Soil and Sediment-based Cultural Records and The Heart of Neolithic Orkney World Heritage Site Buffer Zones

Jonathan Paul Cluett

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 research material has been duly acknowledged and cited.

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Abstract

The designation of World Heritage Sites (WHS) by UNESCO is the principal international and formally recognised strategy allowing the conservation of sites of outstanding cultural value throughout the world. This study demonstrates that soils and sediments influenced by cultural activities retain cultural records (soils and sediments-based cultural records, hereafter abbreviated to SSBCR) associated with WHS, and further the understanding and contribute to the cultural value of WHS. Considering *The Heart of Neolithic Orkney WHS* and its surrounding landscape as the study location, systematic fieldwork is combined with geoarchaeological analyses including soil organic matter content, pH, particle size distribution, phosphorus concentration, soil magnetism and thin section micromorphology to determine the nature of the SSBCR. Chronologies of the formation of SSBCR and of palaeo-environmental records were ascertained using radiocarbon analyses and optically stimulated luminescence analysis. Findings of particular importance to the interpretation of the WHS are the identification of a Late Neolithic SSBCR located between the WHS monuments. This SSBCR is a valuable cultural record of a specific Late Neolithic community and provides significant insight into the interaction between settlement and ritual aspects of the Orcadian Late Neolithic. An understanding of these interactions is of crucial importance to a fuller interpretation of the WHS and to the wider discussion of the Orcadian Neolithic. The implications of this research to other WHS designated for their cultural value are discussed, together with future conservation considerations for this specific WHS.

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List of Abbreviations

HRGS	High Resolution Gamma Spectometry
IBZ	Inner Buffer Zones
ICOMOS	International Council on Monuments and Sites
OSL	Optically Stimulated Luminescence Dating
PSD	Particle Size Distribution
SSBCR	Soils and Sediments-Based Cultural Records
SUERC	Scottish Universities Environmental Research Centre
TSBC	Thick Source Beta Counting
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WHS	World Heritage Site

Chapter 1 - Rationale

1.1 Introduction

Soil is an important resource within a landscape and it is utilised by communities in settlement. The use of soil can be described as being culturally defined and is dependant upon the people groups, their knowledge and cultural practices within a landscape. It is the soil which provides the interface between the majority of early cultural activities associated with settlement and the physical landscape. Geoarchaeological investigations have demonstrated successfully that soils and sediments are able to retain significant information resulting from early settlement. From this it is possible to infer the cultural activities of past communities.

It is difficult to classify soils and sediments retaining a cultural record within any soil classification. For example, the term *anthrosol* may be applied to soils that have been modified profoundly by anthropogenic activities (Bridges 1997). When considering anthropogenic activities within a long term temporal framework however, it can be argued, at least within the United Kingdom, that the majority of soils have been influenced profoundly by anthropogenic activities and could therefore be classified as anthrosols. For the purpose of this research anthropogenic influence exerted upon the landscape and identified within soils and sediments is hereafter referred to as a 'soils and sediments-based cultural record' (SSBCR) when it can be directly related to specific cultural practices of a people group. This thesis differentiates between soils-based cultural records and sediment-based cultural records using definitions of soil and sediment which are common to soil science and environmental science (Gregorich *et al* 2001). A soils-based cultural record refers to a cultural record which has been imposed upon a pre-existing soil profile formed *in situ* upon the parent material. A sediment-based cultural record suggests transportation and is used in this thesis where sediment has formed entirely as a result of anthropogenic sedimentation processes. Anthropogenic horizons which are unable to be related to specific cultural groups are discussed as ‘anthropogenic horizons’. The elucidation of SSBCR through geoarchaeological analytical research has contributed to the understanding of past groups of people and their interactions with physical landscapes.

This thesis identifies the UNESCO 1972 Convention Concerning the Protection of World Cultural and Natural Heritage as the major global legislation concerned with conserving sites of outstanding natural or cultural value. This Convention is responsible for the designation of World Heritage Sites including those sites whose ‘outstanding cultural significance’ must be preserved for future generations (UNESCO World Heritage Centre 2006). It is recognised that human activity by past peoples must have had an effect upon soils, sediments and landscapes within and around sites now designated as World Heritage Sites for their cultural value. This thesis therefore postulates how soils and sediments should be considered and assessed as contributing to the overall cultural value preserved at World Heritage Sites and discusses the implications for the management of these SSBCR. This broad question is examined by considering The Heart of Neolithic Orkney World Heritage Site and its associated inner buffer zones, and uses research questions which are specific to this site, but which have a wider resonance.

1.2 Soil as a Cultural Record

It is widely accepted that soils do not occur by chance in a landscape, but that they develop and have properties resulting from the interplay of specific factors. Traditionally these factors have been identified as being the natural parent material, climate, vegetation, soil biota, topography and time (Jenny 1941, Fitzpatrick 1986). More recently, however, the importance of the effects of human activities in the formation of soil and the archaeological potential of soil has been recognised (Foster and Smout 1994, French 2003). Through interactions with the environment, and the exploitation and harnessing of its natural resources, human beings have incessantly modified soils and in so doing have defined the modern 'cultural landscape' in which soils are situated (Foster and Smout 1994). The modification of soils through anthropogenic activities is identifiable at various geographical scales including, for example, within site formation processes, within arable field systems and across extensive communal rangelands (Foster and Smout 1994, French 2003).

Different cultural groups utilise and modify their soil resources in differing ways. As a result, information regarding these practices and retained within soils, can help elucidate the nature of human influence upon the environment and landscape, providing information concerning cultural land use and insight into the behaviour of past communities (Goudie 1993). When considering this retention of cultural records within soil, it is perhaps surprising that the potential value of soil in contributing to an understanding of past communities has not been fully appreciated or incorporated into a global conservation strategy. However, in the absence of any appropriate global conservation strategy, geoarchaeological research has been at the forefront of investigating the cultural record retained within soils and sediments using palaeosols associated with archaeological sites.

Geoarchaeology is the combined study of archaeological and geomorphholological records and the recognition of how natural and human induced processes alter landscapes (French 2003). As a result of geoarchaeological research, there is now a wide body of evidence to suggest that soil has the ability to retain significant cultural information pertaining to its formation and utilisation within anthropogenic activities. Examples of the identification and interpretation of cultural records through geoarchaeological research evident within a North Atlantic context of temperate climate and northerly latitudes (the region in which Orkney is located). In the Outer Hebrides, geoarchaeological research has identified palaeosols within coastal sands which retain evidence of anthropogenic amendment (Ritchie 1979, Whittington and Edwards 1997). Some of these palaeosols have been amended by Bronze Age and Iron Age communities and have been used to identify periods of localised stability and soil formation within the coastal sands (Gilbertson *et al* 1999). Geoarchaeological research into relict arable soils dating from *c*700 AD in the agriculturally marginal landscape of Lofoten, northern Norway, has indicated the deliberate management of erodible sandy soils in sloping locations to create areas suitable for cultivation (Simpson *et al* 1998b). This indicates that despite the climatic and economic marginality of arable land activity in Lofoten, land management practices were developed and applied to permit barley production from small areas. In Iceland, geoarchaeological research has been of use in interpreting archaeological features (Simpson *et al* 1999b) and has contributed to the understanding of settlement abandonment (Simpson *et al* 2004). It has also identified the fuel resources utilised at settlement sites in Iceland and has contributed to the discussion of a social regulation of these fuel resources (Simpson *et al* 2003).

Geoarchaeological research has successfully identified and interpreted various cultural records retained within soils and sediments in Orkney (Figure 1). This has made significant contributions to the knowledge and understanding of the resource selection and land management of past communities from the Late Neolithic/Early Bronze Age (*c*3000-2000 BC) through to the Early-Modern Period (*c*1800 AD). At Tofts Ness, Sanday (Figure 1), anthropogenic soils have been identified as being associated with Bronze Age activity. Analysis indicates that formation was deliberate, through the application of grassy turf material together with domestic waste (Simpson *et al* 1998b). This indicates that people in Bronze Age Orkney had an understanding of the need to actively increase the fertility of the land and minimise land degradation, suggesting that they possessed significant environmental knowledge in order to farm in this locality. It is likely that it was the application of manuring techniques at Tofts Ness that allowed arable activity in what was a highly marginal farming environment (Simpson *et al* 1998b). Further research at Tofts Ness has provided additional insight into the manuring practices of Bronze Age people at this site. The primary faecal matter added to the soil was identified as being derived from humans with a limited porcine input (Bull *et al* 1999). These results highlight the importance of human faecal inputs within arable land management strategies, but also indicate the importance of pigs to the Bronze Age community.

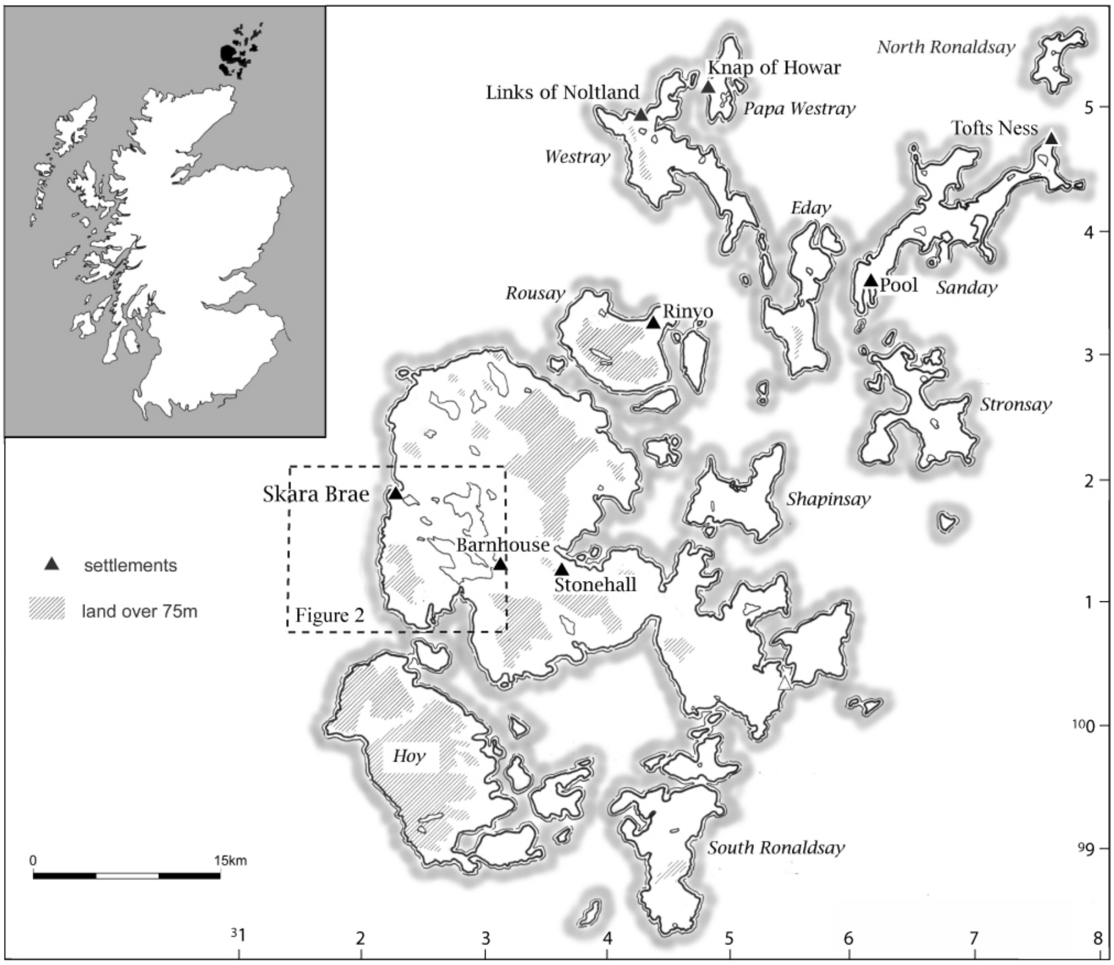

Figure 1 Geographical location of Neolithic settlements on Orkney. Adapted from Simpson *et al* 2006

On mainland Orkney, deepened top soils have been identified associated with the Bilbster soil series (Macaulay Institute for Soil Research 1981). These deep top soils have been established as anthropogenic in origin and are dated as being formed between *c*1200 and *c*1800 AD (Simpson 1997). These cultural soils have enabled an interpretation of infield land management practices in the Marwick area between *c*1200 and *c*1800 AD, suggesting a degree of organisation and regulation within the cultural landscape (Simpson 1997). They provide clear insight into past agricultural practices having formed from a manuring practice which involved the application of grassy turf material from hill land with composted domestic livestock manure and a minor seaweed element (Simpson 1997). Further research testing the extent to which free soil lipids reflect known manuring practices has allowed specific organic manure inputs to be identified (Simpson *et al* 1999a). The results clearly demonstrate the application of composted turf and ruminant animal manure to the deep top soil area and also identify the presence of porcine manure. The identified porcine manure is suprising when compared to the manuring inputs identified within historical documentation and, as at Tofts Ness highlights the importance of pigs to these communities. These studies suggest that this manuring was deliberate, though apparently not uniform across the landscape and consequently suggests a degree of resource organisation and regulation within the community.

Geoarchaeological investigations on Orkney and elsewhere in the North Atlantic region have clearly demonstrated that soils and sediments are able to retain cultural records, the elucidation of which has furthered the understanding of the cultural activities of past communities from the Late Neolithic/Early Bronze Age through to the Early-Modern period. It is suggested that the identification and analyses of any Neolithic anthropogenic soils and sediments through geoarchaeological research would contribute to the Orcadian Neolithic cultural record.

1.3 Neolithic Orkney

Much has been written and discussed concerning the Orcadian Neolithic with great emphasis being placed upon the interactions between Neolithic Orcadians and the landscape and associated monuments (Renfrew 1985 and Ritchie 2000). This is in many ways inevitable as Orkney is without doubt represented by the most diverse and complete material record of the Late Neolithic period in the British Isles. Given its archaeological wealth, it is unsurprising to see particular areas selected for social analyses. There is still great debate, however, surrounding these social analyses and the idea of 'culture' within the Neolithic.

Renfrew (1979) argues for a segmented society, a landscape composed of individual people groups which were clearly defined, operated independently and exercised control over their own productive resources. In addition to this it is argued that the later large monuments and henges were built as a result of centralising tendencies around 2700 BC. A reappraisal of past excavations and recent results from Pool, Stonehall and Crossietown (Figure 1) continues to challenge this model of societal development and it is now clear that a wide variety of settlement forms characterised the Neolithic period in Orkney (Card 2005). This recent research into Neolithic Orkney continues to demonstrate a far more complex situation than was previously considered and it is apparent that the neat period packaging of particular forms of settlement pattern, social organisation and material culture is breaking down under renewed exploration (Richards 1999, Card 2004). It now seems likely that a wide variety of settlement forms existed in Neolithic Orkney and that these settlement forms varied greatly in their material culture, including architecture and spatial organisation.

Discussion concerning Orcadian Neolithic and Early Bronze Age cultural identities has tended to focus upon the activities involved in the construction of a dense concentration of structural archaeological monuments. These include the chambered tomb of Maeshowe and the henge monuments at Stenness and Brodgar within what has been termed a ritual landscape (Card 2005). Richards (1990) highlights that it is perhaps inevitable that it is the monuments, both chambered tombs and henge monuments that have provided the basis for previous social analyses. In addition to this, however, it is suggested that Orkney provides an excellent, perhaps unique opportunity to provide insight into the relationship between ritual and domestic life in both the Orcadian and broader Neolithic contexts (UNESCO World Heritage Centre 2006, Card 2004, Richards 1990). Richards (2005) has begun to address this research opportunity and has succeeded in bringing together the monumental and the domestic into a coherent relationship, albeit focused upon the local context of Barnhouse Neolithic Settlement. This provides a compelling case of the importance for this Neolithic village to the construction and subsequent utilisation of the monuments. Furthermore, Richards (2005) has begun to highlight the importance of domestic cultural resource use and the impact of Neolithic people upon the environment surrounding settlement as contributing to the discussion of Neolithic cultural identity. Cultural identity in Late Neolithic Orkney was clearly expressed at multiple levels but the majority of people's lives must have revolved in and around the settlement (Louwe Kooijmans 2000). Anthropogenic soils and sediments may represent SSBCR and can therefore contribute greatly to our understanding of Neolithic cultural activities, particulary within construction, the utilisation of fuel resources and within the production of food.

1.3.1 Soils and Sediments in Construction

The Heart of Neolithic Orkney has been designated a WHS because of its Late Neolithic and Early Bronze Age monuments. It is apparent that soils and sediments have been utilised and disturbed in the construction of these monuments. The creation of ditches, for example, around the Stones of Stenness and Maeshowe involved the removal of a significant volume of soil and questions remain as to why ditches were required around these monuments and indeed where the soil from these ditches was re-deposited. Recent research has also identified that a substantial volume of clay from the Loch of Harray was used to level and form the oval platform prior to the construction of the chambered tomb of Maeshowe (Challands *et al* 2005).

Excavations at Neolithic settlement sites in Orkney have observed deliberate and varied uses of cultural sediments (traditionally referred to under the blanket term midden) as being incorporated into site construction (Simpson *et al* 2006). Childe and Grant (1946) describe midden material as being used to create artificial terraces for settlement construction in steeply sloping areas at Rinyo, Rousay (Figure 1). At the Knap of Howar, Papa Westray (Figure 1), areas of existing midden had been cleared from the floor of a structure and these deposits were then used as a wall core between dry stone walling, contributing to a stable and weatherproof structure (Ritchie 1984). Excavations at the Links of Noltland, Westray (Figure 1) also show the use of cultural sediments in site construction (Clarke and Sharples 1985). At Barnhouse Neolithic Settlement, double-skin dry stone walls are free standing but are surrounded by turf from nearby pastures with additions of lacustrine silt derived from the adjacent loch and only minor amounts of midden evident (French 2005).

More recent research concerning the cultural sediments involved within the construction of Skara Brae identifies a complex relationship between construction and the cultural sediments. The foundations of both earlier and later structures are countersunk into cultural sediments and the double dry stone walling is packed with these cultural sediments. There is also evidence of cultural sediments accumulating against structures (Clarke 1976). Further analysis of samples from these cultural sediments identifies specific resource selection by Neolithic settlers. Cultural sediments incorporated into the construction of the earlier phases of settlement are dominated by peat/turf fuel residues with the later settlement incorporating a wide range of household waste materials which may have been used to help stabilise increasing sand blow. Silty clay material mixed with a very small amount of household waste is associated with wall construction and is readily distinguishable from the more mixed sediments that form the matrix to settlement construction (Simpson *et al* 2006). In contrast, cultural sediments which are not directly associated with structures contain large quantities of household waste and a significant herbivore dung content (Simpson *et al* 2006). This research has identified specific resource selection within Neolithic settlement activity, and the absence of dung material within those materials selected for use within settlement construction may suggest a different post-depositional function within Neolithic settlement activity.

1.3.2 Soils and Fuel Resource Utilisation

An adequate supply of fuel is, of course a prerequisite for subsistence and the presence of hearths in early settlements such as Skara Brae clearly demonstrates that Neolithic Orcadians utilised fuel resources (Clarke and Sharples 1985). Fuel residues form major components of Late Neolithic cultural sediments, usually termed middens. The term midden is applied broadly within archaeology, referring to deposits containing domestic waste from settlement activity.

Cultural sediments (midden) containing a high fuel ash content have been identified at the Links of Noltland, the Knap of Howar, Pool, Tofts Ness and Skara Brae, although the characterisation of specific fuel resources within these cultural sediments has not been routinely undertaken (Clarke and Sharples 1985, Hunter 2000, Simpson *et al* 1998b and Simpson *et al* 2006). It has previously been assumed, at least at the settlement of Skara Brae, that it was peat that constituted the major fuel resource in the Late Neolithic, although others have argued that the growth of peat suitable for burning did not begin on Orkney until after this period (Clarke and Sharples 1985). Recent research (Simpson *et al* 2006) appears to ratify the assumption with regards to the utilisation of peat as a fuel at Skara Brae. However, questions as to the range of fuel resources utilised at other Neolithic settlements on Orkney and the interaction of Neolithic settlers with the land surrounding settlement sites remain as yet unanswered. An opportunity exists here for further study regarding the utilisation of fuel resources by Neolithic communities.

1.3.3 Soils, Sediments and Food Production

The need for sustainable food production may have been especially important within this ritualistic landscape, where the building of even a modest tomb must have entailed considerable physical strain. Renfrew (2000), comments that the first settlers to Orkney are likely to have been the first farmers with cereal plants, sheep and cattle. This supports the view of Ritchie (1985) that the first settlers to Orkney practised mixed farming, as further evidenced by research from Barnhouse Neolithic Settlement (Hinton 2005). This previous research work identifies organic residues from pottery and charred plant remains thereby indicating that the diet included milk and cereals along with other edible wild plants, including hazelnuts and crab apples, which are likely to have been harvested from the vicinity of the settlement. There is also evidence to suggest the importance of barley to diet and the location of bones of cattle, pig and sheep or goat in and around the settlement suggests that these animals were an important food resource (King 2005). Late Neolithic pollen assemblages at Maeshowe, for example, consist of a substantial amount of ribwort pollen but also that of cereals, and are interpreted as reflecting mixed agricultural practice, probably with a pastoral bias (Davidson and Jones 1985). Indeed it is argued that it was the domestication of animals along with the exploitation of wheat and barley resources that are the principal defining features of the Neolithic period (Whittle 1999).

Evidence for animal domestication and the increasing use of wheat and barley within the Neolithic raises questions concerning land resource use and management by Neolithic people. It implies that the land around the settlement must have been used and valued as pasture and arable land by Neolithic setters in Orkney (Ritchie 1985). Faunal assemblages associated with Late Neolithic Orcadian settlements indicate that the animal husbandry appeared to have involved roughly equal proportions of cattle and sheep, with only a small number of pigs. This is supported by evidence from Barnhouse Neolithic Settlement where the faunal assemblages consisted of cow, sheep and/or goat and pig (King 2005). Evidence from Skara Brae suggests that a large percentage of the cattle were slaughtered at the end of their first year. This may suggest an animal husbandry management system which involved the slaughtering of cattle as a response to inadequate supplies of winter fodder. Certainly the availability of winter fodder has been identified as being of critical importance to settlement sustenance within later settlements in the North Atlantic (Simpson *et al* 2004). Animal husbandry was clearly important to the Orcadian Neolithic but as yet research has not identified specific management practices associated with pastoral land management. Excavations have not identified byres for housing cattle over the winter and the construction techniques of the houses excavated precludes the possibility of animals and humans sharing the same accommodation, which has been a practice in the more recent past (Clarke and Sharples 1985).

The importance of barley to Neolithic settlers has been well illustrated by evidence including that from Barnhouse Neolithic Settlement. It is suggested that this barley was produced locally, however, there remains little evidence to indicate how and where this barley was cultivated (Hinton 2005). It has been suggested that at Barnhouse Neolithic Settlement cereals may have been grown in small arable plots adjacent to the settlement within an infield system (Jones and Richards 2005). At present this hypothesis remains untested but it is without doubt that Neolithic settlers utilised the resources around settlement sites in order to produce food and that the land around settlement sites was identified as having high value to the sustenance of the settlement. A question remains however, as to whether the land and soil resources around settlement sites were simply exploited or deliberately managed in such a way as to provide sustainable food production.

When considering the management of areas around Neolithic settlement sites for a sustainable food resource it is apparent that sites with good assemblages of subsistence data are rare, making the interpreting of deliberate management practices difficult (Whittle 1999). Furthermore, with the ambigious exception at Pool (Card 2005, Hunter 2000), there is very little evidence for the intensification of cereal cultivation or indeed any agricultural intensification within the Neolithic period on Orkney. The range of subsistence residues in the Later Neolithic settlements such as Skara Brae does not appear to differ greatly from those seen in earlier structures such as the Knap of Howar, Papa Westray, although it is without doubt that new resources became available during this period (Whittle 1999). These new resources included cultivated cereals, principally wheats and barleys. The relative importance of these cereals and the impact of any deliberate agricultural practices upon the Neolithic society remain to be established.

There is some evidence that indicates the practice of deliberate cultivation and land management for cultivation around settlement sites in Neolithic Orkney. The area around Links of Noltland has been identified as being intensively cultivated in the Neolithic over a period of some time. Ard marks indicate that the land has been ploughed and a considerable volume of cultural sediment (midden) has been found in the ploughed soil (Clarke and Sharples 1985). It seems clear that one of the important functions of this cultural sediment (midden) was as a fertiliser on the fields, which implies an apparent recognition for the need to fertilise the soil. The idea of using midden material as fertiliser is further re-enforced by the presence of 1100 m^2 of midden enriched soil being found around the Links of Noltland (Clarke and Sharples 1985). This large area of soil suggests a deliberate and systematic approach to the process of fertilising, involving high inputs of labour. Questions remain as to why and how early settlers were involved in this process.

Despite the evidence that suggests that cultural sediment (midden) was deliberately added to soil in order to fertilise it, there are still many unanswered questions. It is possible that the use of these cultural sediements to fertilise represents localised cultural knowledge which, in a possibly segregated society, may result in only some communities adopting this practice. This provides an opportunity to investigate the cultural knowledge of specific communities. Simpson *et al* (2006) provide evidence to suggest that different Orcadian Neolithic communities utilised cultural sediments (midden) in different ways in settlement construction; implying that Neolithic people were making distinct choices in their resource utilisation. At Skara Brae there is no evidence of animal manures being used in the construction process which raises the question as to whether or not animal manures were preferentially used to manure arable field systems. It is anticipated that different Orcadian communities utilised different waste materials in the enhancement and fertilisation of land around the settlement. At present there has been no attempt to identify the content of the cultural sediments (midden) which have been used as a fertiliser and this is therefore a potential area for further research.

