	Amorphous black	Amorphous yellow	Orange clay	Fungal tissue	Fe/Mn accumulation	Fe depletion	Fe/MN Nodule	Fe/Mn Hypocoatings	Psuedomorphic ferruginous	Sandy coatings/infill	Silty clay coatings/infill	CaCo3	Excremental
8016	101	E	Channels, vughs and chambers	OP	Random, poorly sorted	3	2	1		1							1						Light yellowish grey organo-mineral (PPL) Light greenish yellow (OIL)	Stipple speckled micro-crystallitic	t				1	1	1			⊙⊙								⊙⊙
8016	101	D	Vughs and channels	OP	Mostly random some orientation of shell sand. moderate sorting	2	2	t			t						t					t	Mixed dark brown, organo-mineral (PPL) Light yellowish brown and orangey brown (OIL)	Stipple speckled micro-crystallitic		2				1	1			⊙⊙							⊙⊙⊙	t
8016	101	C	Vughs and channels	OP	Random, moderate sorting	t	2	1		t						1		t			t		Light brown and grey organo-mineral (PPL) Yellowish grey (OIL)	Stipple speckled micro-crystallitic						2	2			⊙⊙								
8016	101	B	Vughs and channels	OP	Random, unsorted	t	1			t	2					1	2				2		Dark greyish brown organo-mineral (PPL) mixed white and brown (OIL)	Stipple speckled micro-crystallitic		1	1			2	2			⊙⊙⊙		⊙						
8016	101	A	Vughs and channels	OP	Random, poorly sorted		2	1		t	2					t	1				1		Greyish brown organo-mineral (PPL) Yellowish brown (OIL)	Stipple speckled micro-crystallitic			1	1	1		1					⊙				⊙		

Infill deposit, structure 8. Frequency class refers to the appropriate area of section (from Bullock et al. 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures: t = trace (<1%) ⊙ = Rare (1-2%) ⊙⊙ = Occasional (2 – 5%) ⊙⊙⊙ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)																		FINE MATERIAL (<63µm)													PEDOFEATURES									
						MINERAL COMPONENT									ORGANIC COMPONENT									MINERAL COMPONENT						ORGANIC COMPONENT																
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Turf fragments	Rubified minerals	Large shell	Well decomposed plant	Vesicular char	Charcoal	Charred plant remains	Burned peat	Burned turf	Pottery	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Diatoms/phytoliths	Ash	Clay aggregates	Heat altered clay fragments	Punctuations	Amorphous red/orange	Amorphous black	Amorphous yellow	Pigment	Orange clay	Fungal Tissue	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Fe/Mn Hypocoatings	Psuedomorphic ferruginous	Phosphatic	Sandy coatings/infill	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
198	9874	SINGLE	Complex packing voids and intergrain microaggregates	Enaulic	Random, poorly sorted	3	3				1		t	1			1	t	t			t	t	Brown organo-mineral (PPL & OIL)	Stipple speckled micro-crystallitic			1	t	1	t	1										⊙				
197	9874/9889	SINGLE	Complex packing voids and intergrain microaggregates	CP / Monic	Random, well sorted	4	2				1			t			t	1	1				t	Brown organo-mineral (PPL & OIL)	Stipple speckled micro-crystallitic		t			1		1			2		⊙					⊙⊙⊙		⊙⊙	⊙	