The incorporation of cultural sediments (midden) into arable soils suggests the deliberate use of soil and its potential management as a resource in order to grow food, although it is entirely conceivable that it was the cultural sediment (midden) itself which was regarded as the resource and cultivated within agricultural practices such as at Tofts Ness (Guttman 2001, Guttmann *et al* 2006). Either way, it suggests that food was deliberately grown as is demonstrated by the carbonised plant remains recovered from Skara Brae and Barnhouse Neolithic Settlement, which are dominated by barley (Sharples 2000, Hinton 2005). This view of systematic fertilising around settlements is enhanced by the cultural sediments (middens) surrounding the Knap of Howar settlement. At this site the houses are flanked on either side by cultural sediments (middens) which have been spread out to a uniform thickness of 0.35 m over an area of 500 m^2 (Clarke and Sharples 1985). It would appear that around at least some Neolithic settlement sites, deliberate systematic fertilisation of soils was taking place. It is possible that this practice contributed to the success of more complex Neolithic settlement sites such as Skara Brae which has been described as a product of a ‘confident farming community’ (Ritchie 1985). This emphasises the potential importance of the use of the surrounding land to the success of the settlements in the Neolithic cultural landscape.

1.4 Conserving Orkney's Neolithic Cultural Record

The conservation of Orkney's structural Neolthic record is not a new phenomenon. Under increasingly intensive and changing agricultural practices the Stones of Stennes and the Ring of Brodgar were brought into state care of HM Office of Works in 1906 and were subsequently restored with many of the fallen stones being re-erected. Skara Brae was placed under the guardship of HM Office of Works in 1924 and consolidation work was undertaken to stabilise the settlement structures (Card 2005). More recently, the designation by UNESCO of The Heart of Neolithic Orkney World Heritage Site has ensured the future conservation of the dense concentration of Late Neolithic and Early Bronze Age structural archaeological monuments located on mainland Orkney. These monuments include the chambered tomb of Maeshowe and the henge monuments at Brodgar and Stenness.

1.4.1 World Heritage Site (WHS) Designation

In 1972 the General Conference of the United Nations Educational, Scientific and Cultural Organisation (UNESCO) adopted the 'UNESCO 1972 Convention Concerning the Protection of the World Cultural and Natural Heritage' (UNESCO World Heritage centre 2006). The primary aim of this Convention is to define and conserve natural and cultural heritage by drawing up a list of sites whose outstanding values should be preserved for all humanity and to ensure their protection through a closer co-operation among nations (UNESCO World Heritage Centre 2006). The list is known as the World Heritage List and in order to be adopted onto the list as World Heritage, a site must satisfy the selection criteria adopted by the World Heritage Committee (Appendix A). The World Heritage Committee consists of representatives from 21 State Parties, and is the statutory body responsible for selecting and protecting World Heritage Sites (WHS).

The criteria required of a proposed WHS are that it is a site of outstanding universal natural or cultural value. According to the World Heritage Convention cultural heritage is defined as 'a monument, group of buildings or site of historical, aesthetic, archaeological, scientific, ethnographical or anthropological value' while natural heritage is further defined as a site which 'designates outstanding physical, biological and geological features; habitats of threatened plants or animal species and areas of value on scientific or aesthetic grounds or from the point of view of conservation' (UNESCO World Heritage Centre 2006). Mixed sites are recognised as containing both outstanding natural and cultural values and since 1992 significant interactions between people and the natural environment have been recognised as cultural landscapes (UNESCO World Heritage Centre 2006).

As of 2007 there are 830 designated WHS in 184 State Parties in the world (UNESCO World Heritage Centre 2007). Only 162 of these sites are designated because of their outstanding natural heritage including sites such as the Grand Canyon (USA) and the Galápagos Islands (Ecuador). The vast majority of WHS (644), including The Heart of Neolithic Orkney have been designated because of their outstanding cultural value, providing a portal into man's rich ancestral past, with 24 sites designated as mixed properties. Sites designated because of their outstanding cultural value are varied and do include archaeological sites. Examples are found on all continents and include Stonehenge in England, dated as being built 3100 BC and whose 'astronomical' cultural significance is still being explored (English Heritage 2003), L'Anse aux Meadows in Newfoundland Canada which is the remains of an 11th century Viking settlement providing evidence of the first European presence in North America and the cultural landscape and archaeological remains of the Bamiyan Valley in Afghanistan which represent artistic and religious developments from the 1st century to the 13th century (UNESCO World Heritage Centre 2006).

At present the designation of WHS under United Nations legislation remains the principal international and formally recognised strategy allowing the conservation of sites of cultural value within the world. However, despite the great variety of sites that have been designated as World Heritage due to their international cultural significance, it appears that at present there has been no explicit consideration for the potential cultural value of soils and sediments within WHS nominations or subsequent management plans. The probable cultural records of anthropogenic soils and sediments and the cultural value of such records does not appear to be promoted by UNESCO, who have no documented knowledge of any research into SSBCR associated with any WHS designated for cultural value (Schenk *pers comm.* 2003). Despite this, however, there has been geoarchaeological research which has been conducted upon the WHS of St Kilda, Scotland (Meharg *et al* 2006). Although this contributes to the cultural value preserved upon St Kilda, the research was undertaken prior to the designation of St Kilda as a mixed WHS, with the recognition of its cultural value alongside the previously identified natural value. This research does not therefore appear to have been advanced by UNESCO for the conservation of the cultural value of St Kilda, but it does demonstrate that it is entirely feasible that research concerning SSBCR is being conducted within and around World Heritage Sites designated for their cultural value.

1.4.2 The Heart of Neolithic Orkney World Heritage Site (WHS)

The archaeologically important The Heart of Neolithic Orkney, located upon mainland Orkney, was inscribed as a WHS in 1999. It was justified for inscription as a WHS because of the monuments of Orkney, dating back to 3000 – 2000 BC, which are recognised as being an outstanding testimony to the cultural achievements of the Neolithic peoples of northern Europe (UNESCO World Heritage Centre 2006). The WHS itself comprises six, geographically discrete elements which are located within two geographically separate inner buffer zones (IBZ) drawn fairly tightly around the principal monuments (Foster and Linge 2002, Figure 2).

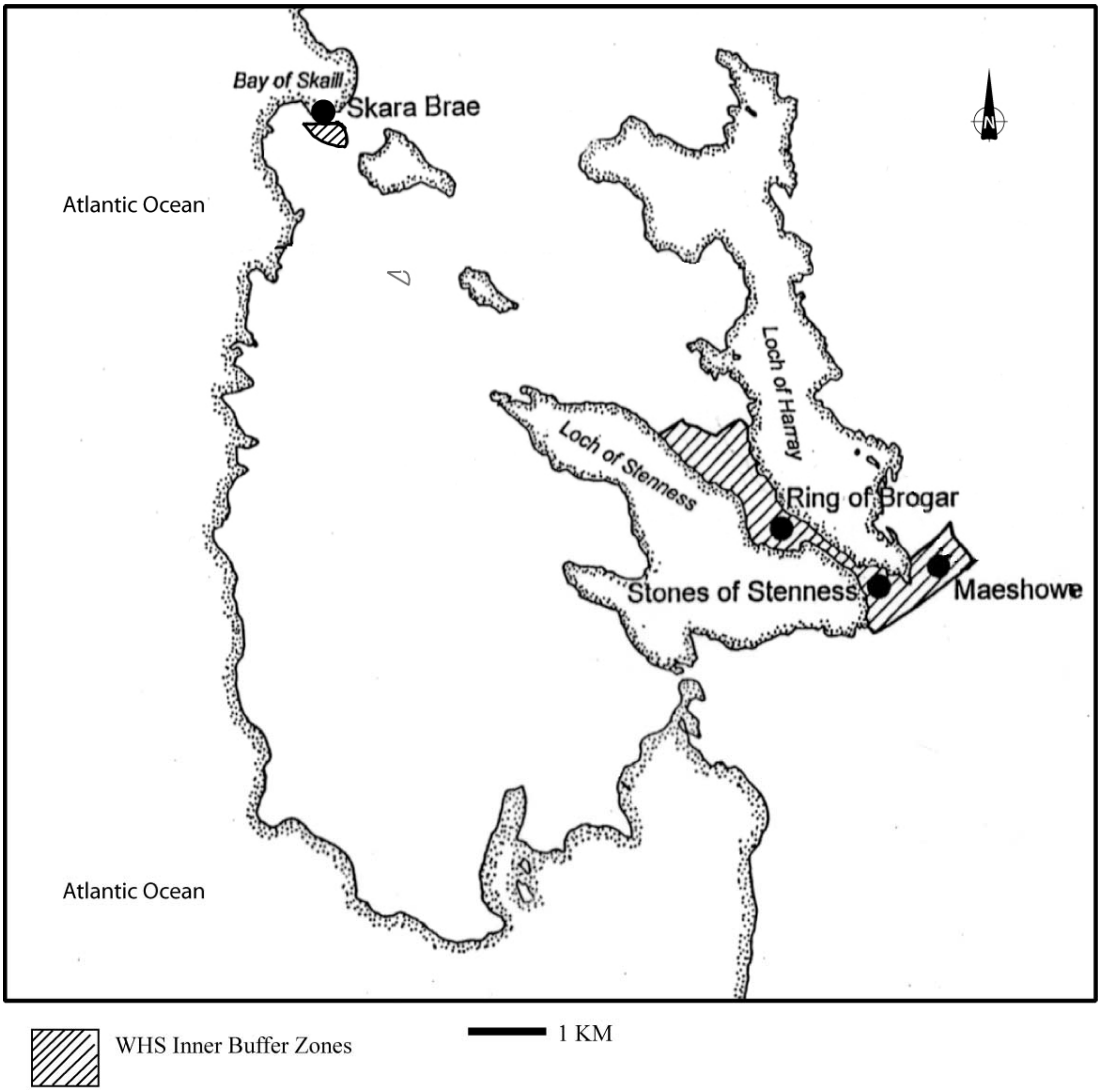

Figure 2 Geographical extent of the WHS IBZ

The Neolithic settlement of Skara Brae is located within one inner buffer zone (IBZ) on the west coast of mainland Orkney (Figure 3), whereas the chambered tomb of Maeshowe, the Stones of Stenness, along with the associated Watch Stone and Barnhouse Stone and the Ring of Brodgar with its associated monuments, are located within the other inner buffer zone (IBZ) located between the Lochs of Stenness and Harray (Figure 4).

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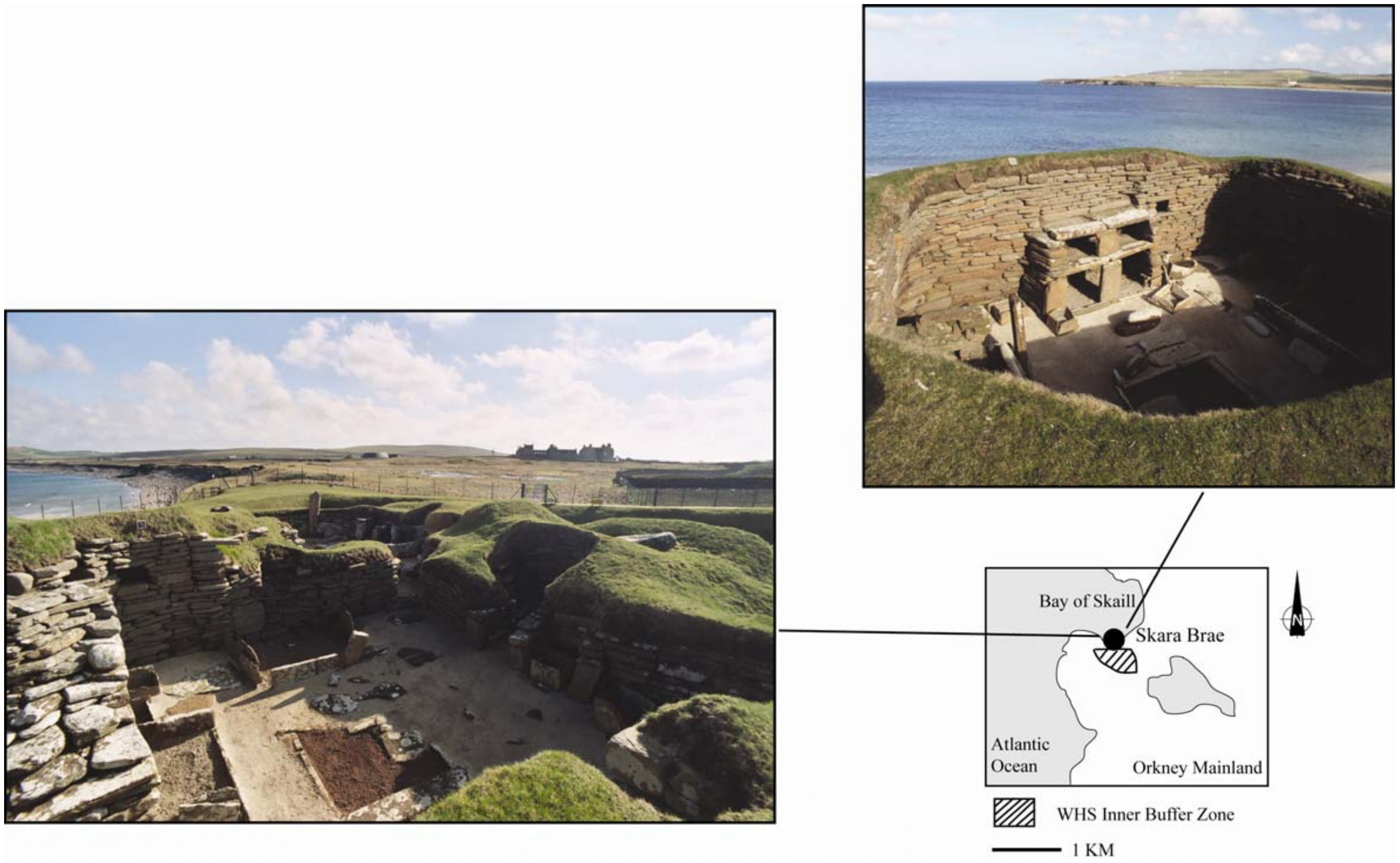


Figure 3 The WHS Neolithic Village Skara Brae. Adderley *pers comm.*

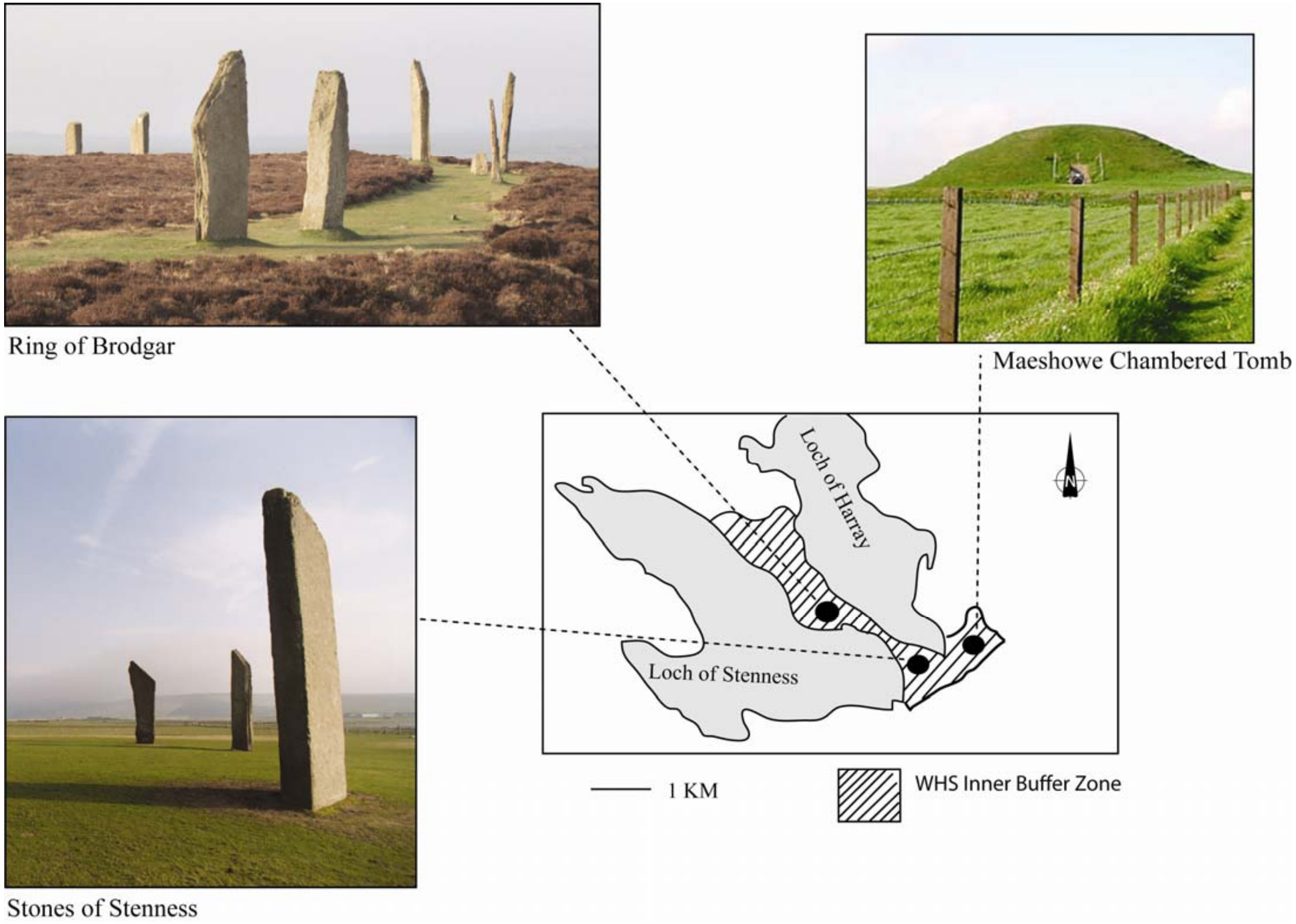


Figure 4 WHS monuments within the Brodgar IBZ. Adderley *pers comm.*.

Both the IBZ's are further incorporated into outer buffer zones. The outer buffer zone at Skara Brae is defined by the curtilage of a nearby category A listed building, Skaill House and the outer buffer zone at Stenness/Brodgar is defined by a national landscape designation, the Hoy and West Mainland Scenic Area. The formation of buffer zones around WHS is encouraged by UNESCO but these buffer zones have been designated by Historic Scotland who followed advice from The International Council on Monuments and Sites (ICOMOS UK), and used existing statutory designations to define the boundaries of the two levels of buffer zone. This two tier buffer zone was principally designated with the intention to protect the immediate setting of principal sites and areas of high archaeological value, as well as their wider landscape setting (Foster and Linge 2002). In terms of protection therefore, the IBZ carries more stringent controls than the outer buffer zone and its presence does acknowledge that the discrete sites which comprise the WHS are located within a wider archaeological landscape. The research described in this thesis has taken place within the IBZ associated with the WHS. It is worth emphasising that the buffer zones are designated as administrative technical terms appropriated for the future management of the WHS and are not archaeological terms. The designated inner and outer buffer zones do not therefore have any archaeological significance or represent any archaeological boundaries.

1.5 Research Opportunities

The previous discussion has allowed the identification of several opportunities for geoarchaeological research to make significant contributions to further the understanding and preservation of the cultural value conserved within The Heart of Neolithic Orkney WHS. These research opportunities can be broadly grouped under the following headings:

1.5.1 The Identification of Soils and Sediments-Based Cultural Records (SSBCR)

The monumental structural Neolithic cultural record is obvious within the IBZ. The WHS monuments along with the landscape within the IBZ constitute a major cultural landscape whose archaeological importance is enhanced by the concentration of well-preserved settlement and ritual sites in close proximity to one another (UNESCO World Heritage Centre 2006). It has been argued that Neolithic people utilised soil as a resource during the settlement process and that the properties of soils and sediments within the IBZ have therefore been influenced by Neolithic activities. The identified influence is hereafter referred to as a SSBCR when it can be related to specific cultural practices of specific cultural groups. This research considers it most probable that some record of Neolithic activities within this landscape will be retained within soils and sediments resulting in SSBCR within the WHS IBZ.

1.5.2 The Interpretation of Soils and Sediments-Based Cultural records (SSBCR)

The identification in itself of SSBCR is of significance to geoarchaeological research but, it is the potential for this to further our understanding of people within landscapes which is of arguably greater value. Despite the anticipated Neolithic influence upon this landscape it is entirely feasible and indeed most probable that SSBCR will be identified within the IBZ which have formed as a result of much later anthropogenic activities than those associated with the Neolithic period. The landscape within the IBZ contains clear evidence of multiperiod landscape utilisation from the Late Neolithic through to present day (Card 2005). An opportunity exists therefore to determine the period of formation of any identified SSBCR in order to correctly assign the anthropogenic activities involved in the formation and utilisation of the SSBCR to the correct societal group.

Two important research areas involving the elucidation of this information from SSBCR are firstly, the materials and processes involved with the formation of the record, and secondly, the function of the SSBCR with regards to the community and possibly wider society responsible for its formation. It is anticipated that the integration of multiple analytical techniques will lead to scientifically robust data allowing the materials and processes of formation of any identified SSBCR to be clearly identified. It has been demonstrated within geoarchaeological research that the integration of individual analyses greatly increases the security of such interpretations (Courty *et al* 1989).

The determination of any post-depositional function associated with SSBCR, is more problematic and is likely to lead to more subjective interpretations and conclusions. The combination of qualitative research including historical literature with analytical results and the identification of specific features within thin section has been successfully combined to determine the post-depositional arable function of the deepened soils in West Mainland Orkney (Simpson 1997). Within the wider context of identifying a post-depositional function of a SSBCR, interpretational security is therefore potentially limited, both by the absence of historical literature, and by inability to identify historical and pre-historical processes that have acted upon the soil. This has implications for the interpretation of any post-depositional function of Neolithic SSBCR, where no documentary evidence exists to aid interpretations of post-depositional function. Any identified SSBCR must however be interpreted within the context of all available archeological evidence, which may support a particular post-depositional function.

1.5.3 Research Questions

The discussion of research opportunities has resulted in the development of the following specific research questions that have been addressed at four field sites within the WHS IBZ.

1) What evidence is there of a SSBCR?

After this research question has been substantiated, the research questions listed below are discussed.

2) What was the period of formation of the SSBCR?

3) What were the materials and processes involved in the formation of the SSBCR?

4) What is the post-depositional function of the SSBCR to the community responsible for its formation?

To facilitate the interpretation of data sets where there was ambiguity, multiple working hypotheses were used to help address the research questions.

This thesis is comprised of nine chapters including this introductory chapter. Chapters 2 and 3 discuss appropriate field sites and geoarchaeological analyses, including methodologies utilised to answer the specific research questions. Chapters 4 identifies and discusses appropriate control sites for this research and chapters 5-7 discuss the identification and interpretation of SSBCR at individual sites within the WHS IBZ. These chapters display field observations followed by results of analytical analyses which are then intergrated into discussions concerning the period of formation, the materials and processes of formation and any post-depositional function associated with the SSBCR. Chapter 8 does not identify SSBCR, but identifies and discusses a palaeo-environmental record in the IBZ surrounding Skara Brae. Chapter 9 discusses the conclusions of this research in relation to the initial research questions. This chapter concludes by identifying the effects of recent agricultural practices upon SSBCR and suggests appropriate agricultural practices for the conservation of these cultural records.

Chapter 2 - Research Design I; Field sites and Chronology

This chapter identifies potential field sites within The Heart of Neolithic Orkney WHS IBZ from which to address the research questions identified in Chapter 1. It identifies the need for appropriate control sites and discusses the identification and subsequent utilisation of appropriate control profiles. The theoretical and methodological approaches to determining the period of formation of SSBCR using the chronological techniques of radiocarbon analyses and optically stimulated luminescence analysis are also discussed.

2.1 Field Sites

Orcadian soils have predominantly formed from Devonian Middle Old Red Sandstone under climatic conditions dominated by a high frequency of strong winds and high annual precipitation. Climatic data between 1961 and 1990 identifies rainfall of greater than 1 mm an average of 183 days per annum and annual precipitation often exceeds 1000 mm (Met Office 2006). Soils within the Brodgar IBZ are predominantly freely drained and imperfectly drained podsols referred to as the Bilbster Soil Series. These soils have formed from glacial drift derived from flagstones and sandstones, mudstones and limestones of the stromness Flags and Rousay Flags of the Middle Old Red Sandstone. Some drainage impedance is common within the Bilbster soil series and the dominant process of gleying is evident within soils at a low altitude, which are in close proximity to the water table (HY 290 138). The IBZ surrounding Skara Brae in the Bay of Skaill is composed almost entirely of calcareous sand which has been deposited by aeolian deposition (Macaulay Institute for Soil Research 1981).

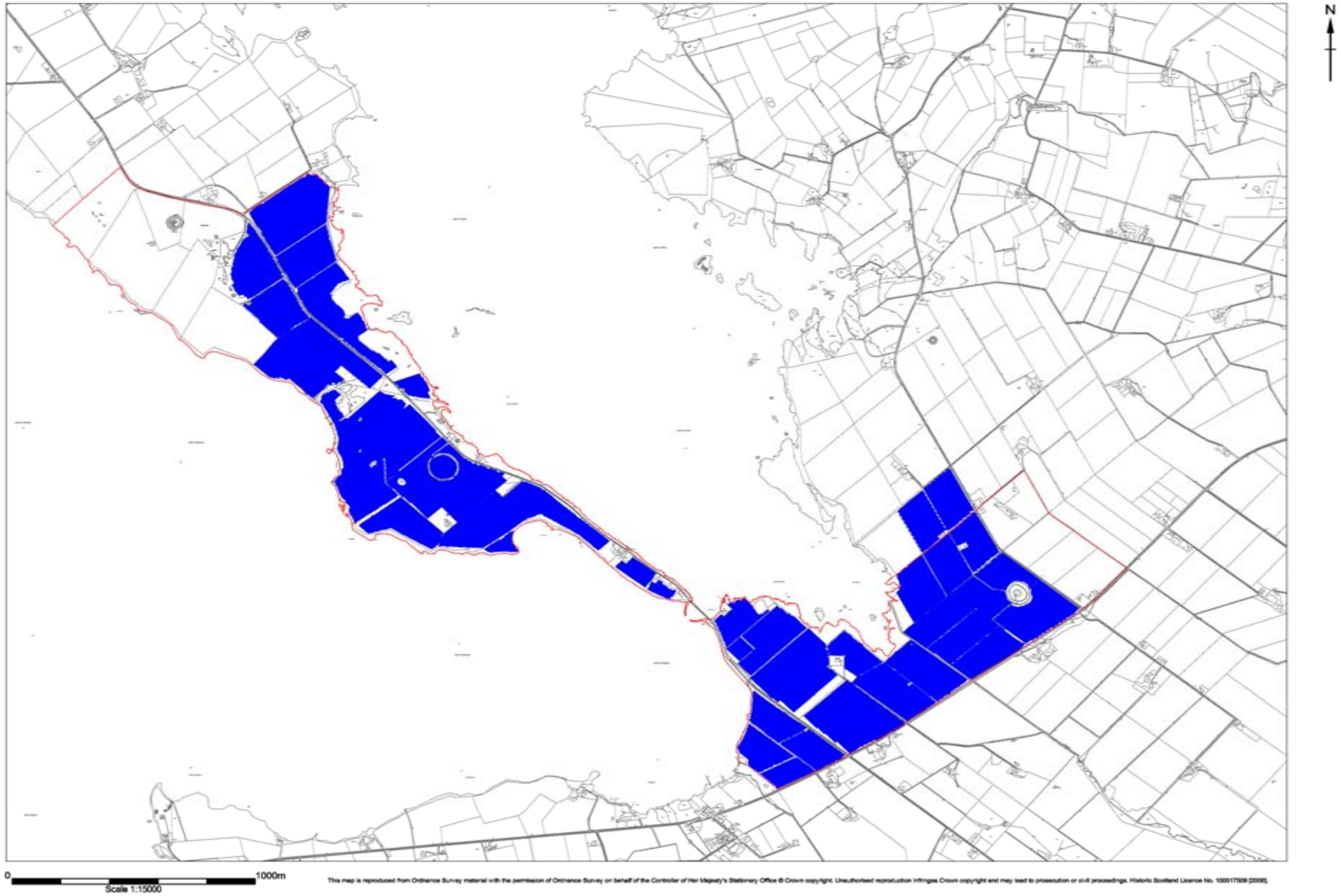
It has already been argued that settlement was the key process of habitation and as such provides a focus for the interaction of Neolithic people with the landscape. Field sites for this study were therefore located around settlement sites within the WHS IBZ in order to investigate SSBCR resulting from cultural activities involved in early settlements. It was anticipated that any Neolithic SSBCR associated with land management strategies or resource utilisation would be closely geographically associated with Neolithic settlement sites.

2.1.1 Identification of Settlement Sites

Some Neolithic settlement sites are already obvious within the WHS IBZ. Neolithic settlement sites such as Skara Brae have already been excavated, as has Barnhouse Neolithic Settlement (French 2005). Geophysical surveying within the World Heritage Area Geophysics Programme, a project proposed as a long term strategy to geophysically survey an extensive area within the WHS IBZ as part of the continued research into the WHS, has also indicated the possibility of further areas of archaeological interest within the WHS IBZ (See Gater and Shiel 2002, 2003 and 2004 and Orkney College Geophysics Unit Survey Reports 2004 and 2005 for full geophysical survey reports).

Geophysical surveying is a non-destructive means of probing for artefacts and features from above the ground, by searching out the sizes, shapes and extents of differences detectable to physical sciences (Nishimura 2001). The method of survey used within the WHS IBZ is magnetometry (Downes *et al* 2005). Magnetometry is the technique of measuring and mapping patterns of magnetism in the soil. If there is a magnetic contrast between a feature and the surrounding soil, there will also be a slight difference in their effect on the Earth's magnetic field, which can be detected by magnetometer surveys. Ancient activity, particularly burning, produces Iron Oxides (Fe_2O_3 and Fe_3O_4) which are the most widely distributed strongly magnetic substances on the earth's surface. Buried features such as ditches or pits, when they are filled with burnt or partly burnt materials can show up clearly and give an image of sub-surface archaeology (Gaffney and Gater 2004).

During 2002, the first phase of this geophysical survey was carried out with the aim of establishing the nature and extent of the buried archaeology in the landscape surrounding four of the sites that make up the WHS; Skara Brae and Maeshowe were not included in this stage. This geophysical survey was extended in 2003 to examine the nature and extent of the buried archaeology in the landscape surrounding the Stones of Stenness, The Ring of Brodgar and Maeshowe, and the area of survey has been extended yearly to other areas within the WHS IBZ (Figure 5). (See Gater and Shiel 2002, 2003 and 2004 and Orkney College Geophysics Unit Survey Reports 2004 and 2005 for full geophysical survey reports). Further geophysical, magnetometer surveys have been conducted around the Skara Brae site and were used within this project (Griffiths *pers comm.*).



1000 m

Figure 5 Extent of magnetometry survey undertaken within the Brodgar WHS IBZ. Ovenden *pers comm*.

All magnetometry surveys shown within this thesis were obtained using fluxgate magnetometers configured to gradiometer mode. Using this system two sensors are maintained vertically 1 m above one another with the lowest sensor 0.1-0.3 m above the ground surface. The top sensor measures the earth's magnetic field while the lower sensor also measures the earth's magnetic field but is affected by any buried feature which is in closer proximity to it. Any anomaly due to the buried feature is then calculated by subtracting the top sensor measurement from the bottom sensor measurement. Results are expressed in nanoTesla (nT), a measurement of the total magnetic flux divided by the area measured, with strong positive results indicating increased magnetic disturbances created by features beneath the ground such as buried features which have been filled with burnt or partly burnt materials. Information from the geophysical survey has been combined with research from the Brodgar Farm Report (Ballin Smith and Petersen 2003), further resistivity survey (Mackintosh and Damianoff 2003) and with information from the Soil Survey Scotland (Macaulay Institute for Soil Research 1981) to determine the location of field sites.

A preliminary field visit and collaboration with Orkney Archaeological Trust (OAT) confirmed that several of the potential field sites identified by geophysical surveys were appropriate for the research specified in this project. The land around the settlement sites at the Ness of Brodgar, around the probable double Bronze Age house at Wasbister, around Barnhouse Neolithic Settlement and around Skara Brae has been identified as being the most appropriate field sites from which to answer the research questions identified in the rationale. It was anticipated that geoarchaeological research at these field sites would identify a Neolithic SSBCR which may contribute to the interpretation of The Heart of Neolithic Orkney WHS and contribute further to the understanding of Neolithic cultural activities.

2.1.2 The Ness of Brodgar

The strength and nature of magnetic responses over the Ness of Brodgar suggests the presence of a complex of archaeological features (Figure 6). It is likely that these features represent areas which have been burnt and as such are indicative of habitation (Gater and Sheil 2002). The results of the geophysical survey suggest a dense complex of archaeological features likely to be indicative of early settlement activity. This is supported by resistivity survey (Mackintosh and Damianoff 2003) which has succeeded in identifying a number of previously unidentified built structures, thereby validating the comment by Gater and Shiel that the extent of the settlement at the site is substantial (Gater and Shiel 2002).

A report into a stone found during ploughing of a field at this site, and tentatively identified as a cist lid, has identified the presence of Late Neolithic structures (Ballin Smith and Petersen 2003), and confirmed the presence of Neolithic settlement. A trench within this field was excavated which revealed part of a building. The shape and construction of the partly revealed building, with orthostats in combination with high quality dry stone coursed masonry indicates it is Late Neolithic in date (Ballin Smith and Petersen 2003). It was anticipated that a SSBCR would be identified around this Late Neolithic settlement contributing to the understanding of the WHS and allowing comparison with SSBCR at other sites within the WHS inner buffer zones. It was anticipated that research into this location would provide insight into the relationship between ritual and domestic life in the Neolithic period. Preliminary descriptions of the partly revealed buildings indicate similarities to those at Barnhouse Neolithic Settlement, although there are some differences. It is likely that these differences represent the appropriation of local knowledge or the need for different function. It is anticipated that either will be reflected in any associated SSBCR.

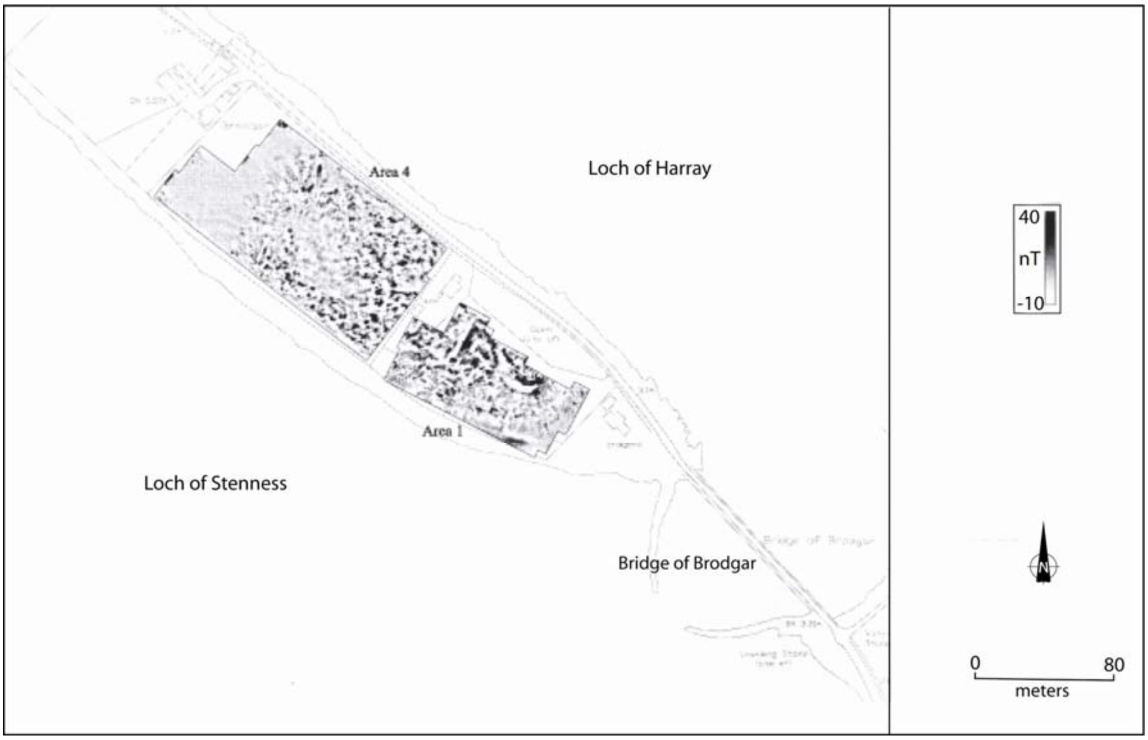


Figure 6 Magnetometry survey results the Ness of Brodgar (Gater and Shiel 2002)

2.1.3 Wasbister

Magnetometry survey data suggests the possibility of another settlement site located approximately half way between the Ring of Brodgar and the Ring of Bookan within the WHS IBZ (Gater and Shiel 2002, Orkney College Geophysics Unit 2005). The magnetometry survey indicates what appears to be a complex of field systems, and/or enclosures around a feature identified as a probable double Bronze Age house (Figure 7). Although probably Bronze Age and not Neolithic it is conceivable that this site is multi period in nature (Card *pers comm.*) and that the dating of any anthropogenic soils around the site may confirm the presence of Neolithic soil based cultural record. The presence of preserved field systems at this site would be of great interest to this research as it seeks to investigate the use of soil as a resource by early people groups.

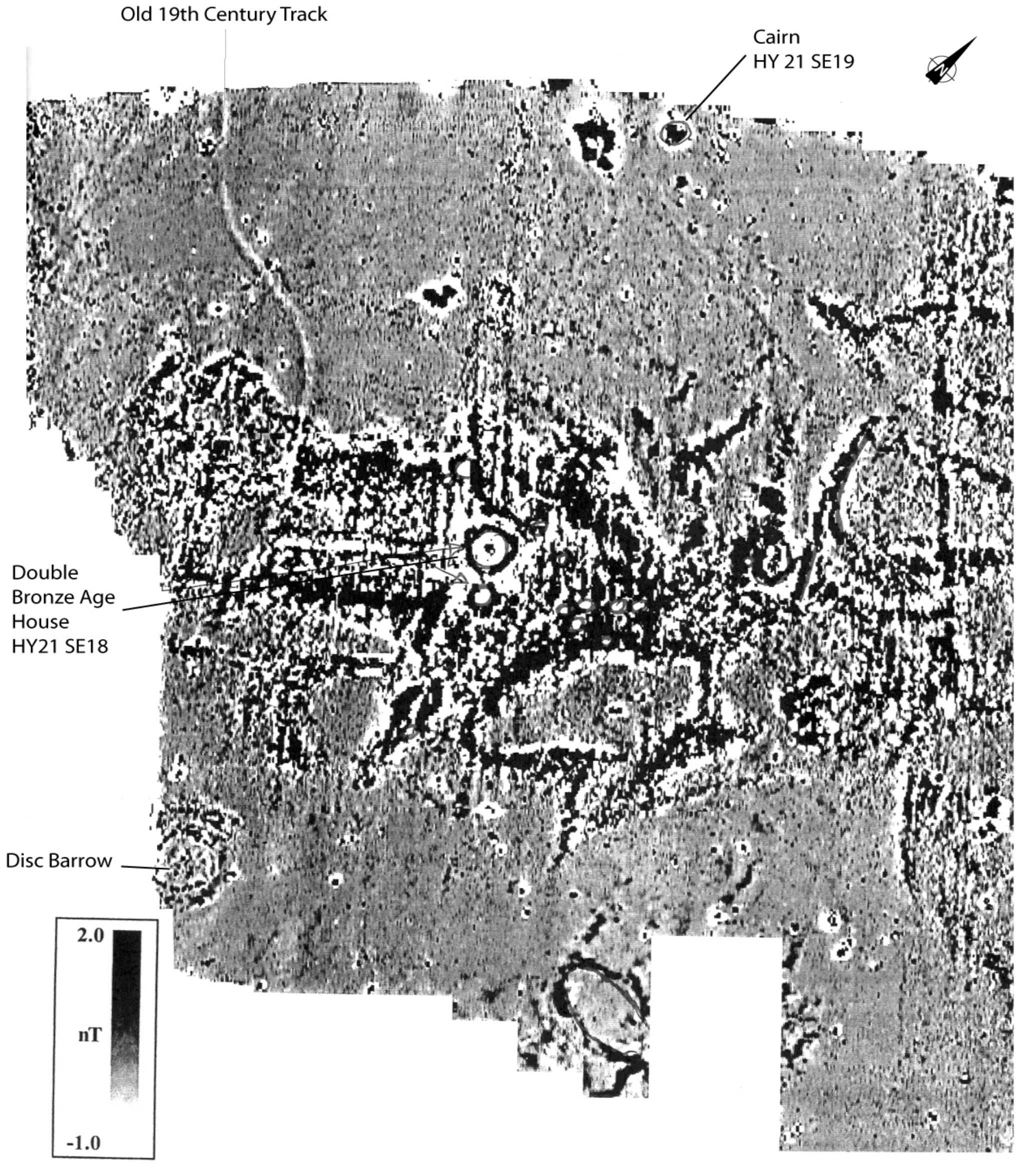


Figure 7 Magnetometry survey results Wasbister (Gater and Shiel 2003)

2.1.4 Barnhouse Neolithic Settlement and Big Howe

Geophysical survey was conducted to the South East of Barnhouse Neolithic Settlement and around Big Howe Iron Age Broch (). There are some groups of anomalies in the northern most part of the field which are typical of those associated with an early settlement. As yet these anomalies remain undated but preliminary interpretations identify them as being a continuation of Barnhouse Neolithic Settlement (Gater and Shiel 2002). It is anticipated that the land around this settlement and extending towards Big Howe may have been utilised by the Neolithic Barnhouse Settlement community and may therefore contain SSBCR that can contribute to the understanding of the Neolithic activities at Barnhouse Neolithic Settlement.

The presence of this likely extension to Barnhouse Neolithic Settlement, combined with the presence of the Iron Age Broch also indicates the multi period nature of this site. Evidence from the geophysical survey suggests this area is criss crossed with linear lines associated with past ridge and furrow cultivation as well as modern day ploughing (Figure 8). The evidence suggests that this landscape has been in constant use since the Neolithic. As such it provides a good opportunity to investigate how early society-environment relationships influenced the activity of later societies, and indeed may prove to be extremely valuable in recognising the impact of considerably later prehistoric settlement activity upon the preservation of earlier SSBCR.

Figure 8 Magnetometry survey Barnhouse Neolithic Settlement and Big Howe (Gater and Shiel 2002)

2.1.5 Skara Brae

The Neolithic settlement of Skara Brae is located on the West Coast of Mainland Orkney in the Bay of Skaill (HY 231 188). The settlement has been extremely well preserved due to a combination of the rapid deposition of wind blown sand and the presence of midden material at the site. As such Skara Brae is undoubtedly the best, known surviving prehistoric settlement in Northern Europe (Clarke and Sharples 1985). It is possible that the excellent preservation of structures and artefacts at this site will also extend to excellent preservation of the Neolithic landscape round the site.

Rapid deposition of wind blown sand at Skara Brae makes it comparable to the site at Tofts Ness, Sanday, Orkney. At Tofts Ness, extensive deposits of shelly wind blown sands have buried the early Tofts Ness landscape allowing good site survival and fossilisation of the associated landscapes under the sand. The area provided outstanding opportunities to examine sequences of early society-environment relationships within a landscape context (Simpson *et al* 1998b). Geophysical surveys around Skara Brae (Figure 9, Griffiths *pers comm.*) do indicate the possibility of a fossilised landscape extending from the settlement to the south under deposits of shelly sand.

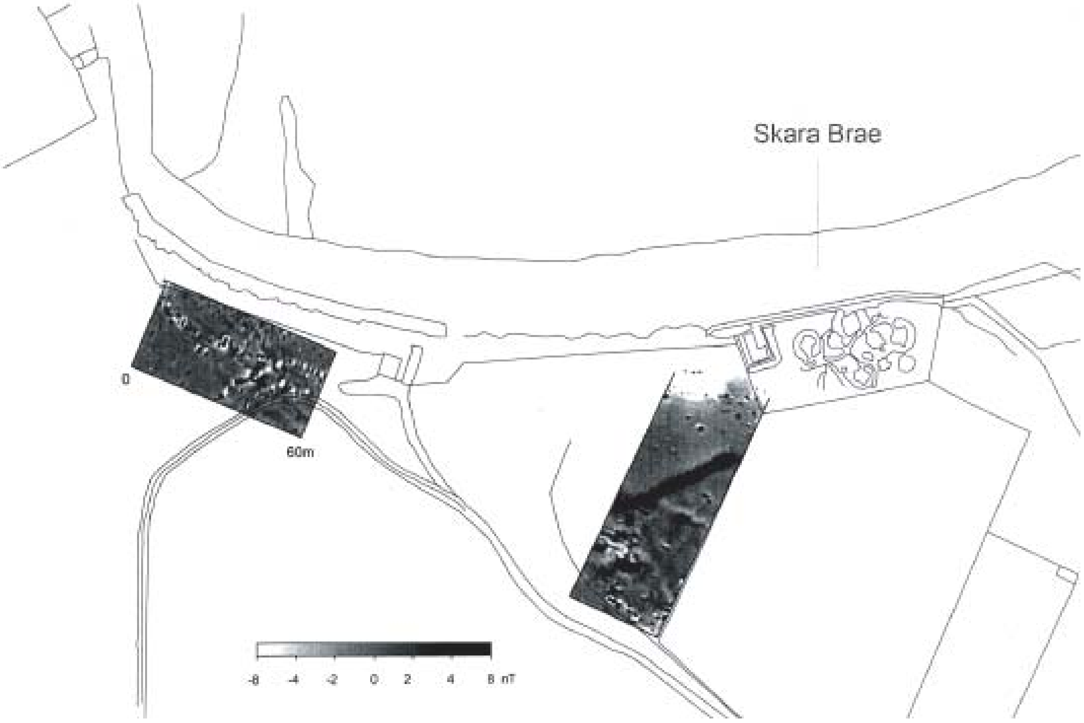
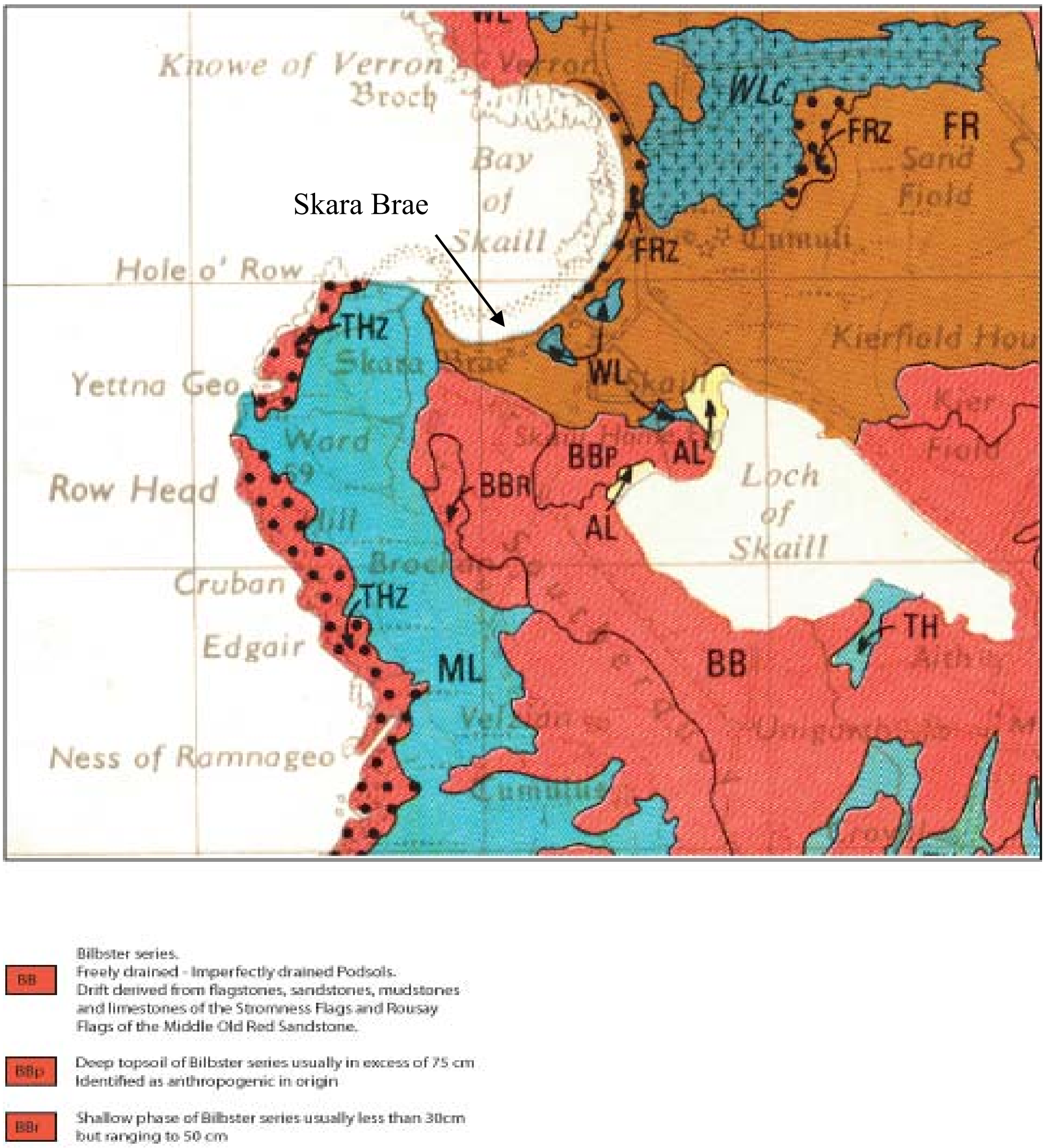


Figure 9 Magnetometry survey results Skara Brae **(Griffiths *pers comm.)***

It is considered possible that a buried landscape in such close proximity to Skara Brae would have been influenced by Neolithic cultural activities associated with settlement and may retain a SSBCR. Any SSBCR associated with Skara Brae will presumably have been preserved by wind blown sands in a similar way to which the settlement itself has been preserved.