Structure 12 Infill/ floor. Frequency class refers to the appropriate area of section (from Bullock et al. 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures: t = trace (<1%) ⊙ = Rare (1-2%) ⊙⊙ = Occasional (2 – 5%) ⊙⊙⊙ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)																		FINE MATERIAL (<63µm)													PEDOFEATURES									
						MINERAL COMPONENT									ORGANIC COMPONENT									MINERAL COMPONENT						ORGANIC COMPONENT																
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Turf fragments	Rubified minerals	Large shell	Well decomposed plant	Vesicular char	Charcoal	Charred plant remains	Burned peat	Burned turf	Pottery	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Diatoms/phytoliths	Grey material	Clay aggregates/ ldomains	Heat altered clay fragments	Punctuations	Amorphous red/orange	Amorphous black	Amorphous yellow	Pigment	Orange clay	Fungal Tissue	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Fe/Mn Hypocoatings	Psuedomorphic ferruginous	Phosphatic	Sandy coatings/infill	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
9127 / 9131	96	Single	Crumb, granular channels, chambers & vughs	Complex	Random, poorly sorted		1		t	t	1						t						1	Mid brown & grey organo-mineral (PPL) yellowish brown & grey (OIL)	Stipple speckled micro-crystallitic	t	2				2		t				⦿⦿⦿	⦿	⦿⦿⦿	⦿⦿⦿	⦿⦿⦿		⦿⦿⦿	⦿⦿		+ ⦿⦿⦿
9133 /9132 /9131	97	C	Channels, chambers and vughs	Open porphyric	Random, poorly sorted		2	1			2											t	t	Mid brown organo-mineral (PPL) Yellowish brown (OIL)	Stipple Speckled micro-crystallitic		1	2			2	1					⦿⦿⦿		⦿⦿⦿				t	⦿⦿⦿		⦿
		B	Channels, chambers and vughs	Open porphyric	Random, poorly sorted	t	2				2							1				t	t	Mid brown & grey organo-mineral (PPL) dark brown & white (OIL)	Stipple Speckled micro-crystallitic	t	3	1			2	1	t				⦿⦿		⦿⦿⦿					t		⦿
		A	Vughs and channels	Open porphyric	Random, poorly sorted		2	1			3							t				t	t	Light brown & grey organo-mineral (PPL) brown & white (OIL)	Stipple speckled micro-crystallitic	t	4			t	3	2	t			t			⦿⦿					⦿⦿		⦿⦿

'Infill' deposit, alcove-like feature associated with Structure 8. Frequency class refers to the appropriate area of section (from Bullock et al. 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures: t = trace (<1%) ⦿ = Rare (1-2%) ⦿⦿ = Occasional (2 – 5%) ⦿⦿⦿ = Many (5 – 10%)

Appendix V: Thin section description tables, anthrosols at the Links of Noltland

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)															FINE MATERIAL (<63µm)												PEDOFEATURES						
						MINERAL COMPONENT							ORGANIC COMPONENT								MINERAL COMPONENT					ORGANIC COMPONENT													
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Cramp	Turf fragments	Well decomposed plant material	Charcoal	Charred plant remains	Vesicular char	Burned peat	Unburned bone	Burned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Diatoms/Phytoliths	Clay aggregates	Heat altered clay fragments	Punctuations	Amorphous reddish orange	Amorphous black	Amorphous yellow	Amorphous pink	Pigment	Fungal Tissue	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Psuedomorphic ferruginous	Sandy coatings/infill	Silty/dusty clay coatings/infill	Excremental
9058/9073	74	B	Channels, vughs and chambers	Open porphyric	Random poorly sorted		3	1	1	1	3		t			t				1	Brown organo-mineral (PPL) Brownish orange and yellow (OIL)	Stipple-speckled micro-crystallitic	t						t						⦿				
		A	Channels, vughs and chambers	Open porphyric	Random un-sorted		3	1	1	1	3		1			t				1	Dark brown organo-mineral (PPL) Brownish orange and yellow (OIL)	Stipple-speckled micro-crystallitic	1				t	1					t		⦿⦿				⦿⦿⦿

Field bank sample group: frequency class refers to the appropriate area of section (from Bullock et al. 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures: t = trace (<1%) ⦿ = Rare (1-2%) ⦿⦿ = Occasional (2 – 5%) ⦿⦿⦿ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)															FINE MATERIAL (<63µm)												PEDOFEATURES						
						MINERAL COMPONENT								ORGANIC COMPONENT							MINERAL COMPONENT					ORGANIC COMPONENT												
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Cramp	Turf fragments	Well decomposed plant material	Charcoal	Charred plant remains	Vesicular char	Burned peat	Unburned bone	Burned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Diatoms/Phytoliths	Clay aggregates	Heat altered clay fragments	Punctuations	Amorphous reddish orange	Amorphous black	Amorphous yellow	Amorphous pink	Pigment	Fungal Tissue	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Psuedomorphic ferruginous	Sandy coatings/infill	Silty/dusty clay coatings/infill	Excremental
9058	78	C	Compact with vughs and channels	Open porphyric	Random poorly sorted	t	1	t	t	t	1		t		t				t	t	Brown organo-mineral (PPL) Yellowish brown (OIL)	Stipple-speckled micro-crystallitic				1	t	1					⊙⊙		⊙				
9058	78	B	Compact with vughs and channels	Open porphyric	Random poorly sorted	1	2	1	1	t	2		1	t	t	t			1	t	Very dark brown organo-mineral (PPL) Dark yellowish brown (OIL)	Stipple-speckled micro-crystallitic		t	t	1		1	t	t		t	⊙⊙		⊙⊙	⊙⊙	t	⊙⊙	
9058	78	A	Compact with vughs and channels	Open porphyric	Random poorly sorted		2	1	t					t	1					t	Light greyish brown organo-mineral (PPL) Yellowish brown (OIL)	Stipple-speckled micro-crystallitic				1	t	1	t		1		⊙⊙		⊙⊙	⊙⊙			
9058/ 9073	82	Single	Channels, vughs and chambers	Open porphyric	Random, unsorted		2	1		t	2					1	t			2	Brown – dark brown organo-mineral (PPL) brownish orange and yellow (OIL)	Stipple-speckled micro-crystallitic	t	t			2	2					⊙⊙⊙						⊙