Deepened top soils have also been located in close proximity to the Neolithic settlement of Skara Brae (HY 265 186) (Figure 10). Deep top soils are found within the Bilbster Soil Series, a freely or imperfectly drained cultivated podsol developed on drift derived from the Stromness and Rousay Flags of the Middle Old Red Sandstone. Within this series is a deep top phase which has a mineral top phase generally in excess of 0.75 m (Macaulay Institute for Soil Research 1981). Research upon these deep soils has indicated that they are anthropogenic in origin

(Davidson and Simpson 1984) and that the formation of them is likely to have commenced *c*1200 AD, ending in *c*1800 AD (Simpson 1997). Despite the later commencement of the formation of these anthropogenic soils, Simpson (1993) suggests that it is entirely conceivable that deep top soil formation commenced in the Neolithic period, continuing through the various cultural groups that have inhabited Orkney.



BB	Bilbster series. Freely drained - Imperfectly drained Podsols. Drift derived from flagstones, sandstones, mudstones and limestones of the Stromness Flags and Rousay Flags of the Middle Old Red Sandstone.
BBp	Deep topsoil of Bilbster series usually in excess of 75 cm Identified as anthropogenic in origin
BBr	Shallow phase of Bilbster series usually less than 30cm but ranging to 50 cm

Figure 10 Soil Survey Orkney: West Mainland (Macaulay Institute for Soil Research 1981)

2.1.6 Control Sites

A key issue pertaining to the use of the analytical methods and the interpretation of the SSBCR associated with the field sites identified is the need for appropriate control. Appropriate control would assist any interpretation of Neolithic cultural practices, and any conservation implications from the SSBCR from individual sites to be better understood within the context of the wider landscape across The Heart of Neolithic Orkney WHS IBZ. It was decided to attempt to identify a pre-settlement control site, and a control site which represents known historical agricultural intensification. It was anticipated that the use of these two control sites would better contextualise the Neolithic SSBCR within a known framework of unused, pre-settlement soils and much later intensively managed arable soils.

The identification of a suitable pre-settlement control site remains problematic on Orkney. Orkney has supported a permanent human population from at least 3500 BC (Ritchie 1985) which has resulted in the multi period structural cultural record within the landscape and an anticipated multi period nature of associated SSBCR. The continual anthropogenic influence upon this land by successive cultures makes it extremely difficult to define or indeed identify a pre-settlement soil. It is possible that as at Tienland, mainland Scotland, a fossilised soil horizon may exist beneath a glacial moraine on Orkney (Fitzpatrick 1965). The fossilisation of any such soil horizon would obviously pre-date settlement and would therefore be of use to this project. The glacial moraines near Finstown (HY 350 138) provided an appropriate place to attempt to identify a pre-settlement soil for use as a control site.

A suitable control site of known intensively used and managed soil was identified in the deepened top soils near Skaill Home Farm, Bay of Skaill (HY 235 184). The deepened top soils associated with the Bilbster soils series (Macauley Institute for Soil Research 1981) are anthropogenic in origin and represent a SSBCR whose formation commenced in the late 1200s AD and continued until the late 1800s AD (Simpson 1997). This SSBCR represents known agricultural intensification and extreme anthropogenic amendment resulting from specific cultural practices determined through a combination of historical literature and analytical geoarchaeological research (Simpson 1997).

The use of these two controls allows the properties of SSBCR identified within The Heart of Neolithic Orkney WHS IBZ to be contrasted with the properties of a pre-settlement soil not influenced by anthropogenic activities, and soil properties resulting from known extreme amendment associated with specific cultural practices between the late 1200s AD and the late 1800s AD (Simpson 1997). These two controls represent opposite ends of a spectrum of amendment to Orcadian soils and it was anticipated that the soil properties of SSBCR identified within the WHS IBZ would be *within* the range of properties exhibited by these two controls.

2.2 Chronology

The Heart of Neolithic Orkney has been designated a WHS because of the Neolithic monuments, dated as constructed between 2000-3000 years BC, and recognised as being an outstanding testimony to the cultural achievements of the people of Northern Europe (UNESCO World Heritage Centre 2006). There is a requirement therefore to obtain secure dates of formation of any SSBCR within the multiperiod IBZ, in order to allow any contribution to the cultural identity of Neolithic or later people groups to be correctly assigned. In accordance with the WHS research agenda (Downes *et al* 2005), the development of a secure chronology for the formation of SSBCR within the WHS IBZ is a key priority to the research within this landscape and may be established through radiocarbon analyses and optically stimulated luminescence analysis (Ashmore and Sanderson 2005).

2.3 Radiocarbon Dating

Radiocarbon dating has been widely and successfully applied to archaeological and geoarchaeological research concerning the Orcadian Neolithic, spanning about 1500 years from *c*3500 BC to *c*2000 BC. This period is usually divided into two general phases, an early phase and a late phase with the transition period generally considered to have occurred around *c*3000 BC (Card 2005). The application of radiocarbon (^{14}C) measurements to the determination of chronologies relies upon the natural production of ^{14}C in the atmosphere. ^{14}C is a secondary effect of cosmic ray interactions with the atmospheric gas molecules which result in the production of neutrons. Radiocarbon is formed by the reaction of low energy neutrons with ^{14}N which is then rapidly oxidised to form $^{14}CO_2$ (Taylor 2001). Within $^{14}CO_2$, ^{14}C is distributed through the Earth's atmosphere by stratigraphic winds becoming generally well mixed by the time ^{14}C-tagged CO_2 molecules reach the Earth's surface. Most ^{14}C is absorbed in the oceans, while 1-2 percent becomes part of the terrestrial biosphere, primarily by means of photosynthesis. Plant materials and animals which are directly or indirectly dependent on plants are therefore tagged with ^{14}C. Metabolic processes in living organisms maintain the ^{14}C concentration in approximate equilibrium with atmospheric ^{14}C concentrations. When metabolic processes cease (at the point of death) the amount of ^{14}C begins to decrease by radioactive decay at a rate that can be measured by the ^{14}C half life, from which the date of death can be inferred

(Taylor 2001). For a comprehensive review of principles, assumptions and limitations of radiocarbon dating in archaeological science see Taylor 2001.

The development of direct counting of ^{14}C atoms present within a carbon sample using Accelerator Mass Spectrometry (AMS) has been of particular benefit to archaeological and geoarchaeological research. It has allowed major reductions in the size of the sample required with radiocarbon dates being successfully obtained from samples of gram amounts of carbon to milligram amounts and, with additional efforts, to the level of less than 100 micrograms (Taylor 2001). AMS has also allowed major reductions in the counting time required which has greatly increased the efficiency of the process. Literature review has identified that the following materials may be used for radiocarbon analyses.

2.3.1 Charcoal

The use of charcoal material for radiocarbon analysis has become standard to provide dates and chronologies for archaeological sites and geoarchaeological research (see Taylor 2001, Simpson *et al* 2000). Charcoal does have an existing ^{14}C age which dates the death of the plant material and may greatly predate the burning of the plant material and the production of charcoal. It is usual for the ^{14}C age of charcoal to predate the formation of the soil or sediment in which it is found. Single entity pieces of charcoal, defined by Historic Scotland as *'anything being demonstrably a single part of an organism, in which the absolute chronological relationship between all components forming that part can be established to the nearest calendar year'* (Ashmore 1999) were submitted for radiocarbon analysis. Historic Scotland support the submission of single entity samples for radiocarbon analysis as reviews of previous dating programmes have demonstrated that combining pieces of charcoal to produce carbon for dating can produce serious errors because the survival of charcoal on archaeological sites can occur even when there is no stratigraphic evidence for multiperiodicity (Ashmore 1999).

2.3.2 Bone

Bone consists of long chains of proteins (collagen) in which particles of poorly crystallised inorganic material (bio-apatite) are embedded. Traditionally collagen which has its origins solely in proteins in the diet has been used to provide radiocarbon dates for unburnt bone samples (Lanting *et al* 2001). Recent advances in radiocarbon dating of cremated bone are proving to be extremely useful in providing radiocarbon dates for archaeological sites and chronologies within archaeological research (Sheridan *pers comm.*, Lanting *et al* 2001, Lanting *et al* 1998). It is anticipated that radiocarbon dates from non cremated and cremated bone will also contribute significantly to the formation of chronologies within geoarchaeological research.

The dating of cremated bone is made possible by the collagen in bone which contains poorly crystallised inorganic material, primarily calcium phosphate (bio-apatite). This bio-apatite contains a certain amount of carbonate (0.5-1%), substituting phosphate in the crystal lattice (Lanting *et al* 1998). Structural carbonate originates in blood bicarbonate and therefore is directly related to the food a human or animal has consumed. As such it can be assumed that any inherited age of the structural carbonate is low and of the same order of magnitude as the inherited age of bone carbon (15 to 20 years at the most) (Lanting *et al* 1998). The radiocarbon dating of cremated bone is made possible because during the process of cremation at temperatures between 525 ^{o}C and 645 ^{o}C the bioapatite recrystallises and larger crystals are formed (Mays 1998, Lanting *et al* 1998). It is this structural carbonate which can be dated through AMS radiocarbon dating.

2.3.3 Soil Organic Matter

The term soil organic matter is used to encompass all of the organic components of a soil including living biomass, dead roots and other recognisable plant residues and a largely amorphous and colloidal mixture of complex organic substances which is no longer identifiable as tissues. It is this third category of soil organic matter which is considerably altered amorphous organic matter and is the product of humification, involving predominantly biochemical processes which are referred to as the soil humic substances (Brady and Weil 2002, Duchaufour 1982).

Humic substances comprise about 60-80 % of soil organic matter and are comprised of large molecules with variable, rather than specific structures and composition. These substances are characterised by aromatic ring type structures that include polyphenols and comparable polyquinones which are even more complex. The complex nature of these organic materials is responsible for their resistance to microbial decomposition and their corresponding longevity within soils (Brady and Weil 2002). Historically humic substances have been classified into three chemical groupings based upon solubility. This classification identified humic substances as being composed of fulvic acids, humic acids and humin (Brady and Weil 2002, Duchaufour 1982). Fulvic acids are the lowest in molecular weight and lightest in colour, are soluble in both acid and alkali and are most susceptible to microbial decomposition. Humic acids are medium in molecular weight and colour, soluble in alkali but insoluble in acid and are intermediate in resistance to degradation and humin is the highest in molecular weight, darkest in colour and is insoluble in both acid and alkali and is the most resistant to microbial decomposition (Brady and Weil 2002).

These fractions of soil organic matter have been used to radiocarbon date soil in attempts to study the chronology of soil development, but the significance of the measured dates can remain a problem as soil organic matter is the product of an ongoing process (Wang *et al* 1996). Fresh carbon is continuously incorporated, but at varying rates into any defined fraction of the soil organic material which results in the radiocarbon measurement of any soil organic matter fraction actually representing the mean radiocarbon measurement within that fraction and not that of a single entity. The dating of SSBCR through radiocarbon measurement is also difficult due to the radiocarbon age of applied material, rejuvenation effects associated with cultivation and the pedogenic movement of carbon through the profile. Apparent ages deduced from the ^{14}C content of soil organic matter fractions have been recognised as being to young because of contamination by recently introduced carbon for example through recent plant roots (Wang *et al* 1996, Hormes *et al* 2004). Within an archaeological context apparent ages deduced from the ^{14}C content of soil organic matter have also been recognised as being too old as frequently material which already has a radiocarbon age is incorporated into SSBCR. This is evident for example when attempting to date the commencement of the Plaggen agricultural systems of Northwest Europe as turf material with an existing radiocarbon age was deliberately added to the plaggen soil to maintain soil fertility (Bokhurst *et al* 2005).

Despite these problems and limitations the radiocarbon measurement of soil organic matter has been of some use in providing chronologies for geoarchaeological research. In the absence of finds of substantial charcoal or bone, Simpson *et al* (1998) successfully used the humic acid fraction of soil organic matter along with stratigraphic relationships to provide a reasonable estimate of the commencement and cessation of a SSBCR resulting from Bronze Age cultural activity at Tofts Ness, Sanday, Orkney. Simpson *et al* (2000) have also successfully used radiocarbon measurements from the humic acid fraction of peat material alongside wood and charcoal AMS radiocarbon measurements to successfully provide a chronology of fishing activity within Langenesværet, Vesterålen, Northern Norway. It is suggested that with careful interpretation the dating of the soil organic matter will be of use in establishing a chronology for this research.

For soil samples and peat samples, the commonly dated fractions of soil organic matter are the humic acid and the humin fractions. The fulvic acid fraction is not usually used for radiocarbon analyses as this fraction is more mobile than the other fractions (Simpson *et al* 2000, Brady and Weil 2002, Duchaufour 1982). Opinions as to the suitability of the humin and humic acid fraction of soil organic matter for radiocarbon analyses differ but it does appear that the majority of research requiring radiocarbon dating of soil organic matter concentrates upon the humic acid fraction (for example see Shore *et al* 1995, Wang *et al* 1996, Bokhurst *et al* 2005). There are apparent benefits in dating the humic acid fraction of soil organic matter over the humin fraction of soil organic matter. The humic acid fraction is a chemically defined fraction (alkali soluble and acid insoluble) whereas the humin which is often regarded as the material which remains after successive alkali and acid extraction may contain material unrelated to the humification process and not associated with the formation of the soil (Simposn *et al* 2000). It has therefore been decided to date the humic acid fraction of the soil organic matter from appropriate samples.

2.3.4 Sampling Strategy

When interpreting ^{14}C dates in geoarchaeological research the precise relationship between the ^{14}C date and the specific activity of archaeological interest must be carefully considered. All too often the date provides an age that is only a proxy for the period of cultural activity of interest, as when old or heart wood is used to date the human use of that wood (Ashmore and Sanderson 2005). This is likely to be a consideration within any SSBCR identified where it is entirely possible, or indeed probable that the date of the sample will not be the same as the context in which it has been found. For example ^{14}C dates obtained from charcoal and bone material indicate the date of death of the organism and not necessarily the date of burial and inclusion into the SSBCR.

Despite these considerations, the development of secure chronologies for the formation of SSBCR has been established within Orcadian geoarchaeological research through the use of multiple radiocarbon analyses and stratigraphic relationships with structural archaeology (Simpson 1993 and 1997). The archaeological sensitivity of the landscape within the WHS IBZ precluded the expansion of soil profiles into structural archaeology, as to excavate would result in the destruction of the structural cultural archaeological record (Richards 2005). This prevented interpretational security from being obtained from any stratigraphic relationships with structural archaeology. It was anticipated that the interpretational security of the chronology of formation of SSBCR within the WHS IBZ would be significantly enhanced through the radiocarbon analyses of multiple samples, of differing origins, from the same archaeological context or soil horizon. Where possible, samples of bone and charcoal were submitted for radiocarbon analyses along with a bulk soil sample for radiocarbon analysis of the humic fraction of the soil organic matter. It was anticipated that comparison of the results of multiple samples from the same archaeological context would provide greater interpretational security concerning the chronology of formation of the associated SSBCR.

Prior to AMS radiocarbon analyses, charcoal samples were identified at Glasgow University Archaeology Research Division (GUARD, Ramsay *pers comm*) and bone samples were identified at Scottish Urban Archaeology Trust (SUAT, Smith *pers comm.*). All radiocarbon analyses and humic acid extractions were conducted by the Scottish Universities Environmental Research Centre (SUERC) using standard protocols.

2.4 Optically Stimulated Luminescence Dating (OSL)

The principle of optically stimulated luminescence dating (OSL) is based upon the measurement of luminescence emitted from a crystalline material following the absorption of energy from an external source. The external source of energy is naturally occurring radioactive isotopes (U Th K) which emit a variety of rays which ionise atoms. Negatively charged electrons are knocked off atoms in the ground state (valence state) and transferred to a higher energy state (conductive band). Positively charged holes remain in the atom in the valence state. After a short time of diffusion most electrons recombine with the holes thus returning the mineral back to its original state. However, all minerals contain defect sites at which electrons can be trapped. Quartz and feldspars are two minerals commonly available and commonly used for dating purposes. For a measure of luminescence signal the trapped electrons have to be activated, in the case of OSL by light (Feathers 2003).

Materials with suitable luminescence properties can be dated because at some point in the past traps are emptied of their charge by sufficient exposure to light. This amounts to a zeroing event. If measurement of luminescence was made immediately after this zeroing, no signal would be observed. Subsequently traps become refilled because of continued ionisation by radioactivity and a latent luminescence signal steadily accumulates. When luminescence is measured in the laboratory, this natural signal will be proportional in size to the time since the last zeroing event. The age equation is written as a simple ratio:

$$\text{Age (ka)} = \frac{D_E(\text{Gy})}{D_R(\text{Gy/ka})}$$

D_E = equivalent dose in grays (unit for absorbed dose)

D_R = average dose rate over time

Age is given in 1000's years (ka)

Figure 11 Equation for OSL age determination (Feathers 2003)

When dating the period of deposition of sediments the dating event is the last exposure to sufficient sunlight which is the depositional event. When dating the formation of SSBCR however, once an active soil is buried, surface exposure to light no longer occurs so that OSL dates the burial event, which for SSBCR is the construction event (Feathers 2003, Bokhurst *et al* 2005).

The recent methodological developments of single aliquot and single grain dating allow an opportunity for archaeologists to date the period of formation of SSBCR. This has been demonstrated in the Outer Hebrides by Gilbertson *et al* (1999) who identified the history of aeolian deposition and soil formation over the last 14–15,000 calendar years along the exposed and gale-prone Atlantic coastlines, based upon a chronology ascertained through OSL. In the Northern Isles of Scotland OSL has also been used to date the construction of SSBCR associated with archaeological sites. Sommerville *et al* (2001) obtained preliminary ages from aeolian sands associated with archaeological sites at Tofts Ness using OSL techniques on extracted quartz which are broadly consistent with external age controls provided by radiocarbon dating and stratigraphic relationships, suggesting dates from the first and third millennium BC (Sommerville *et al* 2001). Likewise Burbidge *et al* (2001) evaluated the OSL dating potential of a SSBCR associated with an agricultural infield area at Old Scatness Site, Shetland and determined that OSL dating has significant potential for dating Neolithic SSBCR.

Research suggests that OSL dating is an appropriate method of dating to use, in conjunction with radiocarbon analyses to date the period of formation of SSBCR within the WHS IBZ. OSL is likely to be especially useful at sites within the World Heritage Site which are dominated by aeolian deposition, where a potential lack of organic material precludes or restricts the use of ^{14}C dating. This was found to be the case within the IBZ surrounding Skara Brae, where aeolian deposition of calcareous sand is dominant, see chapter 8.

2.5 Conclusion

In conclusion, field sites have been located within close proximity to Neolithic and probable Neolithic settlement sites in order to attempt to identify SSBCR, the interpretation of which would be of benefit to the further interpretation of The Heart of Neolithic Orkney WHS. These sites are located across the breadth of the WHS IBZ, allowing the investigation into people and the surrounding environment on a wide spatial scale in the field, as is the best scenario for geoarchaeological research (French 2003). Appropriate control profiles have been identified which are outwith the IBZ but which remain geographically and contextually relevant for the interpretation of any identified SSBCR. Radiocarbon analysis and optically stimulated luminescence are both appropriate analytical techniques to use to identify the period of formation of any identified SSBCR.

Chapter 3 - Research Design II; Quantitative and Qualitative Analyses

In order to address the research questions identified in Chapter 1, an integrative approach has been adopted combining field observations, laboratory analyses and qualitiative research. This chapter discusses field observation and soil sampling stategies before discussing the measurement of the key soil properties of soil organic matter, soil pH, soil particle size distribution, soil phosphorus content and soil magnetism, along with the use of thin section micromorphology to address the research questions. These soil properties greatly influence soil development and processes within the soil, and are also considered useful quantifiable properties able to reflect anthropogenic influences upon the soil. The measurement of these soil properties has therefore been widely applied to geoarchaeological investigations (see following). This chapter concludes with a brief discussion of the use of qualitative research along with a list of historical documentary sources used to address the research questions.

3.1 Field Observations and Sampling

Geophysical survey data was used at each field site to systematically locate soil profiles and avoid the probable structural archaeological record. Soil profiles were described by soil horizon or archaeological context following standard soil science survey procedures and included Munsell colour, texture and structure (Hodgson 1997). The horizon notation adopted by the Soil Survey of England and Wales (Hodgson 1997) has been used throughout this thesis and profiles were recorded by scale drawings and photographs. Anthropogenic influences upon soil and sediment formation and utilisation can often be elucidated from field evidence (Goudie 1993) and field observations were therefore pivotal in determining the presence of anthropogenic horizons representing SSBCR and enabling the sampling of undisturbed and bulk soil materials. Field observations identified anthropogenic horizons by the presence of anthropogenic inclusions including charcoal, bone and pottery Bulk soil samples and Kubiena tin samples for thin section micromorphological analysis were taken from soil horizons or archaeological context. Bulk soil samples were air dried and sieved to 2 mm with all subsequent quantitative analyses undertaken upon this air dried < 2 mm fraction unless otherwise specified.

3.2 Quantitative Analyses

3.2.1 Soil Organic Matter Content

Soil organic matter can be defined as the organic fraction of the soil that includes plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesised by the soil population (Brady and Weil 2002). Within soils unaffected by anthropogenic activities, the prime source of soil organic matter is plant debris, such as dead leaves and branches that fall onto the soil and are then biologically decomposed at variable rates. The slightly altered plant material that covers a mineral soil is referred to as the litter which, during subsequent decomposition forms either soluble or gaseous compounds by mineralisation or amorphous compounds that bond with minerals, particularly clays, to form clay-humus complexes. This latter, altered amorphous organic matter which is more stable and resistant to biodegradation than fresh organic matter and is more slowly mineralised is referred to as the soil humic substances, with the term humification used to describe all soil processes involved in changing fresh organic matter into these humic substances (Duchaufour 1982, see section 2.3.3).

The term soil organic matter therefore refers broadly to a complex collection of physical and chemical soil components which are able to greatly affect physical, chemical and biological properties and functions of the soil (Duchaufour 1982). Soil organic matter and surface vegetation act together to protect the soil surface from run off and erosion, and soil organic matter acts as a binding agent stabilising soil by affecting soil structure, texture and porosity (Brady and Weil 20002). Soil organic matter is an important nutrient reserve for plant growth and may influence the retention of soil nutrients such as phosphorus (Crowther 1997). Furthermore, soil organic matter influences a soils base status and contributes to a soils capacity for cation exchange and pH buffering (Brady and Weil 2002, Duchaufour 1982). Despite its complex nature and its important influence upon these soil properties and soil functions, the soil organic matter is generally referred to as one soil property within geoarchaeological research.

Within soils which have been influenced by anthropogenic activities, the soil organic matter content of the soil may reflect the anthropogenic influence, and therefore the soil organic matter content of soils is commonly undertaken in geoarchaeological investigations. On Orkney, deep anthropogenic top soils associated with plaggen manuring systems have been characterised using a range of soil parameters, including soil organic matter content (Simpson 1997). Despite the large volume of organic material used to fertilise these soils, the organic matter content is not particularly high ranging from 2.3-6.7 % (Simpson 1997). This relatively low soil organic matter content may be associated with the arable function of anthropogenically deepened top soils, and any intense arable agriculture. Tillage increases the rate of organic decomposition by braking up and increasing the surface area of soil aggregates for microbial decomposition and may lead to an increased loss of soil organic matter through runoff. Cropping also prevents soil organic matter from being returned to the soil through plant debris (Brady and Weil 2002, Simpson 1985).

The soil organic matter content of soil samples was measured using loss on ignition (LOI). Samples were oven dried in crucibles at 105 °C, were weighed when cool and were then fired within a furnace at 425 °C for 4.5 hours to remove all organic matter by combustion. Loss on ignition (LOI) was estimated by weighing samples before and after the organics were combusted. Replicates were taken for horizons within profiles at each site and associated errors were extrapolated to corresponding horizons within the same site (full results Appendix B).

3.2.2 Soil pH

Soil pH, commonly referred to as soil acidity or alkalinity is a measure of the comparative concentration of H^+ and OH^- ions in the soil. It is expressed as the negative logarithm of the H^+ ions on a scale of 1-13, with pH 7 representing neutral conditions where the H^+ and OH^- ions are balanced. Above pH 7 OH^- ions exceed H^+ ions resulting in alkaline (basic) conditions and below pH 7 H^+ ions exceed OH^- ions resulting in acidic conditions (Brady and Weil 2002). The range of pH common to temperate mineral soils is pH 5-7, with acidic peats typically ranging from pH 2.5-3.5 (Brady and Weil 2002).

The pH of a soil is partly determined by the base status of its parent material, but it is also able to be changed in response to a variety of environmental processes. For example, increased precipitation can cause increased leaching of base-forming cations (Ca^{2+}, Mg^{2+} and Na^+) from a soil leaving the soil dominated by Al^{3+} and H^+ ions and therefore lowering the pH. Also, increasing vegetation growth resulting from seasonal variability can lower pH by producing acids through roots and the increased activity of microorganisms involved in decomposition (Duhaufour 1982). Anthropogenic activities are also able to influence soil pH. For example, modern agricultural management involving the use of ammonium-based fertilisers lowers pH as does the planting, growth and subsequent harvesting of crops which remove soluble cations thereby lowering soil pH. Conversely, practices such as the addition of calcium carbonate as fertiliser will raise soil pH (Brady and Weil 2002). Soils of intermediate pH status are also able to minimise any impact that changing soil properties may have upon pH through the action of reserve ions predominantly located on the clay minerals and soil organic matter (Brady and Weil 2002). This is known as a soil's buffering capacity and in order for anthropogenic activities to be identified within soil pH these activities must therefore be sufficient to change the pH of a soil outwith of its normal buffering capacity.