Field bank sample group: frequency class refers to the appropriate area of section (from Bullock et al. 1985):

t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)

Frequency class for textual pedofeatures: t = trace (<1%) ⊙ = Rare (1-2%) ⊙⊙ = Occasional (2 – 5%) ⊙⊙⊙ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)															FINE MATERIAL (<63µm)												PEDOFEATURES						
						MINERAL COMPONENT							ORGANIC COMPONENT								MINERAL COMPONENT					ORGANIC COMPONENT													
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Cramp	Turf fragments	Well decomposed plant material	Charcoal	Charred plant remains	Vesicular char	Burned peat	Unburned bone	Burned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Diatoms/Phytoliths	Clay aggregates	Heat altered clay fragments	Punctuations	Amorphous reddish orange	Amorphous black	Amorphous yellow	Amorphous pink	Pigment	Fungal Tissue	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Psuedomorphic ferruginous	Sandy coatings/infill	Silty/dusty clay coatings/infill	Excremental
9160	131	Single	Channels, vughs and chambers	Open porphyric	Random, unsorted	1	2				2	t		t	t			1	t		Dark brown organo-mineral (PPL) Brown (OIL)	Stipple speckled micro-crystallitic	t				t					t	⊙⊙		⊙⊙	t			t

Field bank sample group: frequency class refers to the appropriate area of section (from Bullock et al. 1985):

t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)

Frequency class for textual pedofeatures: t = trace (<1%) ⊙ = Rare (1-2%) ⊙⊙ = Occasional (2 – 5%) ⊙⊙⊙ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)															FINE MATERIAL (<63µm)													PEDOFEATURES						
						MINERAL COMPONENT							ORGANIC COMPONENT								MINERAL COMPONENT					ORGANIC COMPONENT													
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Cramp	Turf fragments	Well decomposed plant material	Charcoal	Charred plant remains	Vesicular char	Burned peat/turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Diatoms/Phytoliths	Clay aggregates	Heat altered clay fragments	Punctuations	Amorphous reddish orange	Amorphous black	Amorphous yellow	Amorphous pink	Pigment	Fungal Tissue	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Psuedomorphic ferruginous	Phosphatic	Silty/dusty clay coatings/infill	Excremental
177	9543	SINGLE	Bridged grain microaggregate & crumb/ compound packing voids	Enaulic	Random, well sorted	4	1	2			t			t	t		t	t			Dark brown organo-mineral (PPL) Brown (OIL)	Stipple speckled micro-crystallitic															t	⊙	⊙⊙
176	9555	SINGLE	Single grain and bridged grain microaggregate	Monic / Enaulic/ Chitonic	Random, well sorted	4	1	2						t				t			Dark brown organo-mineral (PPL) Brown (OIL)	Stipple speckled micro-crystallitic					t										⊙		
175	9558	SINGLE	Single grain and bridged grain microaggregate	Monic / Enaulic	Random, well sorted	3	1	3			t			t	t	t				t	Dark brown organo-mineral (PPL) Brown (OIL)	Stipple speckled micro-crystallitic					t										⊙⊙⊙		
174	9585	SINGLE	Single grain and bridged grain microaggregate	Monic / Enaulic	Random, perfectly sorted	5	1	2													Brown organo-mineral (PPL) yellowish brown (OIL)	Stipple speckled micro-crystallitic																⊙	