It seems inevitable that as within recent history, land management within the historic and prehistoric periods must have affected soil pH. This is perhaps evidenced within plaggen soils of northwest Europe where the low pH generally associated with these soils is explained by the known addition of sods from acidic turf land. However, the great many environmental and anthropogenic variables able to affect soil pH make it difficult to attribute specific soil pH results to specific anthropogenic activities in the absence of knowledge of these specific anthropogenic activities. This is anticipated to be the case concerning any Neolithic SSBCR. Furthermore, it is often difficult to differentiate the soil pH associated with relict anthropogenic soils from the soil pH determined by present land management (Dercon *et al* 2005).

It is unlikely that soil pH will be of use in identifying SSBCR within the WHS IBZ. However, soil pH is often referred to as a master variable as changes in soil pH are able to affect biological, chemical and physical properties of the soil. It is anticipated that the measurement of soil pH will be important in interpreting the results of all other quantitative variables being measured within this research. For example, soil pH greatly influences the preservation of archaeological evidence with acidic conditions favouring pollen preservation but destroying bone, shell and wood (Renfrew and Bahn 1996). Soil pH may therefore greatly affect both the features observed, and the abundance of features observed within thin section micromorphological analysis. Furthermore, the measurement of soil pH is fundamental to the interpretation of soil phosphorus results as the mobility of phosphorus is intrinsically linked to soil pH (3.2.4).

pH was measured by suspending samples in distilled water and by using a pH meter. Replicate measurements were made upon samples from one profile at each site in order to determine the error associated with pH measurements (full results Appendix B).

3.2.3 Soil Particle Size Distribution

The particle size distribution of a soil refers to the proportion of different sized mineral constituents of the soil. Excluding the larger rock fragments, soil mineral particles range in size from clays (<2 μm) to silts (2-63 μm) and sands (63-2000 μm, Hodgson 1997). The proportions of the particles in different particle size ranges are referred to as soil texture. Soil texture has a great influence upon many soil properties. It affects the penetration of plant roots into the soil profile and influences the percolation of water through the profile, thereby affecting the translocation of soil particles and plant nutrients (Brady and Weil 2002). Soil texture is directly related to the surface area of the mineral proportion of a soil with a decrease in a soil particle size associated with an increase in the surface area of the mineral component of the soil. An increased surface area within the mineral component of the soil enhances the soils capacity for retaining water, nutrients and other chemicals, increases the rate of the release of plant nutrients from weatherable minerals and may increase microbial reactions within the soil (Brady and Weil 2002).

Soil texture is a relatively stable soil property and it is generally acknowledged that only environmental processes occurring over long periods of time, such as erosion, deposition, illuviation and weathering will influence soil texture (Brady and Weil 2002). The texture of a soil can be changed on a localised geographical scale by anthropogenic land management practices which involve the deposition of large volumes of material with a different textural class. Particle size analysis has been useful to geoarchaeological research investigating past land management. Dercon *et al* (2005) identified a contrast in textural classes of anthropogenic A horizons and underlying B and C horizons in Nairn, Scotland. This contrast identified a greater proportion of fine material in the anthropogenic A horizon and was interpreted as evidence for the incorporation of finer material, possibly beach sand within the land management responsible for the anthropogenic A horizon development. Davidson and Carter (1998) also used particle size analysis along with thin section micromorphology to successfully trace the origins of materials used to amend anthropogenic soils in Papa Stour, Shetland.

The particle size distribution (PSD) was determined on the <2000 μm fraction of the soil, after samples were sieved to 2000 μm to remove the coarse sand. Organic material was removed from the samples by the addition of hydrogen peroxide, samples were suspended in distilled water and dispersion was achieved by the addition of 5 ml Calgon ($Na_6O_{18}P_6$). Particle size distribution was measured using a Coulter Counter and replicate measurements were taken on samples to identify the errors associated with measurements (full results Appendix C).

3.2.4 Soil Phosphorus

Phosphorus is essential for biological growth; it is an essential component of the organic compound ATP (adenosine triphosphate) which drives most biological processes. It is also an essential component of deoxyribonucleic acid (DNA) and of ribonucleic acid (RNA) which directs protein synthesis in both plants and animals (Brady and Weil 2002). In a soil unaffected by anthropogenic influence, phosphorus, predominantly from vegetation debris can be recycled back into the soil as the result of microbial decomposition. However, within soils under the influence of arable agriculture phosphorus is not recycled in this way as the phosphorus taken up by the biomass during vegetation growth is removed from the cycle as the crop is harvested. It may seem intuitive therefore that intense anthropogenic influence in the form of arable agriculture would lead to phosphorus depletion within arable soils. However, the majority of arable soils within industrialised countries resulting from recent, historic and even pre-historic arable land management practices are characterised as having high phosphorus concentrations (Brady and Weil 2002, Heron 2001, Guttman *et al* 2006). This characteristic is explained by the addition of phosphorus to soils within arable land management and an understanding of the chemical processes involving soil phosphorus.

The addition of phosphorus to arable soils to maintain soil fertility is not a new phenomenon with, arable soils as far back as the Neolithic period characterised by a high phosphorus concentration (Guttmann *et al* 2006). Within an archaeological context, pre-industrial revolution, the majority of phosphorus was added to soils through the application of manures and domestic waste activities while in post industrial revolution industrialised agriculture the majority of phosphorus has been added to arable soils in inorganic fertilisers (Leonardi *et al* 1999, Brady and Weil 2002). Phosphorus is cycled into the soil therefore as a result of the microbial decomposition of organic materials or as the direct result of the addition of inorganic phosphorus. Further chemical processes of the phosphorus cycle are such that the majority of phosphorus which enters into a soil becomes chemically fixed within the soil and is therefore unavailable for uptake by plants or from further cycling. The chemically fixed soil phosphorus reserve can therefore theoretically be measured as an indicator of previous phosphorus applications, and is able to provide a long term indication of phosphorus application within anthropogenic activities (Leonardi *et al* 1999).

The measured fixed soil phosphorus reserve is therefore a product of the fixation of phosphorus within soils, a process which must be understood to interpret properly measured phosphorus results along with the implications for understanding anthropogenic activities. When organic residues decompose, phosphorus enters into the soil and normally combines with four oxygen atoms to form the phosphate ion $(PO_4)^{-3}$. In the soil solution, phosphate is present as HPO_4^{-2} (dominant in alkaline soil solutions), and $H_2PO_4^-$ (dominant in acidic soil solutions). These phosphate ions, along with some soluble organic phosphorus compounds are available for uptake by plant roots and mycorrhizal hyphae, although the amount of phosphorus available for plant growth is usually very low, not exceeding 0.01 % of the total phosphorus within a soil (Brady and Weil 2002). The vast majority of phosphate ions within the soil solution however, are chemically fixed and are removed from the soil solution forming phosphorus-containing compounds of very low solubility. This fixation is pH dependant, at low pH phosphate ions react with iron, aluminium and to a lesser extent manganese ions and are removed (fixed) from the soil solution whereas at high pH the phosphate ions react with calcium ions and are removed (fixed) from the soil solution. The fixation of phosphate ions initially occurs by the adsorption of phosphate ions onto the surface of these minerals but continues over time to form increasing insoluble phosphates termed occluded phosphate. Phosphates are most available for plant growth near pH 6.5 in mineral soils however; even at this pH phosphate adsorption onto clay mineral surfaces is possible (Brady and Weil 2002, Heron 2001). These chemically fixed forms of phosphorus are known as the inorganic phosphorus fraction, which is generally resistant to desorption back into soil solution (Brady and Weil 2002).

Phosphorus also exists within the soil in an organic form, indeed the vast majority of phosphorus within soil is organic phosphorus ranging between 20-80% of the soil total phosphorus in surface soil horizons (Brady and Weil 2002, Oehl *et al* 2004). Three broad groups of organic phosphorus compounds are known to exist in soils and are all believed to be synthesised through the actions of micro-organisms. These are inositol phosphates (phosphate esters of a sugar like compound), nucleic acids and phospholipids, with much of the phosphorus in the soil solution present as dissolved organic phosphorus (Brady and Weil 2002). Organic phosphorus forms are more stable than inorganic phosphates in acidic and alkaline conditions however they are also subjected to the processes of mineralisation and are eventually fixed into inorganic phosphates unavailable for plant growth.

Phosphorus therefore occurs within soils as inorganic phosphorus, organic phosphorus and within the soil solution, with the sum of the phosphorus within these fractions referred to as the soil total phosphorus. The total phosphorus concentration of a soil, and the proportion of phosphorus within these fractions may be subject to change resulting from a wide range of environmental variables and anthropogenic influences. For example, a measurement of soil total phosphorus is dependant upon the quantity of phosphorus entering into the soil. The quantity of phosphorus entering into the soil is dependant at least upon the vegetation, which in turn is dependant upon climatic variables. Furthermore, anthropogenic activities which affect land management may reduce the amount of phosphorus entering into the soil by harvesting crops and increasing surface runoff but may also increase the amount of phosphorus entering into the soil through soil fertilisation (Brady and Weil 2002). It has previously been discussed that land management practices associated with arable land management are likely to result in enhanced soil total phosphorus concentrations but it is also apparent that these land management practices will influence the relative proportions of phosphorus within the phosphorus fractions in the soil. The addition of inorganic fertilisers promotes an increase in the inorganic phosphorus fraction of the soil phosphorus whereas the addition of manures initially promotes an increase in the organic phosphorus fraction of the soil phosphorus, which subsequently leads to an increase in the inorganic phosphorus fraction of the soil phosphorus after mineralisation and adsorption onto mineral surfaces (Oehl *et al* 2004). It should further be emphasised that the process of mineralisation is a biochemical process and therefore that any environmental variable or anthropogenic activities affecting biological activity such as changes in pH, temperature, moisture and changes to aerobic conditions will also influence the rate of organic phosphorus mineralisation thereby affecting the proportions of phosphorus within the soil phosphorus fractions.

The fixing of phosphorus into the inorganic phosphorus fraction is a dominant process within the soil phosphorus cycle. The capacity of a soil to fix phosphorus is principally dependant upon the soil mineralogy and texture. Soils rich in iron, aluminium, manganese and calcium have a high capacity for phosphorus fixation and fine grained soils with high clay content are also efficient at fixing phosphorus (Crowther 1997, Hertz and Garrison 1998, Brady and Weil 2002). pH has a dominant effect upon the movement and fixing of phosphorus within soils and therefore any changes in soil properties that affect soil pH such as temperature and soil moisture content) will also affect soil phosphorus results (Brady and Weil 2002). For example at neutral pH there is more available phosphorus within the soil solution and therefore more phosphorus is removed from the soil by vegetation uptake and through leaching. The measurement of total soil phosphorus and the phosphorus fractions within the soils is therefore intrinsically linked to may other soil variables including soil mineralogy, soil texture, pH and the abundance of soil organic matter. All of these variables are also able to be affected by anthropogenic activities and therefore these variables and associated soil processes must be understood and considered in the interpretation of any soil phosphorus measurements within archaeological and geoarchaeological investigations.

3.2.4.1 Phosphorus in Geoarchaeological Research

The application of soil phosphorus surveys to archaeology and geoarchaeology is based upon the premise that higher than ‘background’ quantities of phosphorus are associated with occupation areas (organic waste and refuse), with burials (due to the presence of organic phosphate in bone), or intensive land use (for example as a result of manuring, Heron 2001). Phosphorus analysis has been successfully undertaken on anthropogenic soils and sediments on Orkney as part of multidisciplinary research. Simpson *et al* (1998b) identified fossilised Bronze Age soils as being anthropogenic in origin as they had a higher total phosphate concentration than the calcareous sands within the examined stratigraphy (Simpson *et al* 1998b). In West Mainland, Orkney phosphate analysis demonstrated enhanced levels of phosphate found within deepened top soils helping to identify these soils as anthropogenic in origin and and identify spatial depositional patterns of organic matter across the landscape resulting from differing manuring intensities (Simpson 1997). More recently anthropogenic sediments associated with the Neolithic settlement of Skara Brae have been characterised using a combination of analytical techniques including total phosphorus analysis with results indicating the presence of two discrete anthropogenic sediments within the settlement (Simpson *et al* 2006). This research demonstrates the longevity of phosphorus within soils (David 2001) and suggests that phosphorus analysis is likely to be suitable to analyse SSBCR identified within the WHS IBZ.

Phosphorus analysis has been widely used in archaeology mainly to identify the extent of settlements and arable fields (Heron 2001), but it has also been used to attempt to discriminate between these two functional areas. The fractionation of the organic and inorganic phosphorus has been used to attempt to distinguish manured fields from settlements based upon the premise that the manure adds large quantities of organic phosphorus, whereas settlement activity contributes larger quantities of inorganic phosphorus within ash and bone deposits (Linderholm 1997). This study has demonstrated that the dwelling areas within settlement may have increased concentrations of inorganic phosphorus (Linderholm 1997). The organic and inorganic phosphorus fractionation method has also been successfully applied to identify the boundary of a Roman town and distinguish between the town and an adjacent contemporary arable field system (Macphail *et al* 1997). Advocates for this phosphorus analysis within archaeology argue that this fractionation into organic and inorganic phosphorus provides a more reliable way of detecting the types of fertilisers used within arable soils, as under conditions of good preservation it can distinguish organic from inorganic fertilisers (Guttmann 2001 and *et al* 2005). Such a conclusion does appear somewhat simplistic when considering the complexities involved in the cycling of phosphorus between the soil organic phosphorus fraction and the soil inorganic phosphorus fraction previously discussed. Any comparison of the soil organic phosphorus fraction with the soil inorganic phosphorus fraction in an archaeological soil seems more likely to reflect any changes in soil properties such as biological activity and pH which have occurred since the formation of the anthropogenic soil. Any such changes in soil properties may also result from further anthropogenic activities (see section 3.2.4). Despite its seemingly limited use to this research the fractionation of phosphorus was undertaken on samples from one profile where the post-depositional function of the soils based cultural rcord could not be ascertained. These results were of limited usefulness (See page 145).

Despite the widespread use of phosphorus analysis within archaeological and geoarchaeological research there are still problems associated with this analysis. Existing problems include the inherent heterogeneity in the 'natural' background levels of soil phosphates, the variable retention capacities of phosphate in soil, the vertical variations of phosphorus within soil profiles and the difficulties in disentangling this from more recent applications of fertilisers, manure, grazing animals all of which make secure archaeological interpretation difficult. Combined with these interpretational difficulties it is apparent that laboratory and field protocols for quantifying soil phosphorus vary widely making comparisons of soil phosphorus data problematic (Heron 2001). Some would argue that that 'phosphorus analysis has done more than confirm site interpretation' and with regards to archaeological landscapes phosphorus analysis does not always identify manured soils (Heron 2001, Bull *et al* 1999). Despite these problems, however, a wide range of publications clearly demonstrate the use of phosphorus analysis when combined in integrative geoarchaeological research (Heron 2001). The integrative nature of this research suggests that phosphorus analysis will be a useful tool in identifying soils base cultural records when used in combination with other analyses.

The total phosphorus content of soil samples was determined upon the <90 μm component of the sample. Calcareous material was removed by the addition of HCL and total phosphorus was determined for samples by fusion with NaOH, and subsequent colorimetric determination on the supernatant liquid. Results are expressed in mg/100g oven dried soil and replicate samples were analysed for total phosphorus from horizons in profiles which were sampled for thin section analysis. In all figures results from each horizon (or context) are obtained from one sample unless otherwise specified (N=1 unless otherwise specified, full results available Appendix D). Total phosphorus results from field sites were statistically compared to total phosphorus results from control sites and other field sites using Mann Whitney tests with a significance level of 95%.

Despite reservations as to the usefulness of the measurement of phosphorus by fractionation, the measurement of the organic phosphorus fraction and the inorganic phosphorus fraction was undertaken for comparative purposes of one profile on the Ness of Brodgar (Trench E, see section 5.3.4). The fractionation of phosphorus into the organic and inorganic fractions was achieved by dividing soil samples in half and by heating one sub sample for one hour at 550 ^{o}C to convert any organic phosphorus into inorganic phosphorus. Phosphorus extraction was then completed upon both sub samples by an acid extraction using 10 molar H_2SO_4 and was determined by subsequent colorimetric determination on the supernatant liquid. The phosphorus extracted from the heated sample represents the total inorganic phosphorus content of the sample (including organic phosphorus which has been transformed into inorganic phosphorus by heating), with the phosphorus extracted from the unheated sample representing the initial inorganic phosphorus content. The value for the unheated sample was then subtracted from the value of the heated sample with the difference between the two values representing the concentration of the organic phosphorus fraction of the sample (Linderholm 1997, Guttmann 2001, Guttmann *et al* 2005). Results did not aid interpretation and therefore replicate measurements were not taken (see section 5.3.4).

3.2.5 Soil Magnetism

Soil magnetism forms the basis of magnetic prospection such as has been used widely within the WHS IBZ and is also a soil property which can be used to help identify early anthropogenic activity embedded in soil profiles. The basis for this prospection and analysis is the presence of weakly magnetised iron oxides within the soil. Depending on the state of these iron oxides, which can be produced, modified, transported and deposited by a range of environmental and anthropogenic processes the soil will exhibit between weak and strong magnetism (Weston 1996, Gaffney and Gater 2004). In most soils there are only two strongly magnetic minerals of any importance, magnetite (Fe_3O_4) and maghemite (Fe_2O_3) (Thomson and Oldfield 1986). Magnetite is a primary mineral which occurs in sand size grains in basalt, andesite and (in smaller quantities) in other igneous rocks. It is also formed by magnetotatic bacteria which produce small chains of magnetite crystals in their cells, which build up in the soil (Thomson and Oldfield 1986). Maghemite is a secondary mineral which is known to be produced within the soil environment by a combination of four processes. These processes are oxidation at low temperatures in conjunction with other soil processes, burning with soil organic matter within a temperature range of 150-258 ^{o}C, the dehydration of lepidocrocite to maghemite (which occurs mostly in gley soils) and as a result of reduction-oxidation cycles under normal pedogenic conditions, probably involving soil biota (Thomson and Oldfield 1986).

The magnetic susceptibility of a soil is the most commonly measured soil magnetic parameter (Thomson and Oldfield 1986). The magnetic susceptibility of a material is defined in terms of the magnetism induced in a sample when it is placed within a magnetic field. The more magnetised a material becomes the higher the susceptibility is said to be. The theory underlying magnetic susceptibility and its application to archaeology and soil science can be found in such works as Tite and Mullins (1971), Thompson and Oldfield (1986) and Gaffney and Gater (2004). The central mechanism is the reduction of haematite or goethite to magnetite under the heating and reducing conditions produced by the combustion of soil organic matter associated with surface fires. The magnetite is then re-oxidised to maghemite.

Magnetic susceptibility can be measured as volume susceptibility (κ) and mass specific susceptibility (χ). Mass specific susceptibility has predominantly been used within geoarchaeological research to identify anthropogenic activity upon soils as enhanced mass susceptibility is an indicator of past burning. Mass susceptibility is often undertaken in routine geophysical survey and profile description in studies of pedogenesis involving anthropogenic influence (Weston 1996). Dockrill and Simpson (1994) used mass susceptibility to identify the extent of anthropogenic influence upon soils associated with activity from the Neolithic to the Early Iron Age surrounding the site of Tofts Ness, Sanday, and identified this anthropogenic influence through a correlation of mass susceptibility and total phosphorus analysis. More recently magnetic susceptibility has been used to attempt to differentiate between different fuel sources and has been used to estimate the temperature of burning of these fuels (Peters *et al* 2001, Linford and Platzman 2004).

Geophysical survey results from magnetometry survey within the WHS IBZ have clearly identified and mapped magnetic anomalies which appear to identify significant archaeological features of value to the interpretation of The Heart of Neolithic WHS. Mass susceptibility analysis upon soil samples from within the WHS IBZ is likely to be of importance in furthering the interpretation of this geophysical survey, as magnetic susceptibility is key to the production of coherent results from magnetic surveys (Gaffney and Gater 2004). An advantage of using this analysis to characterise soil properties from within the WHS IBZ is that there is no geological variation, and therefore limited natural variation of iron oxide concentrations within soils across the IBZ. This suggests that any differences in mass susceptibility results are more likely to reflect differences in anthropogenic formation processes involving the extent of the burnt material and/or its temperature of burning (Ovenden *pers comm.*).

Mass susceptibility (χ) was measured in a volume of 10 cm^3 of soil sample using a Barington MS2 Magnetic Susceptibility System which had been calibrated for a sample mass of 10 g. Sample measurements were corrected for magnetic drift and results were converted into mass susceptibilities by dividing by the sample mass and the calibration mass (Thomson and Oldfield 1986). Results are expressed as $\chi\ 10^{-6}\ (m^3kg^{-1})$ and replicate samples were measured to identify associated errors. In all figures results from each horizon (or context) are obtained from one sample unless otherwise specified (N=1 unless otherwise specified, full results available Appendix E). Mass susceptibility results from field sites were statistically compared to mass susceptibility results from control sites and other field sites using Mann Whitney tests with a significance level of 95%.

3.2.6 Thin Section Micromorphology

The technique of thin section micromorphology is based upon the principle that past and present soil processes are reflected in the morphology of soil. The study of soil morphological properties can therefore provide information with regards to soil development and human impacts on soil over time. Thin section micromorphology extends this morphological approach to the microscopic level through the collection of undisturbed samples which are manufactured into soil thin sections and which can subsequently be examined and analysed using a petrological microscope (Davidson and Simpson 2001).

It has been suggested that thin section micromorphology is the best available method of revealing the origins of the constituents of a soil, while at the same time enabling an explanation of the soil formation (Kemp 1998). Early work using micromorphogy applied to archaeological research questions focused on the paleoenvironmental interpretation of buried soils as a means of providing environmental contexts for archaeological sites. Since the 1980s micromorphology has also been applied to site taphronomy and the wider impact of anthropogenic activities upon soil landscapes (Davidson *et al* 1992). As such micromorphology is a useful tool, and has been widely applied in geoarchaeological research, answering both site specific questions such as identifying the formation processes and constituents of particular deposits and questions concerning the wider impact of anthropogenic activity upon soil landscapes (Davidson and

Simpson 2001). Examples of both of these research themes are evident in geoarchaeological research undertaken upon Orkney.

Thin section micromorphology has been used on Orkney to contribute to the understanding of soils and sediments utilised within construction and within arable activity. Simpson *et al* (2006) used thin section micromorphology for the characterisation of sediments associated with midden deposits at the Neolithic settlement, Skara Brae. Thin section micromorphology was chosen as the preferred technique as it holds the potential to provide information about the sedimentary source, physical relationships between the mineral and anthropogenic components and any post-depositional disturbances or soil formation processes that may have taken place. This research identifies individual inputs into the midden material utilised in construction providing a first characterisation of this material and its variance in different parts of the site.

Thin section micromorphology has also been successfully applied to research questions concerning the wider impact of anthropogenic activities upon landscapes within Orkney. At Tofts Ness, Sanday, Orkney geoarchaeological research into the formation of a fossilised Bronze Age anthropogenic soil used thin section micromorphology in conjunction with other analytical methods (Simpson and Dockrill 1998). Research indicates that formation of the anthropogenic soil was through the application of grassy turf material together with domestic waste midden with moderately intense cultivation. This research indicates a deliberate manuring by Bronze Age people which allowed arable activity in what was a highly marginal farming environment.

Simpson (1997) also used thin section micromorphology as part of a multianalytical approach to identify the precise nature, source and depositional pattern of materials used in the formation of anthropogenic deep top soils formed between the late 1200s and late 1800s AD and associated with infield management around Marwick, West Mainland, Orkney. This research suggests that manuring practice involved the application of grassy turf material from the hill land, together with composted animal manure and a minor seaweed component (Simpson 1997). Varying proportions of turf and manure were applied across the area of land that developed as deep top soil and that the cultivation practices associated with these deep top soils were sufficiently intense to contribute to the down slope and down profile movement of fine material.

It is anticipated that thin section micromorphology can contribute to determining the materials and processes of formation and any post-depositional function associated with SSBCR as this analysis enables the assessment of post-depositional changes to soils (Davidson and Simpson 2001). The identification of any post-depositional function based solely upon the identification and interpretation of features observed within thin section has been the subject of much debate within the micromorphological community. This is perhaps best observed concerning evidence of cultivation and post-depositional arable function of anthropogenic soils and sediments. For a fuller review see Carter and Davison (1998), Macphail (1998), Carter and Davidson (2000) and Usai (2001). The summary of these arguments and any conclusion drawn from this wide body of research must be aware of the problem of equifinality (that features observed within thin section may be produced from a variety of pedogenic processes, Kemp 1998), a critical approach to the adoption of data from modern analogues to archaeological soils and an acknowledgement that the interpretational security of micromorphological features and interpretation of processes involved in the formation of these features can be enhanced significantly through the use of supplementary data including the use of historical literature (Davidson and Simpson 2001). Indeed, Courty *et al* (1989) indicate that it is only when micromorphological data is integrated with archaeological, chronological and other environmental data that considerable precision that can be achieved in defining patterns of anthropogenic activities.