Cultivated soil, near structure 13: frequency class refers to the appropriate area of section (from Bullock et al. 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures: t = trace (<1%) ⊙ = Rare (1-2%) ⊙⊙ = Occasional (2 – 5%) ⊙⊙⊙ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)															FINE MATERIAL (<63µm)										PEDOFEATURES							
						MINERAL COMPONENT							ORGANIC COMPONENT								MINERAL COMPONENT					ORGANIC COMPONENT											
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Rubified mineral	Turf fragments	Well decomposed plant material	Charcoal	Charred plant remains	Vesicular char	Burned peat/turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Peat ash	Diatoms/Phytoliths	Clay aggregates	Punctuations	Amorphous reddish orange	Amorphous black	Amorphous yellow	Amorphous pink	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Organic void coating	Phosphatic	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
9420	218	SINGLE	Intergrain microaggregate /coarse packing voids	Enaulic	Random, Well sorted	3	3	t	t		t										Light brown organo-mineral (PPL) Brown (OIL)	Stipple speckled micro-crystallitic				1		t								⊙⊙⊙		
9420	217	SINGLE	Channels, chambers and vughs	complex	Random, moderately sorted	3	t	1	t		1							1	t		Light brown organo-mineral (PPL) Brown (OIL)	Stipple speckled micro-crystallitic	t		t	1		t	t		t			⊙⊙⊙		⊙		
Aeolian sand / 9427	216	B	Channels, chambers and vughs	CP	Random, well sorted	2	1		t						t			t	1		Brown organo-mineral (PPL) Light brown (OIL)	Stipple speckled micro-crystallitic	t	t	t		t		t		⊙						⊙	
		A	Intergrain microaggregate /complex packing voids	Enaulic	Random, Moderately sorted	3	t	1	t		1	t								t	Light brown organo-mineral (PPL) Pale brown (OIL)	Stipple speckled micro-crystallitic			t			t	1						⊙	⊙⊙⊙	⊙	

Cultivated soil, test trench 22, south of auger grid 2: frequency class refers to the appropriate area of section (from Bullock et al. 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures: t = trace (<1%) ⊙ = Rare (1-2%) ⊙⊙ = Occasional (2 – 5%) ⊙⊙⊙ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm) MINERAL COMPONENT							ORGANIC COMPONENT								FINE MATERIAL (<63µm) MINERAL COMPONENT					ORGANIC COMPONENT							PEDOFEATURES						
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Cramp	Turf fragments	Well decomposed plant material	Charcoal	Charred plant remains	Vesicular char	Burned peat	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Diatoms/Phytoliths	Clay aggregates	Heat altered clay fragments	Punctuations	Amorphous reddish orange	Amorphous black	Amorphous yellow	Amorphous pink	Pigment	Fungal Tissue	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Psuedomorphic ferruginous	Sandy coatings/infill	Silty/dusty clay coatings/infill	Excremental
9036/ 9035	80	B	Inter/bridged-grain microaggregate Channels and complex packing voids.	Gefuric	Random,	5	1	t					t							t	Brown organo-mineral (PPL) Brown (OIL)	Stipple-speckled micro-crystallitic					t		t						◉				
9036/ 9035	80	A	Basic CP compact fine organo-mineral material with vughs and channels	Close porphyric	Random,	3	1	t		t	3				t			1			Dark brown organo-mineral (PPL) Brown (OIL)	Stipple-speckled micro-crystallitic					2		t						◉◉	◉		◉◉◉	
9036/ 9035	79	SINGLE	Inter/bridged-grain microaggregate. Channels and complex packing voids.	CP	Random, well sorted	4	1	1	1		1		1		t					t	Brown organo-mineral (PPL) Brown (OIL)	Stipple-speckled micro-crystallitic				1	t		t						◉◉			◉	