Samples of undisturbed soil were taken in Kubiena tins from horizons at each field site and were also taken from both control profiles. Thin sections were manufactured by the University of Stirling Micromorphology Laboratory using standard methods (full methodology available at http://www.thin.stir.ac.uk/methods.html). Thin sections have been described using an Olympus BX-50 microscope according to Stoops (2003) and Bullock *et al* (1985), using plane polarised (PL), cross polarised (XP) and oblique incident (OIL) light sources with a magnification range of X2 to X40 allowing a continuum of observation from the lowest to the highest magnifications. This facilitated a systematic description of the soil basic mineral and organic components (coarse and fine material was separated at 10 µm), soil fabric and microstructure, soil groundmass and soil pedofeatures. Thin section observations were recorded directly into an Excel spreadsheet and summary descriptions have been presented in a standard table format.

The abundance of identified features was described by percentage area in accordance with that proposed by Stoops (2003). However, this description of abundance may be slightly misleading as the percentage area occupied by any particular feature is dependant upon both the size of the feature or fabric unit of interest in comparison to other features or fabric units of interest and also the magnification being used. For example phytoliths and diatoms of the order of magnitude of 100-200 µm will always be recorded as having an abundance of few or very few within a thin section at a low magnification but these features may occur with a relatively high frequency which would not be observed under this abundance categorisation. In order to rectify this for the purposes of this research, features of interest were recorded both by percentage area abundance at a low magnification and by the frequency categorisation used by Bullock *et al* (1985) for textural pedofeatures which records textural pedofeatures as rare, occasional or many. This allows the observation and recording of a low abundance by percentage area of small features such as phytoliths and diatoms but also their occurrence by relative frequency.

Table 1 Abundance classification of features in thin section (Bullock *et al* 1985)

Abundance	**% Area**
Very Dominant	> 70
Dominant	50-70
Frequent	30-50
Common	115-30
Few	5-15
Very Few	< 5

3.3 Qualitiative Research

Ethnographic data and historical documentary records have been successfully incorporated into geoarchaeological research in the Northern Isles of Scotland, contributing to an understanding of spatial manuring patterns and the micromorphological features resulting from specific land management practices (Simpson *et al* 1999a, Davidson and Carter 1998). Ethnographic data in the form of semi structured interviews were conducted with land owners, or tenants at the field sites of the Ness of Brodgar, Wasbister and Barnhouse in order to ascertain recent landscape histories and agricultural practices (Appendix F). An understanding of historical land use within the IBZ has great potential to contribute to discussions of the formation and post-depositional function of identified SSBCR and of the development of best land management and conservation strategies for these important cultural records. The following documentary sources were utilised:

Table 2 Historical Documentary Sources

Documentary source	**Use within this research**
Clouston (1914) **Records of the Earldom of Orkney 1299-1614**	Used to locate Skaill Control within the arable 'tunmal' land within the head dyke of townships.
Mackenzie (1750) **Orcades; or a geographic and hydrographic survey of the Orkney and Lewis Islands**	Geographic and hydrographic survey of the Orkney Islands used to identify early landscape organisation and the arable 'tunmal' land within the head dyke for the locating of Skaill Control
Thomas (1852a) **General Plan of the Antiquaries of Stenness, Orkney**	Used to identify areas of arable rigs within the modern period and to compare these with those idenitified within recent geophysical survey
Thomas (1852) **An account of some of the Celtic antiquities of Orkney, including the Stones of Stenness, tumuli, Picts houses etc. with plans**	Used to identify specific land management practices within the Brodgar IBZ within the modern period
Ordnance Survey First Edition (1882)	Used to identify arable land within field boundaries at Skaill Control
Macaulay Institute for Soil Research (1981) **Soil Survey of Scotland 1981**	Used to locate deepened top soils formed through plaggen management for the locating of Skaill Control

3.4 Conclusion

In order to address the research questions identified in Chapter 1 an integrative geoarchaeological approach has been adopted combining field observations and qualitative research with quantitative analyses. Quantitative analyses have allowed soils within the WHS IBZ to be characterised by a range of soil properties including soil organic matter content, pH, particle size distribution, total phosphorus concentration, magnetic susceptibility and the soil physical properties through the use of thin section micromorphology. The discussed complexities and interdependencies of these soil properties suggest that it is unlikely that the use of any individual soil property would be sufficient to address the research questions identified in Chapter 1. These research questions can only be fully addressed by using a combination of quantitative soil properties along with the use of field observations and any available qualitative data. Table 3 provides a summary of the usefulness of different quantitative soil properties in relation to the research questions identified in Chapter 1.

Table 3 Usefulness of quantitative analyses in addressing research questions

	Identification of SSBCR (Question 1)	**Materials of formation of SSBCR (Question 3)**	**Post-depositional function (Question 4)**
Soil Organic Matter	✓	✓	
pH		✓	✓
Particle Size Distribution (PSD)	✓	✓	
Total Phosphorus	✓	✓	
Mass Susceptibility	✓	✓	✓
Thin Section Micromorphology		✓	✓

Chapter 4 - Control Sites

This research used two control sites to help understand and interpret the SSBCR within The Heart of Neolithic Orkney WHS IBZ. These control sites were deliberately located to identify and characterise a pre-settlement soil, and soils which are anticipated to be the product of intense amendment and agricultural practice between the late 1200s and the late 1800s AD (Simpson 1997). It is anticipated that the use of these two control sites will provide the characterisation of a range of soil properties associated with pre-settlement soils and with later intensive arable soils. It was further anticipated that any Neolithic SSBCR within the WHS IBZ would display characteristics *within* the range of soil properties exhibited by these two control sites, and therefore that the control sites would provide a bench mark for identifying the materials, processes and intensities of formation, and any post-depositional function associated with the identified SSBCR.

4.1 Finstown Control Results

4.1.1 Field Observations

The area around Finstown has many hummocky moraines which have been identified as been deposited by glaciers within the context of a wasting ice mass at the end of the last period of glaciation (Roe 1976). In order to determine whether any pre-settlement soils existed beneath the moraine a profile 2.6 m deep was excavated at HY 348139 from the topsoil, through the moraine to the under lying bedrock. This profile was excavated and cleaned at the top of a small quarry, allowing a continuous profile through the moraine material to the bedrock (Figure 12, Figure 13).

Field observations of this deposit including angular sandstone boulders, pebbles and clay material confirm that this is a glacial deposit. Preliminary interpretations of this profile suggest that there is no fossilised, pre-glaciated landscape at the base of the moraine material and above the bedrock. However, where possible, the profile was sampled for chemical analysis and for thin section micromorphology. These analyses will provide a natural background from which to evaluate SSBCR and it is possible, although perhaps unlikely that these laboratory analyses will reveal the presence and nature of a pre-glaciated, or a pre-settlement soil.

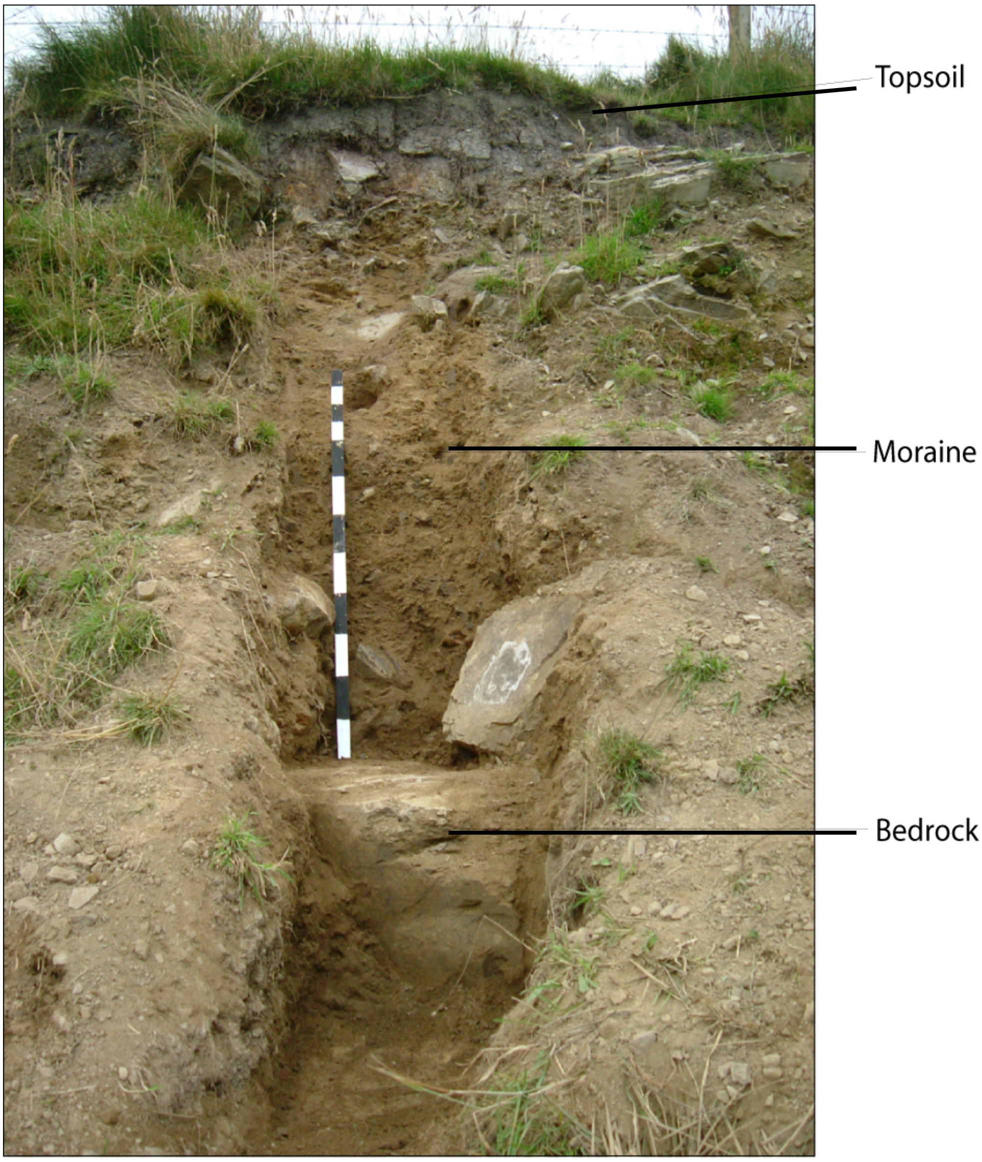


Figure 12 Finstown Control profile

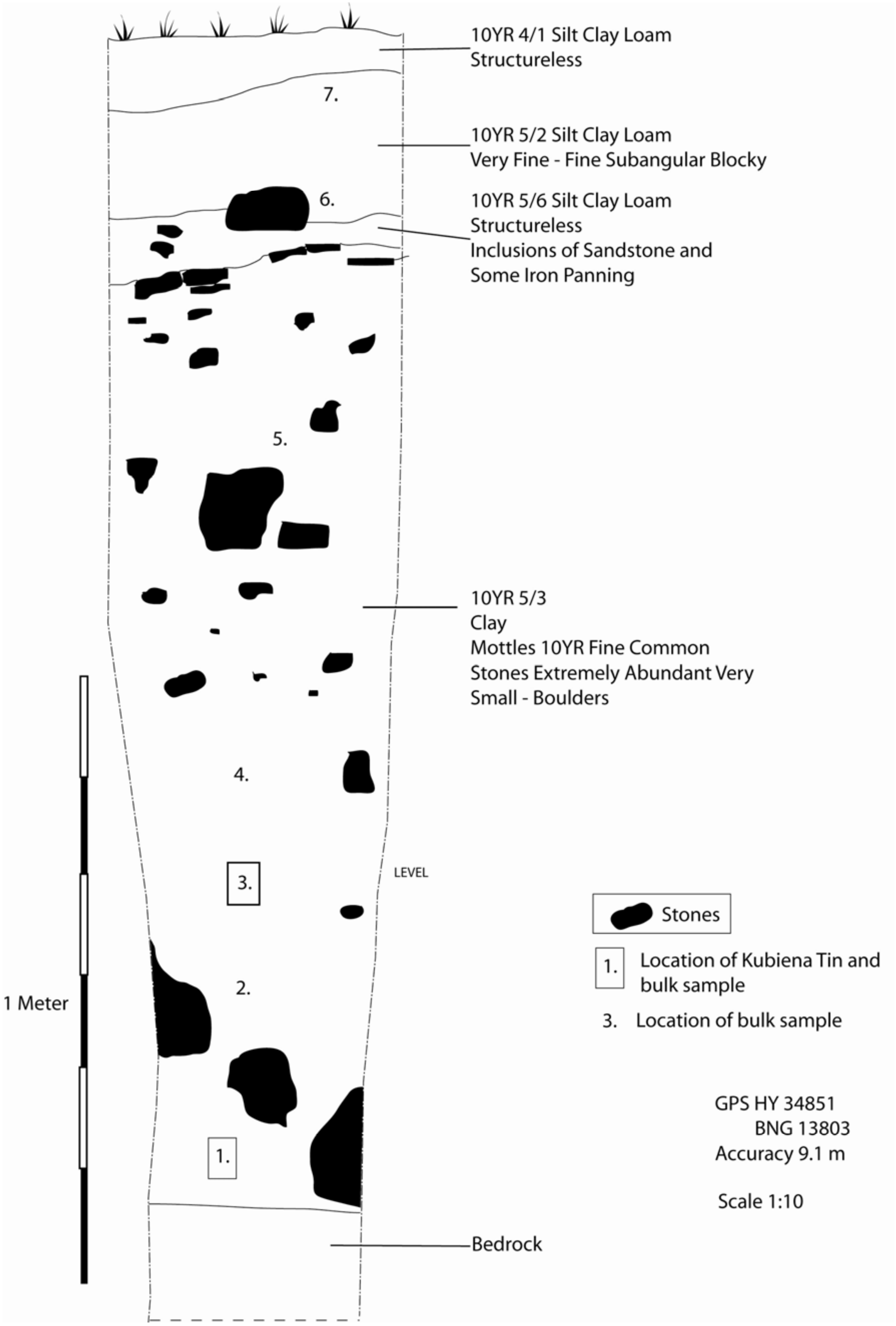


Figure 13 Finstown Control profile

4.1.2 pH and Soil Organic Matter Content

pH throughout the control profile at Finstown ranges from 4.2-5.8 (Table 4). pH is lower in the surface horizons and increases with depth to a pH of 5.8 above the bedrock. Loss on ignition (LOI) results indicate that organic matter content decreases consistently down the profile at Finstown Control from 12.7% in the upper surface horizon to 1.2% in the lowest sample from directly above the bedrock (Table 4).

Table 4 Finstown Control pH and organic matter content

	Range of pH	Range of Organic Matter Content (%)
A Horizon	3.8	13
Glacial Moraine	4.2-4.9	1-3

4.1.3 Particle Size Distribution (PSD)

The PSD from Finstown Control shows clear differentiation between samples from the A horizon (samples 6 and 7) and subsurface samples from the glacial moraine (Figure 14). A horizon samples are dominated by medium and coarse silts with only limited clay content and a very limited sand content. Subsurface moraine samples are dominated by coarse sand particles and contain very little clay and silt material.

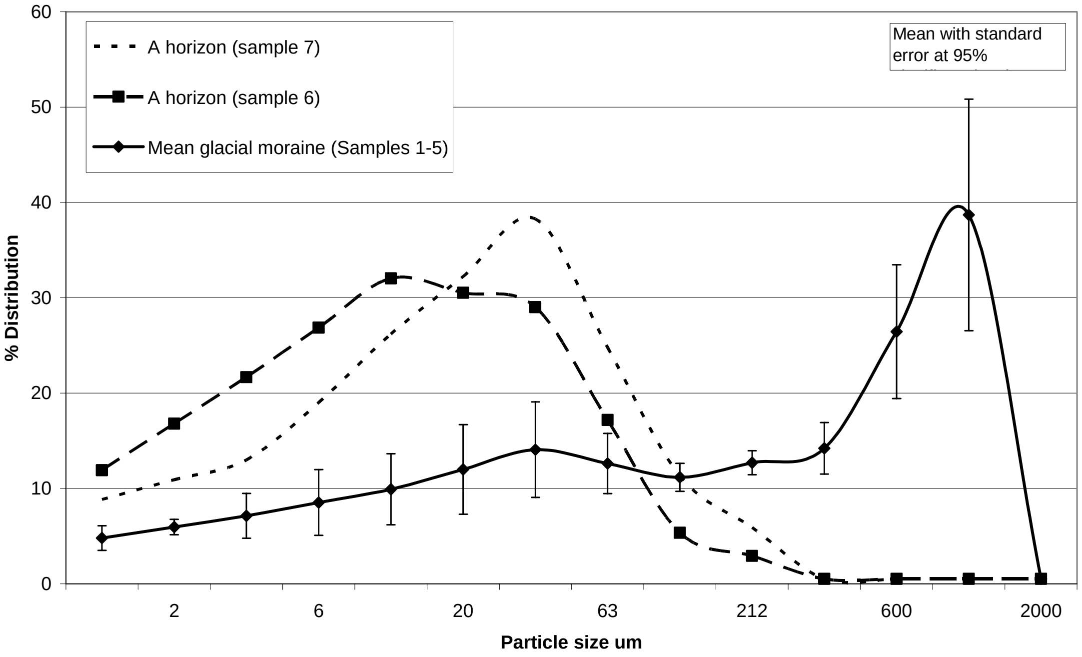


Figure 14 Finstown Control PSD

4.1.4 Total Phosphorus

Total phosphorus concentrations do not vary greatly with depth down the profile from the surface Ah horizon. Samples of the Ah horizon contain a mean total phosphorus concentration of 56 ± 7 mg/100g oven dried soil (Figure 15). The greatest concentration of total phosphorus is found at depth within the profile, directly above the bedrock material and is a concentration of 90 mg/100g oven dried soil.

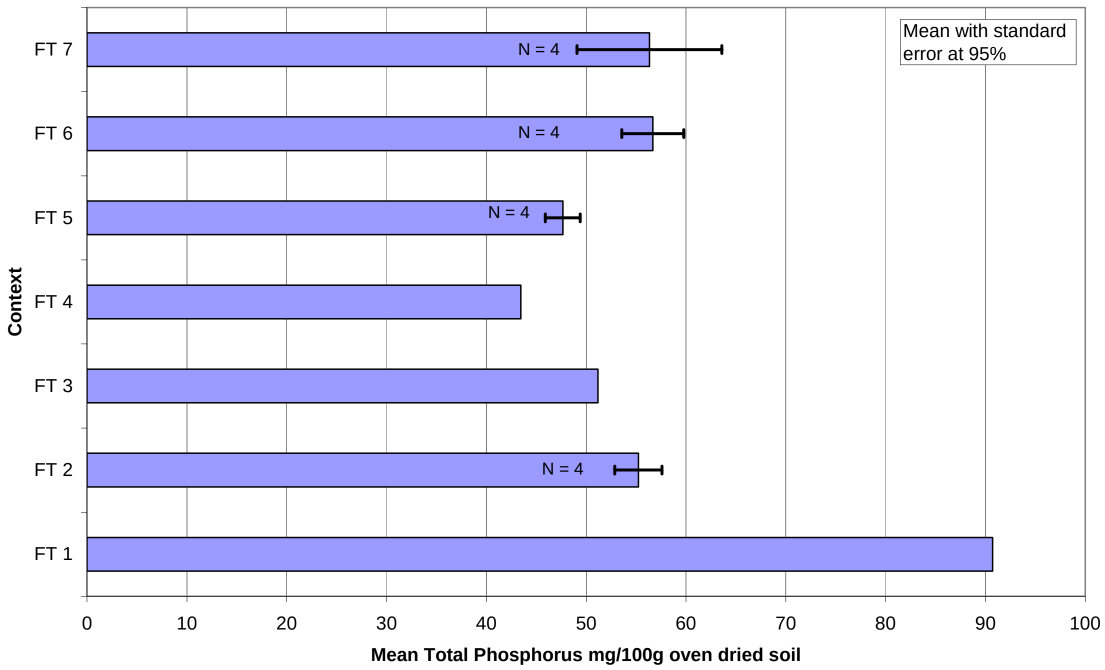


Figure 15 Finstown Control total phosphorus

4.1.5 Mass Susceptibility (χ)

Mass susceptibility results are very low ranging from $0.04\mathrm{x}10^{-6}$ m^3kg^{-1} to $0.14\mathrm{x}10^{-6}$ m^3kg^{-1} (Figure 16). Mass susceptibilities of the glacial moraine are slightly greater than those associated with the A horizon.

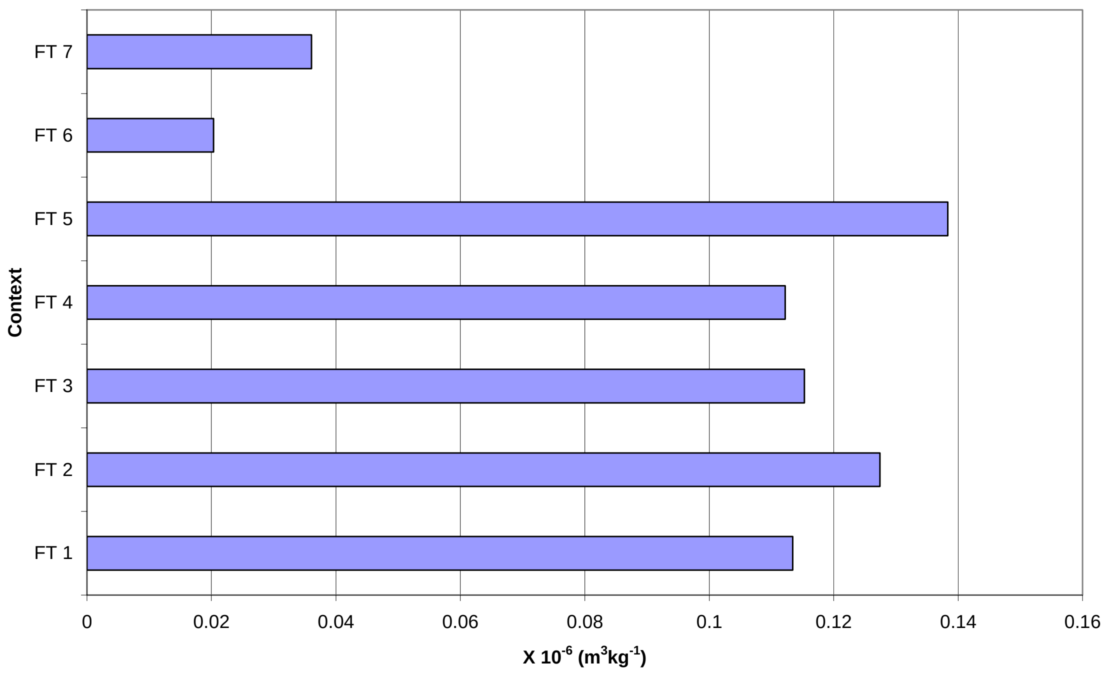


Figure 16 Finstown Control mass susceptibility

4.1.6 Thin Section Micromorphology

Micromorphological analysis of thin sections from samples taken from the glacial moraine material at Finstown identifies the coarse mineral component of the thin sections as being dominated by siltstones (>70%) (Table 5). Siltstones, predominantly composed of quartz are very dominant, angular in shape and are randomly organised (Figure 17). The siltstones are unsorted within the sediment matrix supporting field observations of only glacial moraine material. The siltstones show no evidence of iron depletion stone rim features but there are rare iron depletion pedofeatures within the fine sediment matrix. Very few organic matter features were observed in thin section supporting the low organic matter content of this glacial sediment determined through LOI. Features indicative of anthropogenic amendment such as bone, charcoal, diatoms, phytoliths and fungal spores were not identified within these samples. Many textural pedofeatures were observed, both coatings and infillings and were dominated by limpid clay (Figure 17).

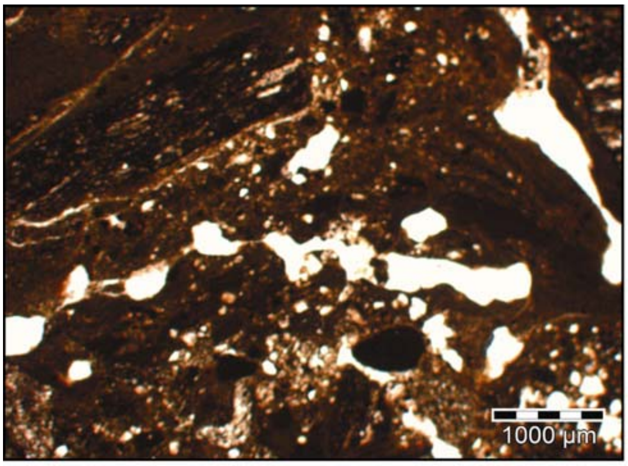
Table 5 Finstown Control thin section micromorphology results

Finstown Control

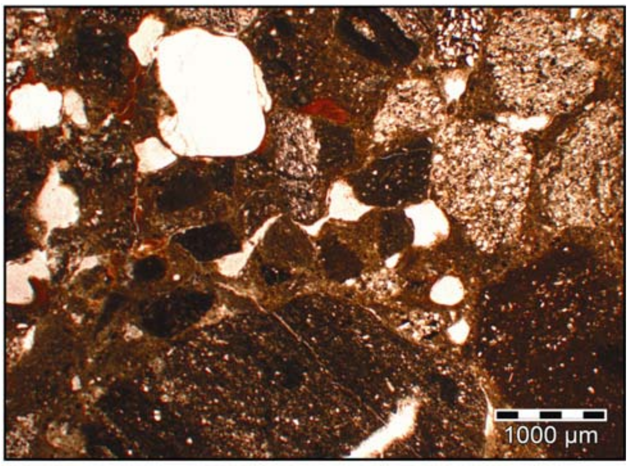
	Coarse mineral material								Coarse organic material					Fine organic material		Pedofeatures														
Context and Sample	Quartz	Calcium Carbonate	Siltstones (Quartz)	Roundness	Diatoms	Phytoliths	Bone	Fine mineral material	Charcoal	Fungal spores	Lignified tissue	Parenchymatic tissue	Amorphous Black >500 um	Amorphous Black <500 um	Amorphous (brown)	Coatings	Frequency	Infillings	Frequency	Amorphous & crypto crystalline nodule iron	Ca - Fe phosphates	Excremental (mamillate)	Excremental (spheroidal)	Fe Depletion on Siltstone	Depletion in Fine Matrix	Void Type Microstructure	Coarse material arrangement	Degree of sorting	Groundmass b fabric	Related distribution
Sample 1	●●●		●●●●	Angular				Grey and light brown (PPL)					●			Limpid clay and silt	xxx	Limpid clay and silt	xxx					No		Complex packing and planes	Random	Unsorted		Porphyric
Sample 3	●●●		●●●	Angular				Grey and light brown (PPL)								Limpid clay and silt	xxx	Limpid clay and silt	xxx					No		Complex packing and planes	Random	Unsorted		Porphyric

Frequency class refers to the appropriate area of section (Stoops 2003) t Trace ● Very few few ●●● Frequent/common ●●●● Dominant/very dominant.
Frequency class for textural pedofeatures (Bullock et al., 1985) t Trace x Rare xx occasional xxx Many

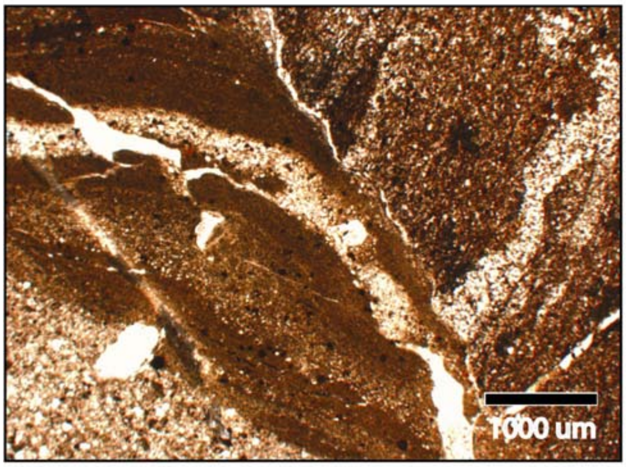
Light sources: Plane Polarised (ppl)
Cross Polarised (xpl)
Oblique Incident (oil)



Angular mineral component within clay matric. Poorly Sorted.



Angular mineral component within clay matric. Poorly Sorted.



Limpid Clay textural pedofeatures .

Figure 17 Finstown Control key micromorphological features

4.2 Discussion

Results from laboratory analyses support initial interpretations based on field observations that this control profile consists of only glacial moraine with no presence of any pre-settlement paleosol. The consistent decrease in organic matter content of samples with depth from 12.7 % below surface vegetation to 1.2 % immediately above the bedrock suggests an absence of organic material at the base of this glacial moraine and does not support the interpretation of the presence of a paleosol beneath this glacial deposit. Surface horizons (Ah) contain organic material from vegetation associated with the present land use of rough grazing but no organic material was observed by field observation at depth within this profile with only very few amorphous black features observed in thin section.

The absence of soil organic matter at the base of this profile is also reflected by particle size distribution (PSD) and total phosphorus results. The PSD for all subsurface samples is dominated by coarse sand and there is no evidence of any different distribution which might be expected to be associated with any paleosol. Total phosphorus concentrations within this control profile are relatively low which also suggests a lack of organic material within the profile. Mean Ah horizon total phosphorus concentration is 56 (± 7) mg/100g oven dried soil and total phosphorus concentrations of the glacial moraine material range from 56 (± 3) to 43 mg/100g oven dried soil. Total phosphorus concentrations directly above the bedrock at the base of the moraine were recorded as being 91 mg/100g oven dried soil and the acidic pH of samples from the entire profile suggests only limited leaching of phosphorus down the profile. As expected the lack of any visible organic material within this moraine profile is reflected in low phosphorus concentrations. The total phosphorus concentrations within the topsoil horizons are likely to reflect organic inputs associated with current land use which is rough grazing land and is therefore not an agriculturally intense system. It is suggested that the slight increase in total phosphorus concentration in the glacial moraine above the bedrock is associated with phosphorus inputs from weathering of the underlying bedrock and not from any organic material associated with soil development (Leonardi *et al* 1999). Samples from FT1 – FT5 are all from the same pedological unit and the mean total phosphorus content from these samples is 54 (± 2) mg/100g oven dried soil, expressed to two standard errors.

The coarse mineral content of samples from this control profile is also consistent with this profile representing only glacial material. The dominance of mineral material which is angular, poorly sorted and randomly organised both in field observations and within thin section (Figure 17) is characteristic of glacial deposits (Davidson and Carter 1998). Despite the range of low pH (4.2 to 5.8) siltstones in thin section do not exhibit depletion rims associated with the mobility and movement of iron. This is consistent with the interpretation of undisturbed glacial moraine material. This material has been deposited at depth before pedogenesis began on the upper most part of the glacial deposit. The resulting pedogenesis under podsolisation (Macaulay Institute for Soil Research 1981) is unlikely to cause depletion features at depth within the glacial deposit as these depletion features occur in the uppermost horizons of well developed podsols as the result of the very active organic compounds produced by litter causing the weathering and translocation of materials including iron (Duchaufour 1982, Romans and Robertson 1985, Simpson 1997). Textural pedofeatures in the form of limpid clay coatings and infillings are present with a frequency of many (Table 5, Figure 17). These are interpreted as being the result of illuviation associated with original deposition of the glacial material.

4.3 Finstown Control Conclusion

In conclusion the profile exposed at Finstown consists of glacial moraine material which overlies the bedrock. There is no fossilised pre-Neolithic settlement paleosol. This conclusion, that the profile sampled represents a sediment which has not been exposed to post pedogenic processes does question the usefulness of this profile in identifying the materials and formation processes involved with the formation of any Neolithic or subsequent SSBCR. However, these results have allowed a characterisation of the glacial material which is pre-settlement and must have been the parent material in original pedogenesis subsequent to glacial retreat. The glacial drift material on Orkney is relatively uniform, being composed of sandstone material derived from the underlying Middle Old Red Sandstones (Roe 1976). It is therefore suggested that this profile does provide a reasonable level of pre-settlement control with a mean total phosphorus concentration of 54 (±2) mg/100g oven dried soil and micromorphological features such as limpid clay textural pedofeatures providing a reasonable platform from which to evaluate later SSBCR.

4.4 Skaill Control Results

A suitable control site representing pre-improvement agricultural intensification and extreme anthropogenic amendment was identified in deepened top soils near Skaill Home Farm, Bay of Skaill (HY 235 184) and this profile was recorded and sampled. It was anticipated that these soils would provide the characterisation of soils associated with the most extreme levels of historical soil amendment, aiding the interpretation of the materials and processes of formation and any post-depositional function associated with SSBCR identified within the WHS IBZ.

4.4.1 Field Observations

Field observations have recorded a soil profile which shows clear evidence of anthropogenic amendment. The profile was excavated down to the glacial drift C horizon, exposed at a depth of 1.35 m (Figure 18). As at Finstown, this glacial material is poorly sorted and includes angular sandstone boulders, pebbles and clay material within a clay matrix. Above the glacial drift, a soil profile extends which is composed of anthropogenic amended material identified by the presence of charcoal and unburnt bone within what are clearly anthropogenic horizons separated by clear and abrupt horizon boundaries. Discrete horizons exist within the anthropogenic soil profile, which were identifiable by subtle differences in colour and texture (Figure 18). An obvious observation within the profile was the abundance of calcareous aeolian deposited sand within the profiles upper horizons.

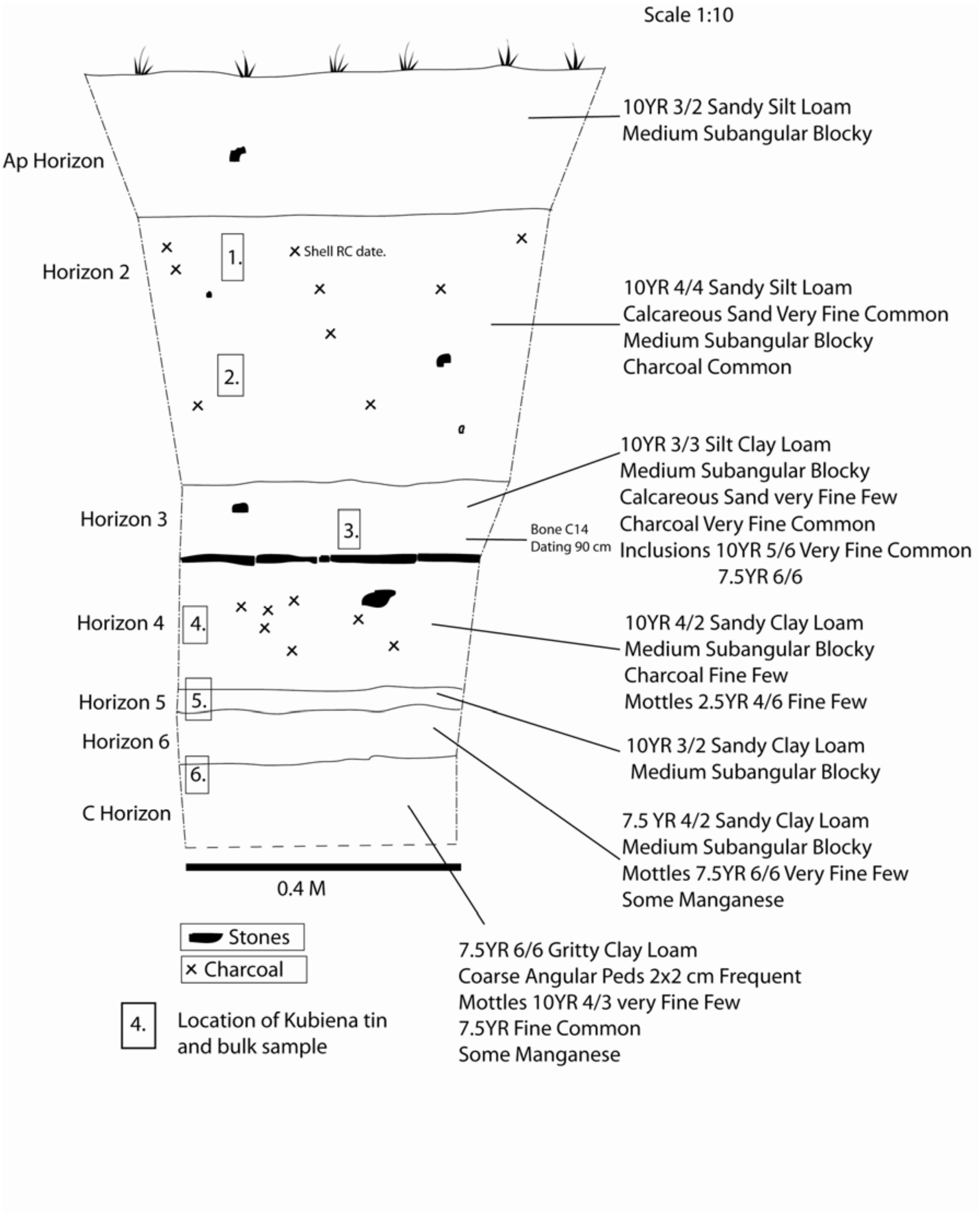


Figure 18 Skaill Control profile

4.4.2 Chronology

A piece of bone was identified at a depth of 0.9 m within the Skaill Control profile (Figure 18). This was identified as a right metacarpal cattle bone (Smith *pers comm.*) and was submitted for radiocarbon analysis. See Table 6 for radiocarbon analyses results and calibrated age ranges.

Table 6 Radiocarbon results

Lab Number	**Reporting Number**	**Sample type**	**Context**	**δ13C**	**14C Age (yr BP ± 1 σ)**	**Calibrated Age Ranges (yr B.C to 2 σ)**
GU-13805	SUERC-9240	Cattle Bone	Skaill Control 0.9 m	-27.7	2530 ± 35	800–530

4.4.3 pH and Soil Organic Matter Content

The pH within Skaill Control is generally around neutral, ranging from pH 6.5-7.4 (Table 7). The anthropogenic horizons 3 and 4 are slightly more acidic with a pH ranging from 6.5-6.9. LOI results do not identify an obvious pattern of changing organic matter content with depth within the profile but it is apparent that anthropogenic horizon 3 has a greater organic matter content than overlying anthropogenic horizon 2 and the surface A horizon (Table 7). The organic matter content of the glacial drift C horizon is low and is comparable to the glacial moraine of Finstown Control.

Table 7 Skaill Control pH and organic matter content

	Range of pH	**Range of Organic matter content (%)**
Ap horizon	7	5
Anthropogenic Horizon (2)	7-7.2	3-4
Anthropogenic Horizon (3+4)	6.5-6.9	5-14
C horizon	7.4	4

4.4.4 Particle Size Distribution (PSD)

PSD shows clear differentiation with depth with the profile at Skaill Control (Figure 19). Horizon 2 (samples 2A and 2B) is dominated by fine and medium sands representing the calcareous sand content. The anthropogenic horizon beneath horizon 2, which has also been identified as being anthropogenic by field observations (sample 3 and 4), is dominated by silt material including fine, medium and coarse silts. The PSD from samples of glacial drift C horizon at the base of this profile (sample 7) are comparable to those associated with the glacial moraine at Finstown Control and show a PSD dominated by coarse sands.

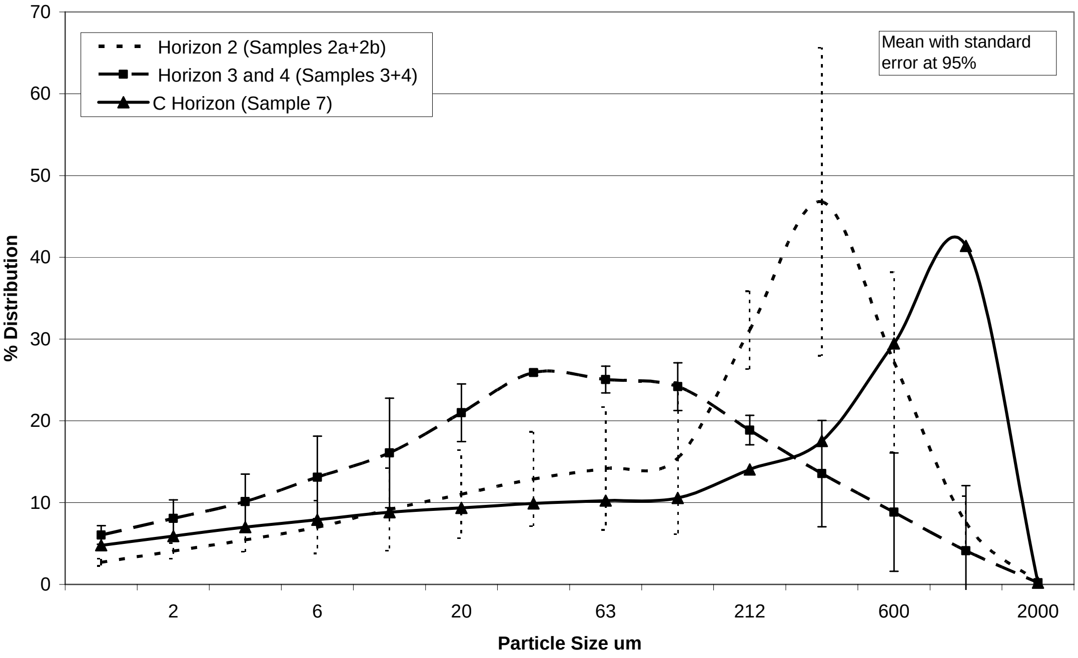


Figure 19 Skaill Control PSD

4.4.5 Total Phosphorus

Total phosphorus analysis clearly identifies the enhanced phosphorus concentrations associated with anthropogenic horizons (Figure 20). Samples from the anthropogenic deepened topsoil identified in the field by the presence of charcoal (Horizon 2a and 2b) have mean total phosphorus concentrations of 206 (± 11) and 181 (± 3) mg/100g oven dried soil. These values indicate that these horizons are enhanced around 4 times from the mean total phosphorus concentration (54 mg/100g oven dried soil) of the moraine material at Finstown Control site. Total phosphorus concentrations within these anthropogenic soil horizons are much greater than the total phosphorus concentrations associated with modern day agricultural practices identified within the A horizon (Figure 20). Total phosphorus concentrations of 155 mg/100g oven dried soil have also confirmed the anthropogenic nature of Horizon 3, although field characteristics suggest that is the result of a different process of formation that associated with Horizon 2.

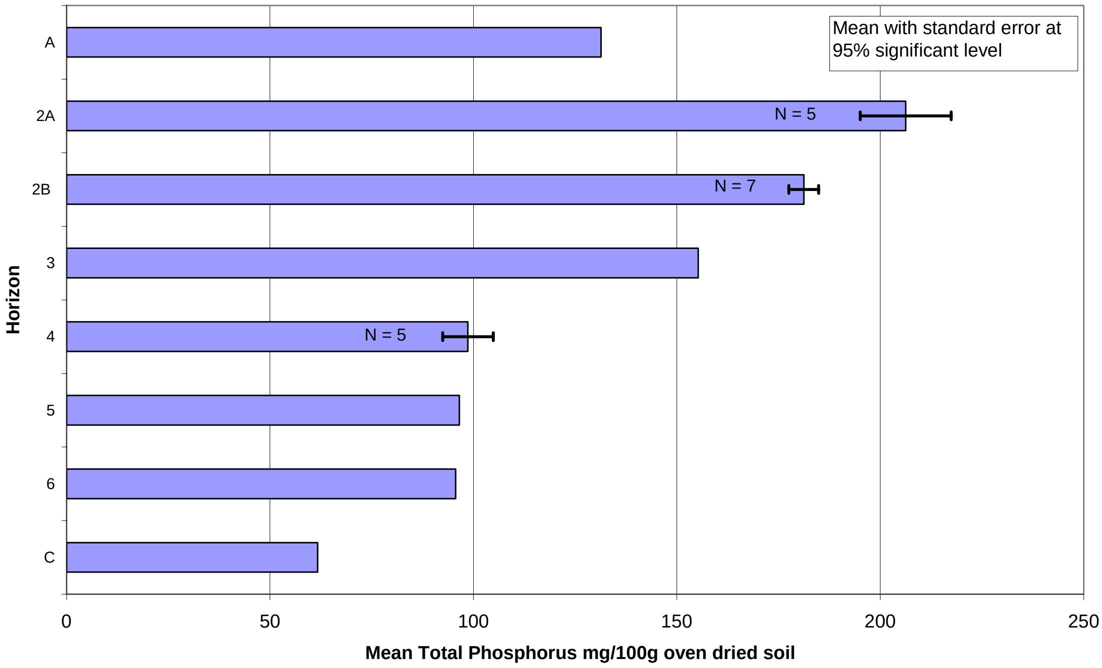


Figure 20 Skaill Control total phosphorus

The total phosphorus concentration of the C horizon at the base of the profile, identified as glacial drift is 62 mg/100g oven dried soil. This is comparable to the mean total phosphorus concentration of the moraine material from Finstown Control (54 (± 2) mg/100g oven dried soil), suggesting that phosphorus associated with intense organic material application and agricultural intensification has not leached down the profile. It is anticipated that the majority of phosphorus within this predominantly alkaline profile would be combined with calcium ions and would therefore be insoluble and unlikely to leach down the profile.

4.4.6 Mass Susceptibility (χ)

Mass susceptibility results from subsurface horizons containing anthropogenic inclusions have an enhanced susceptibility relative to both surface A and subsurface C horizons (Figure 21). The mass susceptibility of the horizons containing anthropogenic inclusions within this profile ranges from $1.26\text{x}10^{-6}$ m^3kg^{-1} to $3.84\text{x}10^{-6}$ m^3kg^{-1}.

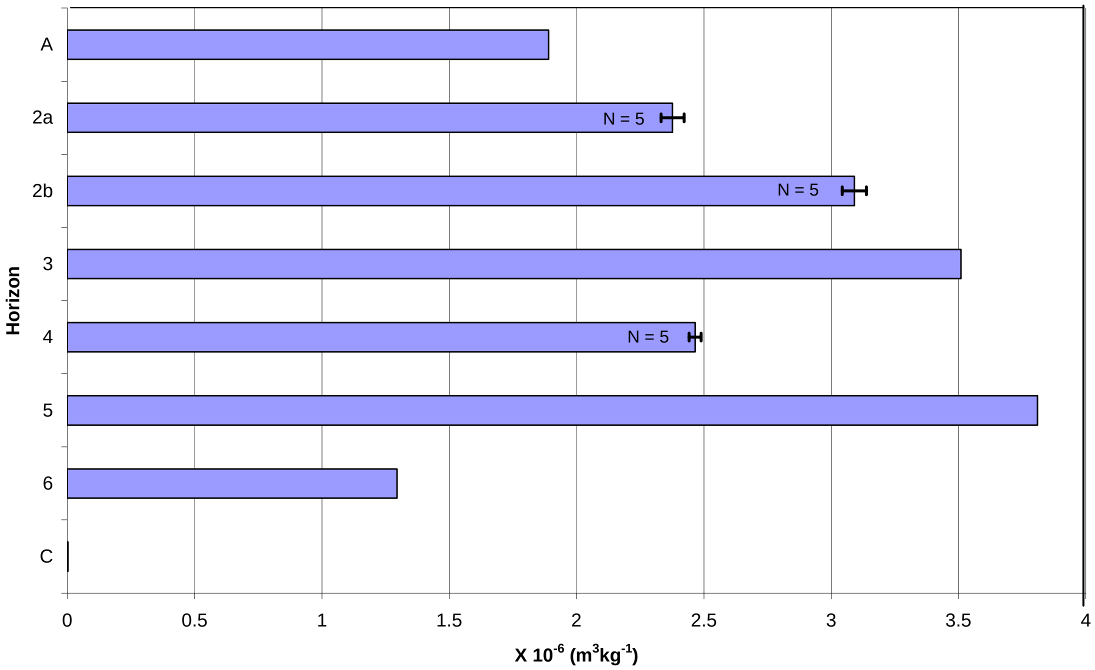


Figure 21 Skaill Control mass susceptibility

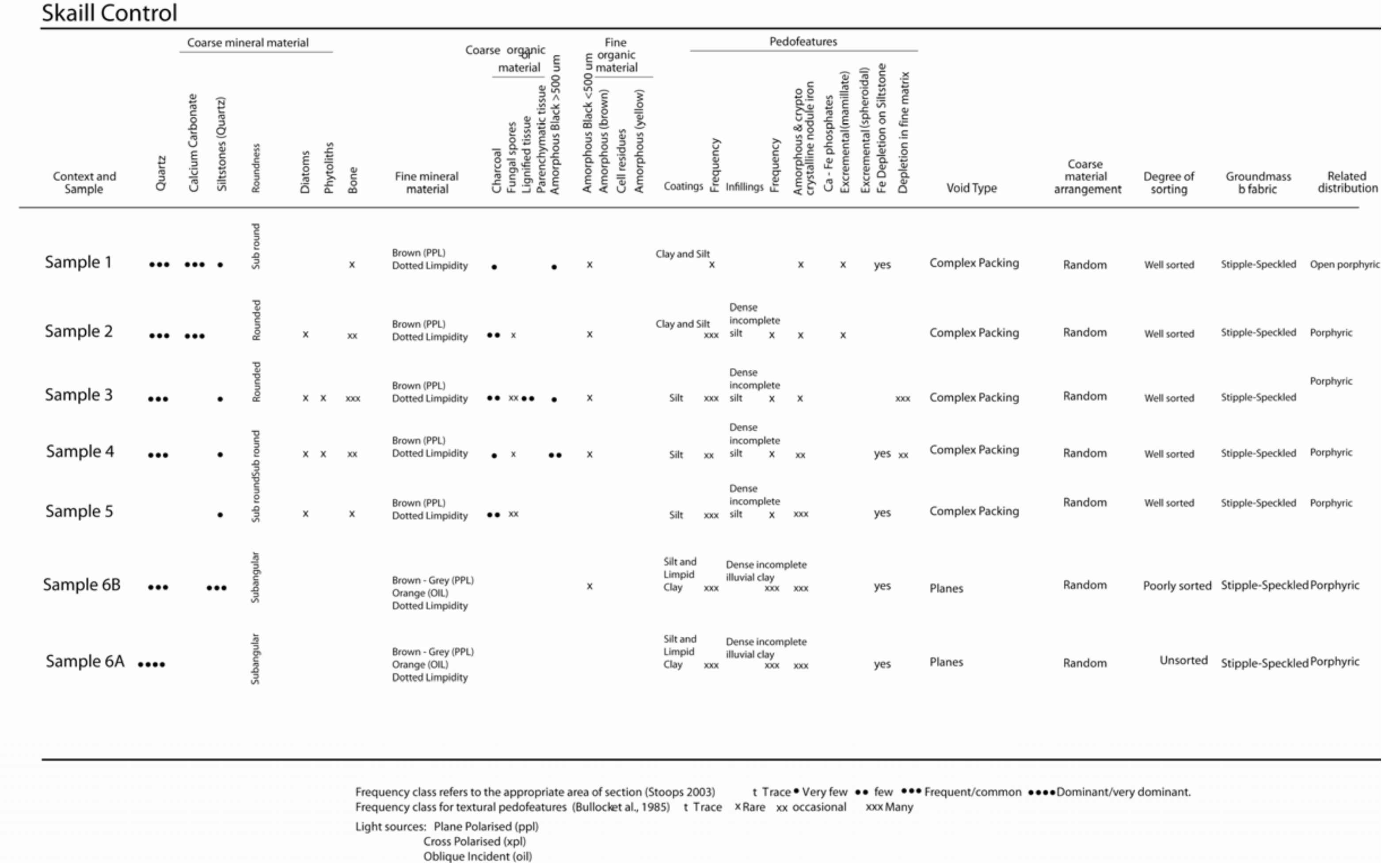
4.4.7 Thin Section Micromorphology

Micromorphological analysis further identifies that the coarse mineral component of the soil within this profile above the subangular glacial drift C horizon is subrounded or rounded and is dominated by its quartz material which has a frequent abundance (30%). Siltstones, also composed of quartz are rare (5%) but are present throughout the profile and the abundance of these siltstones increases to up to 50% of samples from the unsorted glacial drift C horizon below the anthropogenic deepened topsoil. Siltstones in each thin section down the profile exhibit slight iron depletion in the rims typically measuring 125-250 μm, although these depletion features are not observed within every siltstone. It is obvious in thin section that the coarse mineral calcium carbonate component is only evident within slides from horizon 2 (Figure 22), with no calcium carbonate identified in thin section at any greater depth within the profile.