Ground surface over Area 5: frequency class refers to the appropriate area of section (from Bullock et al. 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures: t = trace (<1%) ◉ = Rare (1-2%) ◉◉ = Occasional (2 – 5%) ◉◉◉ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)															FINE MATERIAL (<63µm)													PEDOFEATURES						
						MINERAL COMPONENT							ORGANIC COMPONENT								MINERAL COMPONENT					ORGANIC COMPONENT													
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Cramp	Turf fragments	Well decomposed plant material	Charcoal	Charred plant remains	Vesicular char	Burned peat	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Diatoms/Phytoliths	Clay aggregates	Heat altered clay fragments	Punctuations	Amorphous reddish orange	Amorphous black	Amorphous yellow	Amorphous pink	Pigment	Fungal Tissue	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Psuedomorphic ferruginous	Sandy coatings/infill	Silty/dusty clay coatings/infill	Excremental
9031 / 9036 /9035	81	B	Vughs, channels & chambers	Close porphyric	Random, Moderately sorted	4	2	1		t	2				t					t	Light Greyish Brown Organo- Mineral (PPL) Brown (OIL)	Stipple-Speckled Micro-crystallitic				1	t	2					⦿		⦿⦿			⦿⦿	
9031 / 9036 /9035	81	A	Vughs, channels & chambers	Open porphyric	Random, well sorted	1	2	1	t	t	1			t	t			t		t	Light Greyish Brown Organo- Mineral (PPL) Brown (OIL)	Stipple-Speckled Micro-crystallitic	t			t	1	2	t				⦿		⦿⦿⦿			⦿⦿⦿	⦿⦿
9072	75	B	Weak sub angular blocky. Vughs, channels & chambers	Open porphyric	Random, poorly sorted	t	3	1	t	1	1		t	t	t	1			t	t	Dark Brown Organo-Mineral (PPL) yellowish brown (OIL)	Stipple-Speckled Micro-crystallitic					1	1	2				⦿⦿⦿		⦿⦿		t	⦿⦿⦿	
9072	75	A	Weak sub angular blocky. Vughs, channels &chambers	Open porphyric	Random, poorly sorted		2	t	t		1			t						t	Light Brown/ Grey Organo-Mineral (PPL) Reddish brown (OIL)	Stipple-Speckled Micro-crystallitic					1	1					⦿		⦿⦿⦿			⦿⦿⦿	

Ground surface over Area 5: frequency class refers to the appropriate area of section (from Bullock et al. 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures: t = trace (<1%) ⦿ = Rare (1-2%) ⦿⦿ = Occasional (2 – 5%) ⦿⦿⦿ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)															FINE MATERIAL (<63µm)										PEDOFEATURES							
						MINERAL COMPONENT							ORGANIC COMPONENT								MINERAL COMPONENT					ORGANIC COMPONENT												
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Rubified mineral	Turf fragments	Well decomposed plant material	Charcoal	Charred plant remains	Vesicular char	Burned peat/turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Peat ash	Diatoms/Phytoliths	Clay aggregates	Punctuations	Amorphous reddish orange	Amorphous black	Amorphous yellow	Amorphous pink	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Organic void coating	Phosphatic	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
9099	83	B	Monic / bridge grain microaggregates	Monic / enaulic	Perfectly sorted	5	1	t			t										Light brown organo-mineral (PPL) yellowish brown (OIL)	Speckled micro-crystallitic																
9099	83	A	Massive / some chambers, channel and vughs	OP	Poorly sorted	2	1	t			3			t		t					Light brown organo-mineral (PPL) yellowish brown (OIL)	Stipple speckled micro-crystallitic				1		t			⊙					⊙⊙⊙		
9099	84	B	Monic / bridge grain microaggregates	Monic / enaulic	Perfectly sorted	5	1	t			t										Light brown organo-mineral (PPL) yellowish brown (OIL)	Speckled micro-crystallitic																
9099	84	A	Massive / some chambers, channel and vughs	OP	Poorly sorted	2	1	t			2			t		1					Light brown organo-mineral (PPL) yellowish brown (OIL)	Stipple speckled micro-crystallitic			t	1	t	t			⊙					⊙⊙⊙		

Cultivated soil, soil test pit 1, auger grid 1: frequency class refers to the appropriate area of section (from Bullock et al. 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures: t = trace (<1%) ⊙ = Rare (1-2%) ⊙⊙ = Occasional (2 – 5%) ⊙⊙⊙ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)															FINE MATERIAL (<63µm)										PEDOFEATURES							
						MINERAL COMPONENT							ORGANIC COMPONENT								MINERAL COMPONENT					ORGANIC COMPONENT												
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Rubified mineral	Turf fragments	Well decomposed plant material	Charcoal	Charred plant remains	Vesicular char	Burned peat/turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Peat ash	Diatoms/Phytoliths	Clay aggregates	Punctuations	Amorphous reddish orange	Amorphous black	Amorphous yellow	Amorphous pink	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Organic void coating	Phosphatic	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
9112 / 9108	94	B	Channels, chambers. Complex packing voids	Gefuric/OP	Random, well sorted	4	t				t					t			t		Yellow organo-mineral (PPL) yellowish brown (OIL)	Speckled micro-crystallitic						t										t
		A	Massive	OP	Random, poorly sorted	t	1	t			1	t			t	2					Light brown organo-mineral (PPL) yellowish brown (OIL)	Speckled micro-crystallitic						1			t		⊙			⊙⊙⊙+		
	92	B	Channels/ vughs	OP	Random, moderately sorted	2	1			t	t					t			t	t	Light brown organo-mineral (PPL) yellowish brown (OIL)	Stipple speckled micro-crystallitic				t	t	1								⊙⊙		
		A	Channels/ vughs	OP	Random, moderately sorted	t	2	t		t	1			1	t	1			t		Light brown organo-mineral (PPL) yellowish brown (OIL)	Stipple speckled micro-crystallitic				t		1								⊙⊙		

Cultivated soil, soil test pit 3, auger grid 1: frequency class refers to the appropriate area of section (from Bullock et al. 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures: t = trace (<1%) ⊙ = Rare (1-2%) ⊙⊙ = Occasional (2 – 5%) ⊙⊙⊙ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm) MINERAL COMPONENT								COARSE MATERIAL (>63µm) ORGANIC COMPONENT								FINE MATERIAL (<63µm) MINERAL COMPONENT					FINE MATERIAL (<63µm) ORGANIC COMPONENT					PEDOFEATURES							
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Rubified mineral	Pottery	Turf fragments	Well decomposed plant material	Charcoal	Charred plant remains	Vesicular char	Burned peat/turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Peat ash	Diatoms/Phytoliths	Clay aggregates	Punctuations	Amorphous reddish orange	Amorphous black	Amorphous yellow	Amorphous pink	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Organic void coating	Phosphatic	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
9112	93		Channels/vughs	OP	Random, poorly sorted	t	2	1			3	t					1			t		Mid brown organo-mineral (PPL) reddish brown (OIL)	Stipple speckled micro-crystallitic				t		1								⦿⦿		
9112 / natural	95	SINGLE	Channel, Vughs/ Massive	OP	Random, poorly sorted		2	1			2		t			t	2			t		Brown organo-mineral (PPL) reddish brown (OIL)	Stipple speckled micro-crystallitic				t	1	1			t		t					

Cultivated soil, soil test pit 1, auger grid 1: frequency class refers to the appropriate area of section (from Bullock et al. 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures: t = trace (<1%) ⦿ = Rare (1-2%) ⦿⦿ = Occasional (2 – 5%) ⦿⦿⦿ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm) MINERAL COMPONENT							COARSE MATERIAL (>63µm) ORGANIC COMPONENT								FINE MATERIAL (<63µm) MINERAL COMPONENT					FINE MATERIAL (<63µm) ORGANIC COMPONENT					PEDOFEATURES							
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Rubified mineral	Turf fragments	Well decomposed plant material	Charcoal	Charred plant remains	Vesicular char	Burned peat/turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Peat ash	Diatoms/Phytoliths	Clay aggregates	Punctuations	Amorphous reddish orange	Amorphous black	Amorphous yellow	Amorphous pink	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Organic void coating	Phosphatic	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
9184	117	SINGLE	Complex	Enaulic	Random, moderately sorted	4	2			t	t					t				t	Dark brown organo-mineral (PPL) Reddish brown (OIL)	Stipple speckled micro-crystallitic																⦿⦿⦿
9277 / 9276	119	SINGLE	Complex	Enaulic/ monic	Random, well sorted	4	2				t					t					Brown organo-mineral (PPL & OIL)	Speckled micro-crystallitic				t		t										
9277	120	SINGLE	Crumb / complex packing voids	Monic/ concave gefuric/ enaulic	Random, well sorted	4	2	1			t					t					Light brown organo-mineral (PPL & OIL)	Speckled micro-crystallitic		t		t		t										

Bank or lynchet, soil test pit 5, auger grid 1: frequency class refers to the appropriate area of section (from Bullock et al. 1985):

t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)

Frequency class for textual pedofeatures: t = trace (<1%) ⦿ = Rare (1-2%) ⦿⦿ = Occasional (2 – 5%) ⦿⦿⦿ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)															FINE MATERIAL (<63µm)										PEDOFEATURES							
						MINERAL COMPONENT							ORGANIC COMPONENT								MINERAL COMPONENT					ORGANIC COMPONENT												
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Rubified mineral	Turf fragments	Well decomposed plant material	Charcoal	Charred plant remains	Vesicular char	Burned peat/turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Peat ash	Diatoms/Phytoliths	Clay aggregates	Punctuations	Amorphous reddish orange	Amorphous black	Amorphous yellow	Amorphous pink	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Organic void coating	Phosphatic	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
Glacial till/ 9179	121	B	Channels/vughs	OP	Random, poorly sorted	2	1	t			1				t	t					Mid brown organo-mineral (PPL) light yellowish brown (OIL)	Speckled micro-crystallitic				t		t										t
Glacial till/ 9179	121	A	Massive	OP	Random, poorly sorted		2	1	t	1	1										Yellowish brown organo-mineral (PPL & OIL)	Stipple speckled micro-crystallitic											⦿⦿⦿					
9179	122	SINGLE	Channel/chamber /vugh/intergrain microaggregates	OP/Enaulic	Random, poorly sorted	3	1	t			t	t				1			t		Mid brown organo-mineral (PPL) Yellowish brown (OIL)	Stipple speckled micro-crystallitic		t	t	t		1					⦿			t		t

Possible cultivated soil, soil test pit 5, auger grid 1: frequency class refers to the appropriate area of section (from Bullock et al. 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures: t = trace (<1%) ⦿ = Rare (1-2%) ⦿⦿ = Occasional (2 – 5%) ⦿⦿⦿ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)															FINE MATERIAL (<63µm)										PEDOFEATURES							
						MINERAL COMPONENT							ORGANIC COMPONENT								MINERAL COMPONENT					ORGANIC COMPONENT												
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Rubified mineral	Turf fragments	Well decomposed plant material	Charcoal	Charred plant remains	Vesicular char	Burned peat/turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Peat ash	Diatoms/Phytoliths	Clay aggregates	Punctuations	Amorphous reddish orange	Amorphous black	Amorphous yellow	Amorphous pink	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Organic void coating	Phosphatic	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
9178	123		Channel, chamber, vugh	OP	Random, poorly sorted	3	1				t			t	t	1			t	t	Light brown organo-mineral (PPL) Brown (OIL)	Speckled micro crystallitic						1	t							t		
9178	124	B	Complex	Monic/ concave gefuric	Random, well sorted	4	1	1			1										Light brown organo-mineral (PPL) yellowish brown (OIL)	Speckled micro crystallitic			t													
		A	Channel, chamber, vugh	OP	Random, poorly sorted	3	1	t			1					t					Brown organo-mineral (PPL& OIL)	Speckled micro crystallitic			t								⊙			⊙⊙		

Possible cultivated soil, soil test pit 5, auger grid 1: frequency class refers to the appropriate area of section (from Bullock et al. 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures: t = trace (<1%) ⊙ = Rare (1-2%) ⊙⊙ = Occasional (2 – 5%) ⊙⊙⊙ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm) MINERAL COMPONENT							COARSE MATERIAL (>63µm) ORGANIC COMPONENT								FINE MATERIAL (<63µm) MINERAL COMPONENT					FINE MATERIAL (<63µm) ORGANIC COMPONENT					PEDOFEATURES							
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Rubified mineral	Turf fragments	Well decomposed plant material	Charcoal	Charred plant remains	Vesicular char	Burned peat/turf	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Peat ash	Diatoms/Phytoliths	Clay aggregates	Punctuations	Amorphous reddish orange	Amorphous black	Amorphous yellow	Amorphous pink	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Organic void coating	Phosphatic	Silty/dusty clay coatings/infill	Limpid clay coatings/infill	Excremental
9103 / 9101	91	B	Channels/ vughs	OP	Random, moderately sorted		2	t		t	t			t							Light brown organo-mineral (PPL) yellowish brown (OIL)	Stipple speckled micro-crystallitic				t		1					t					
9103 / 9101	91	A	Complex Packing voids/ intergrain microaggregates/ crumb	Enaulic/ Gefuric	Random, poorly sorted	3	2	t		t	2										Light brown organo-mineral (PPL) yellowish brown (OIL)	Stipple speckled micro-crystallitic			1			t										⊙⊙

Cultivated soil, soil test pit 2, auger grid 1: frequency class refers to the appropriate area of section (from Bullock et al. 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures: t = trace (<1%) ⊙ = Rare (1-2%) ⊙⊙ = Occasional (2 – 5%) ⊙⊙⊙ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)															FINE MATERIAL (<63µm)												PEDOFEATURES						
						MINERAL COMPONENT							ORGANIC COMPONENT								MINERAL COMPONENT					ORGANIC COMPONENT													
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica	Rock fragments	Cramp	Turf fragments	Well decomposed plant material	Charcoal	Charred plant remains	Vesicular char	Burned peat	Burned bone	Unburned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Diatoms/Phytoliths	Clay aggregates	Heat altered clay fragments	Punctuations	Amorphous reddish orange	Amorphous black	Amorphous yellow	Amorphous pink	Pigment	Fungal Tissue	Fe/Mn accumulation	Fe depletion	Fe/Mn Nodules	Psuedomorphic ferruginous	Sandy coatings/infill	$CaCo^3$	Excremental
98	9135 / 9138	B	Sub angular blocky peds & intergrain microaggregates	Enaulic / cracked OP	Random, poorly sorted	5	1	1						t		t				t	Dark brown organo-mineral (PPL & OIL)	Stipple speckled micro-crystallitic	t			t			1										⦿⦿⦿
		A	Single/ intergrain microaggregate & crumb	Monic/ Enaulic	Random, p=erfectly sorted	4	1	2													Light brown organo-mineral (PPL & OIL)	Stipple speckled micro-crystallitic																	⦿⦿⦿
99	9139 /9142	SINGLE	Single/ intergrain microaggregate	Monic / Enaulic	Random, well sorted	4	1				3			t	1						Light yellowish brown organo-mineral (PPL & OIL)	Stipple speckled micro-crystallitic						1	t										⦿⦿

Ground surface test trench 19, south of PIC : frequency class refers to the appropriate area of section (from Bullock et al. 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures: t = trace (<1%) ⦿ = Rare (1-2%) ⦿⦿ = Occasional (2 – 5%) ⦿⦿⦿ = Many (5 – 10%)

SAMPLE			STRUCTURE			COARSE MATERIAL (>63µm)															FINE MATERIAL (<63µm)										PEDOFEATURES					
						MINERAL COMPONENT							ORGANIC COMPONENT								MINERAL COMPONENT					ORGANIC COMPONENT										
CONTEXT	THIN SECTION REFERENCE	MICROSTRATIGRAPHIC UNIT (s)	MICROSTRUCTURE	COARSE/FINE RELATED DISTRIBUTION	COARSE MINERAL ARRANGEMEMENT	Marine shell	Quartz	Quartzite	Feldspar	Mica/Garnet	Rock fragments	Cramp	Turf fragments	Well decomposed plant material	Charcoal	Charred plant remains	Vesicular char	Burned peat	Unburned bone	Burned bone	Nature of fabric (PPL)	b-Fabric (XPL)	Diatoms/Phytoliths	Clay aggregates	Heat altered clay fragments	Punctuations	Amorphous orange	Amorphous black	Yellow amorphous	Pigment	Fe/Mn accumulation	Fe/MN Nodule	Dusty clay coatings/infill	Limpid clay infill	Phospatic	Fe depletion
9274	133	Single	Single grain / pellicular grains	Monic , gefuric	Random, well sorted	6	1	1		t	2										Light yellowish brown organo-mineral (PPL & OIL)	Speckled micro-crystallitic									⊙		⊙			

Ground surface in open area excavation, south of PIC. Frequency class refers to the appropriate area of section (from Bullock et al. 1985):
t = trace (<1%) 1 = Very few (1 -5%) 2 = Few (5 -15%) 3 = Common (15-30%) 4 = Frequent (30-50%) 5 = Dominant (50-70%) 6 = Very dominant (>70%)
Frequency class for textual pedofeatures: t = trace (<1%) ⊙ = Rare (1-2%) ⊙⊙ = Occasional (2 – 5%) ⊙⊙⊙ = Many (5 – 10%)