The anthropogenic influence upon this soil profile was obvious within micromorphological observations which identified the presence of charcoal and uncremated bone within each horizon of this profile except for within the C horizon composed of glacial drift. The majority of the bone is very fine (500-1000 μm) and some is enriched by iron in thin section (Figure 22). Charcoal material was identified within thin section as having an obvious internal cellular structure. Black material identified within thin section with no obvious internal cellular structure was recorded as black amorphous material (Figure 22). The greatest anthropogenic influence in terms of the addition of charcoal and bone appears to be present in samples 2, 3, 4 and 5 and fungal spores, diatoms and a few phytoliths are also present within these samples. The diatoms and phytoliths in slides 3 and 4 are essentially observed within discrete features of the fine matrix which are grey in colour and typically in the region of 1-2 mm in diameter (Figure 22).

Textural pedofeatures are present within each horizon throughout the profile. Clay and silt coatings are observed with rare frequency in slide 1, but with a frequency of many within slides 2–6. The coatings and pedofeatures associated with horizons identified as resulting from anthropogenic formation processes are predominantly silt coatings with some impure clay material (Figure 22). This is in obvious contrast to the coatings and pedofeatures associated with the glacial drift C horizon which are dominated by limpid clay coatings. There are many infilling pedofeatures within the glacial material which are also dominated by dense, incomplete infillings of illuvial clay whereas infillings in the soil horizons above the glacial material are rare and are composed of incomplete infillings of silt material. Typic iron nodules were identified in thin section throughout the profile with their occurrence increasing in frequency towards the base of the profile.

Table 8 Skaill Control thin section micromorphologyresults



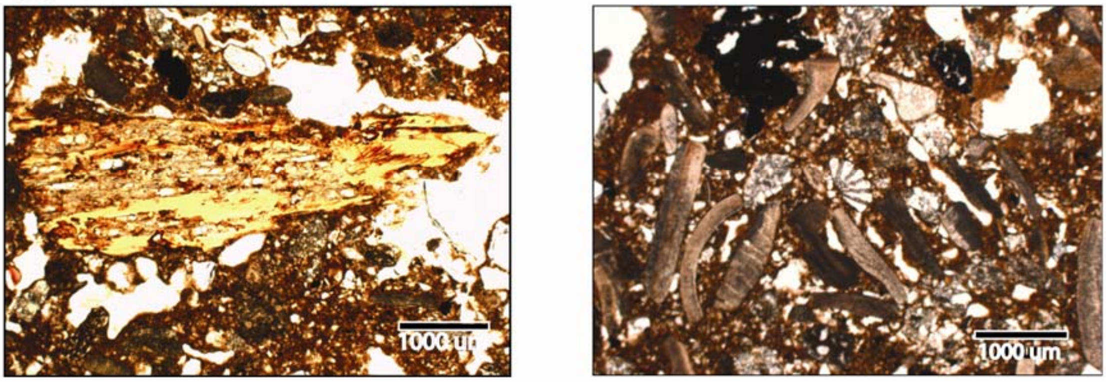
Skaill Control

	Coarse mineral material								Coarse organic material					Fine organic material				Pedofeatures														
Context and Sample	Quartz	Calcium Carbonate	Siltstones (Quartz)	Roundness	Diatoms	Phytoliths	Bone	Fine mineral material	Charcoal	Fungal spores	Lignified tissue	Parenchymatic tissue	Amorphous Black >500 um	Amorphous Black <500 um	Amorphous (brown)	Cell residues	Amorphous (yellow)	Coatings	Frequency	Infillings	Frequency	Amorphous & crypto crystalline nodule iron	Ca - Fe phosphates	Excremental(mamillate)	Excremental(spheroidal)	Fe Depletion on Siltstone	Depletion in fine matrix	Void Type	Coarse material arrangement	Degree of sorting	Groundmass b fabric	Related distribution
Sample 1	•••	•••	•	Sub round			x	Brown (PPL) Dotted Limpidity	•				•	x				Clay and Silt	x			x		x		yes		Complex Packing	Random	Well sorted	Stipple-Speckled	Open porphyric
Sample 2	•••	•••		Rounded	x		xx	Brown (PPL) Dotted Limpidity	••	x				x				Clay and Silt	xxx	Dense incomplete silt	x	x		x				Complex Packing	Random	Well sorted	Stipple-Speckled	Porphyric
Sample 3	•••		•	Rounded	x	x	xxx	Brown (PPL) Dotted Limpidity	••	xx	••		•	x				Silt	xxx	Dense incomplete silt	x	x					xxx	Complex Packing	Random	Well sorted	Stipple-Speckled	Porphyric
Sample 4	•••		•	Sub round	x	x	xx	Brown (PPL) Dotted Limpidity	•	x			••	x				Silt	xx	Dense incomplete silt	x	xx				yes	xx	Complex Packing	Random	Well sorted	Stipple-Speckled	Porphyric
Sample 5			•	Sub round	x		x	Brown (PPL) Dotted Limpidity	••	xx								Silt	xxx	Dense incomplete silt	x	xxx				yes		Complex Packing	Random	Well sorted	Stipple-Speckled	Porphyric
Sample 6B	•••		•••	Subangular				Brown - Grey (PPL) Orange (OIL) Dotted Limpidity						x				Silt and Limpid Clay	xxx	Dense incomplete illuvial clay	xxx	xxx				yes		Planes	Random	Poorly sorted	Stipple-Speckled	Porphyric
Sample 6A	••••			Subangular				Brown - Grey (PPL) Orange (OIL) Dotted Limpidity										Silt and Limpid Clay	xxx	Dense incomplete illuvial clay	xxx	xxx				yes		Planes	Random	Unsorted	Stipple-Speckled	Porphyric

Frequency class refers to the appropriate area of section (Stoops 2003) t Trace • Very few •• few ••• Frequent/common ••••Dominant/very dominant.
Frequency class for textural pedofeatures (Bullock et al., 1985) t Trace × Rare xx occasional xxx Many

Light sources: Plane Polarised (ppl)
Cross Polarised (xpl)
Oblique Incident (oil)

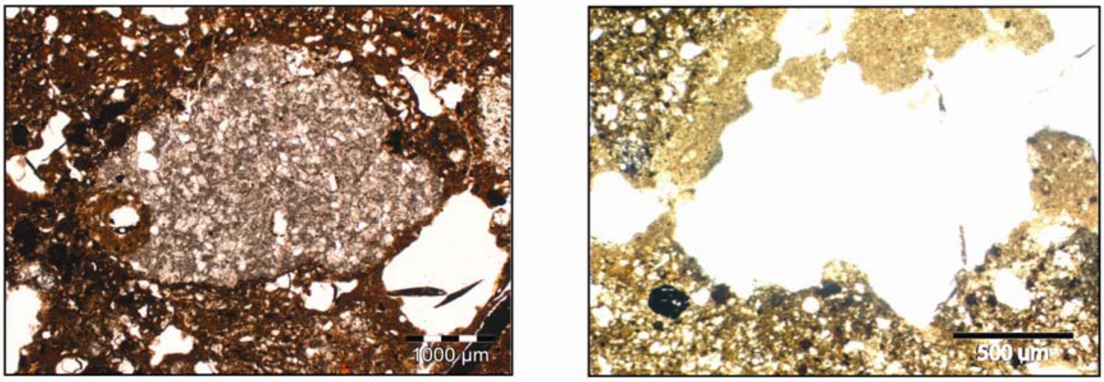
Plaggen Horizon



Sample 2a. Bone identified by haversian cannals

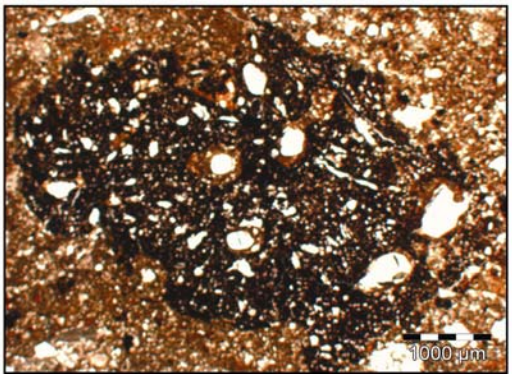
Sample 2b. Calcium carbonate representing a considereable aeolian deposition of sand.

Late Bronze Age/Early Iron Age Horizon



Sample 3. Grey fuel ash depletion feature containing phtoliths and diatoms

Sample 3. Textural pedofeatures, silt coatings



Sample 4. Black amorphous material containing mineral inclusions and interpreted as turf.

Figure 22 Skaill Control key thin section features (PPL)

4.5 Discussion

4.5.1 Period of Formation

Radiocarbon analysis for the cattle bone within the profile at Skaill Control suggests a calibrated radiocarbon age of death of the cattle as being 800-530 cal BC (Table 6). Care must be taken over the interpretation of this single result but the stratigraphic location of the sample from below the plaggen horizon may support the identification of an earlier date than indicated for the commencement of plaggen soil development around Marwick (Simpson 1997). The significant discrepancy between the calibrated radiocarbon date from Skaill Control (800-530 cal BC) with those used to infer deep topsoil formation and cessation at Netherskaill, Marwick (1022-1187 cal AD and 1425-1475 cal AD, Simpson 1993) suggests that it is more likely that the amendment of soils by deliberate anthropogenic activity including the addition of bone and charcoal at Skaill Control occurred significantly earlier than deep top soil formation around Marwick. The calibrated radiocarbon date from the profile at Skaill Control suggests that soil amendment was occurring during the Late Bronze Age/Iron Age (LBA/IA) with the location of the sample 0.28 m above the base of the anthropogenic horizon possibly suggesting that this soil amendment was occurring significantly earlier.

4.5.2 Materials and Processes of Formation

4.5.2.1 C Horizon and Horizons 5 and 6

PSD and total phosphorus results from the glacial drift C horizon at Skaill Control are comparable to results from the glacial moraine at Finstown. Furthermore, the thin section sample from this horizon (slide 6b) is also comparable to the material at Finstown being poorly sorted and dominated by siltstones of quartz mineralogy with a dominant abundance (50%) which is angular and randomly arranged. Many limpid clay textural pedofeatures are again present both in the form of limpid clay coatings and limpid clay infillings and no organic material is present within this glacial material. The material in this C horizon is clearly comparable to the material from Finstown Control and is interpreted as being glacial drift material.

An observation within thin section of this horizon, which is absent from thin section samples from Finstown is the presence of iron depletion features upon the edges of siltstones and the presence of iron enrichment and typic iron nodules indicative of the mobilisation of iron within the fine soil matrix. It is suggested that these features at Skaill are the result of pedogenic processes during initial pedogenesis which must have taken place upon the glacial material immediately after glaciation under podsolisation. These features are unlikely to form outwith surface horizons as a result of podsolisation (Romans and Robertson 1985) suggesting that this material must have been at the land surface during initial pedogenesis before these original soils were buried by the deposition of materials associated with the anthropogenic activities involved in deep top soil formation.

The initial development of soil by natural pedogenic processes before any anthropogenic amendment within this profile is further evidenced by data from soil horizon 6 (thin section 6a). The total phosphorus concentration of 95 mg/100g oven dried soil for this horizon is greater than that of the underlying glacial material but is below the total phosphorus concentration range of Orcadian deepened top soils demonstrating obvious anthropogenic amendment within the Marwick area (Simpson 1997). The thin section from this horizon (6a) remains dominated by features associated with the glacial material including frequent siltstones (30%) and many limpid clay textural pedofeatures, however field observations indicate a subtle change in colour and a gradual boundary between this horizon and the underlying glacial drift and some amorphous black organic material is observed within thin section. The presence of this amorphous black organic material is consistent with this soil horizon representing initial pedogenesis upon the underlying glacial material and the gradual horizon boundary is also suggestive of gradual change during initial pedogenesis.

Horizon 5 is also interpreted as representing early pedogenesis with a similar total phosphorus concentration and some similar micromorphological features to those in horizon 6. The diffuse horizon boundary between horizon 6 and horizon 5 suggests continued pedogenesis under the dominant influence of climate, biota and topography without any significant anthropogenic influence. There are however some obvious micromorphological differences between horizon 5 and 6 (thin sections 5 and 6a) which lead to the interpretation that this horizon represents the initial utilisation and amendment of the soil resource by anthropogenic activity. Evidence for this interpretation is present in thin section with the identification of anthropogenic inclusions including very few (rare) and very fine unburnt bone, few charcoal inclusions and possibly by occasional *sclerotia* fungal spores, which have previously been interpreted within the context of deepened topsoils as being indicative of the addition of animal manures (Simpson 1997).

Textural pedofeatures were again observed within this horizon in the form of silt coatings with a frequency of many and as rare infillings identified as dense incomplete silt infillings. These textural pedofeatures are obviously different from the limpid clay textural pedofeatures observed within the glacial material (Figure 17 and Figure 22). Silt textural pedofeatures have been discussed in great detail within the context of micromorphological interpretations within geoarchaeological research (for example see Carter and Davidson 1998, Macphail 1998, Carter and Davidson 2000 and Usai 2001). The majority of this discussion revolves around the processes involved in their formation and as such these features will be discussed fully within the context of the post-depositional function of this anthropogenic soil. It is sufficient here to suggest that these silt textural pedofeatures features which are obviously different to the previously discussed limpid clay pedofeatures and are present alongside bone and charcoal material in what is clearly an anthropogenic amended horizon, suggesting their likely anthropogenic origin. Horizon 5 has a mean total phosphorus concentration of 96 mg/100g oven dried soil which is similar to that of horizon 6. This suggests that while this horizon has been amended by anthropogenic activity that there has not been an intense application of organic material. This is consistent with the interpretation of representing initial amendment and utilisation of soil within this profile by anthropogenic activities.

4.5.2.2 Horizon 3 and 4

Field observations and other analyses indicate that Horizon 3 and 4 display very similar characteristics and are likely to have been formed as the result of the same processes. As such these two horizons will be discussed as one pedo-stratigraphical unit. The presence of a layer of stones within this pedo-stratigraphical unit (separating Horizon 3 and 4), observed during field work is slightly problematic and cannot easily be explained within the confines of this soil profile. It has clearly been put there by some anthropogenic activity, however; there is no evidence to suggest that these stones represent *in situ* structural archaeology within this profile.

This pedo-stratigraphical unit represents soil which has been amended by anthropogenic activity, made obvious by charcoal and bone inclusion observed in field observations. The horizon boundary between horizon 5 and horizon 4 is clear and is interpretated as a result of the establishment upon the pre-existing profile profile of specific anthropogenic amendment. Field observations, supported by thin section observations confirm that horizon 4 contains very few (>5%, occasional) fine bone fragments and very few (>5%) charcoal inclusions whereas horizon 3 contains few (5-15%, many) fine bone fragments and few (5-15%) charcoal inclusions. Radiocarbon analysis suggests that this horizon developed as a result of Late Bronze or Early Age Iron Age (LBA/IA) cultural practices**.** Total phosphorus analysis can be used to identify the intensity of organic material application to soils and as may be expected due to the greater abundance of anthropogenic organic amendments identified within thin section within these horizons, total phosphorus concentrations of these horizons are greater than for the underlying horizons. The total phosphorus concentration of 155 mg/100g oven dried soil associated with the more amended horizon 3 is well within the range of total phosphorus concentrations associated with anthropogenic deepened top soils within the Marwick area associated with formation between *c.*1200 and the late 1800s AD (Simpson 1997). However, there do remain several clear differences between micromorphological features of soils from these two sites suggesting at least in part differences attributed to formation processes, as may be expected from their formation within different time periods.

A key micromorphologial feature present only within horizons 3 and 4 of this profile are features identified within the fine soil matrix. These features occur with a frequency of occasional-many within Horizon 3 and 4 and are not interpreted as resulting from iron movement in podsolisation. The features are obvious within the soil fine matrix as appearing as discrete grey features which are bright orange under OIL. Under higher magnification these features are seen to contain rare diatoms and phytoliths which are not present outwith of these features within the soil matrix (Figure 22, Sample3). These grey features are interpreted as representing a significant peat/turf ash content within these horizons, with the observation of diatoms suggesting that the most likely source for this material as being formed upon a poorly drained, wet substrate (Simpson and Barrett 1996). The use of turf here and hereafter is used to refer to the uppermost layer of surface soil which is usually matted by grass and plant roots (Gregoritch *et al* 2001). Historical documentation highlights the abundant use of this turf resource as a fertilizer for arable land management on Orkney, for example see Simpson 1997, Clouston 1914 and 1919 and Thomas 1852. Further evidence of the addition of burnt turf material in thin section in these horizons is the presence of black amorphous material, some of which can be identified as having an internal crystallic structure under cross polars which is the result of its mineralogy and supports the interpretation of burnt turf material (Figure 22, Sample 4). The evidence of significant peat/turf ash content within these horizons is further supported from the particle size distribution which is dominated by particles in the coarse silt size class. This is consistent with an interpretation of a significant contribution of peat/turf ash (Guttmann 2001, Simpson *et al* 2006).

Further evidence to support the burning of this material prior to deposition is found in thin section by a feature identified within Horizon 3. This feature could be tephra or siliceous vesicular glassy slag, both of which suggest burning but in the context of this deepened anthropogenic soil it is more likely to be silicateous ash from the ash of plant material (Canti 2003). Interestingly the bone material within these horizons does not show any evidence of being burnt which suggests that the bone has been incorporated into burnt turf material after the turf has been burnt, prompting the consideration of different pathways of deposition of materials into these anthropogenic soils.

The presence of very few (abundance <5%, frequency: many) fungal spores may again indicate the presence of animal manures within these amended soil horizons, suggesting that animal manures were deliberately incorporated within this peat/turf ash material prior to deposition or that animals were deliberately stalled or grazed upon this material subsequent to deposition. The incorporation of material which was previously surface turf material into these horizons is evidenced by the presence of iron depletion features at depth upon siltstones identified in thin section. As previously discussed these features are indicative of podsolisation and their thickness and uniformity with depth suggests that the podsolisation giving rise to them did not take place within a buried soil but within the upper surface of a well developed podsol. As in Horizon 5 textural pedofeatures are dominated by many silt coatings and few dense incomplete infillings of silt, these are discussed further in Section 4.5.3.1.

The radiocarbon date of 800-530 cal BC from horizon 3 suggests the formation of this horizon has occurred as the result of anthropogenic activity within the Late Bronze Age/early Iron Age. This is significantly earlier than the commencement of deepened topsoils formation around Marwick within a plaggen land management system, and it is therefore unsurprising that these results indicate a different process of formation to that observed by Simpson (1997). A proposed model of formation based upon these results and discussion involves the initial removal of turf for use as a fuel resource, the burning of this fuel within domestic settlement activity, the mixing of turf ash with domestic waste including bone and charcoal and the subsequent deposition of this anthropogenic deposit within the landscape for the purpose of maintaining and enhancing soil fertility.

4.5.2.3 Horizon 2

Field observations identify an abrupt boundary between horizon 3 and horizon 2. Horizon 2 has also been augmented with bone and charcoal material and thin sections confirm the presence of few (5-15%, occasional) bone fragments and few charcoal inclusions. The absence of burnt edges on other bone fragments suggests that the bone material has not been burnt prior to deposition. There are no fuel ash features within this horizon, and the PSD is not dominated by silt but by fine sand particles. This suggests that peat/turf ash does not represent a significant input into this soil horizon. It is suggested however, that this horizon has been thickened by anthropogenic activity including the addition of charcoal and bone fragments. There are very occasional diatoms present within the fine soil matrix (not within the grey fine matrix as in horizon 3 and 4) which does suggest the addition of turf material to this soil although there is no indication of any burning prior to deposition and it is concluded that turf material was added without being burnt. The identification of diatoms within fuel residues in horizon 3 and within the fine matrix of horizon 2 along with evidence in both horizons of siltstones with iron depleted rims may suggest that the turf material within both horizons has been removed from the same geographical location.

The total phosphorus results indicate that this horizon contains the greatest concentration of phosphorus within this profile, a statistically greater concentration of phosphorus than within horizon 3 and 4 (Mann Whitney W115, P 0.007 at 95% significance level, 10 replicate samples from horizon 2, 6 replicate samples from horizon 3 and 4). Samples from around Kubiena tin 1 (sample 2A) contain a mean total phosphorus concentration of 206 (± 11) mg/100g oven dried soil and samples from around Kubiena tin 2 (sample 2B) contain a mean total phosphorus concentration of 181 (± 3.6) mg/ 100g oven dried soil. These total phosphorus concentrations are comparable to those of anthropogenic deepened top soils within the Marwick area which have a mean total phosphorus concentration of 234 mg P/100g oven dried soil and a range of 109-509 mg P/100g oven dried soil (Simpson 1997). Total phosphorus results suggest that this horizon has received the greatest intensity of organic material application within the soil horizons in this profile; although thin section micromorphology suggests that there is less bone and charcoal material within this horizon than within horizons 3 and 4. It is suggested that this high concentration of phosphorus is the result of the application, during formation of organic materials which are now entirely decomposed and cannot be observed directly within thin section. The similarity in total phosphorus concentrations and of features in thin section of this soil horizon with previous research into deep top soil formation may suggest that as around Marwick, the intensive agricultural system responsible for the formation of this deepened top soil involved the application of grassy turf material from the hill land together with animal manures (Simpson 1997). Total phosphorus results from this horizon are consistent with those of Simpson (1997) who identifies the intensity of organic material application increasing as deep top soils developed and attributes this to an increasing importance of animal manures in maintaining soil fertility. It should be noted that the presence of bone within this profile is consistent with observations of deepened top soils around Marwick (Simpson 1997), although the relative abundance of bone within this profile may in part be the product of localised preservation factors.

Textural pedofeatures are present within thin section samples from this horizon although they differ slightly in composition to those occurring in horizon 3 and 4. Occasional clay and silt coatings occur within the sample toward the top of this horizon with many silt and clay coatings and occasional dense incomplete infillings of silt occurring towards the base of this horizon. An obvious feature in thin section within this horizon is present within the coarse mineral content of the thin sections. The coarse mineral content of samples from the rest of the profile is relatively uniform with 25-30% quartz which may suggest a common source for all the inorganic material used to amend these soils; however such an interpretation demands a cautious approach in Orkney where there is little geological variation. Of interest within thin section samples from horizon 2 is the presence of frequent (30%) calcium carbonate which is well sorted and well rounded and interpreted as being the result of aeolian deposition of calcareous sand material. The abundance of this material within these horizons suggests an interpretation of formation materials and function of these anthropogenic soils within the backdrop of increasing aeolian deposition of calcareous sand and potential environmental degradation (Chapter 8).

The above discussion suggests that formation of this anthropogenic horizon has occurred as a result of a similar Medieval and Early Modern cultural practice to that observed by Simpson (1997) in Marwick. The summarisation of this practice involves the removal of turf, probably from outwith a hill dyke that would have enclosed the more intensively used agricultural area, and the subsequent use of this turf for bedding within the byre before being composted within the Toft along with animal manures and charcoal from domestic fires. The resulting composted material then performed a post-depositional arable function as it became spread onto the fields to maintain the fertility of the intensively cultivated Tunmal arable land.

4.5.3 Post-depositional Function

4.5.3.1 Horizon 2

Results and analyses of the soil properties of soils from horizons within this profile at Skaill control have identified the obvious anthropogenic amended nature of the soils within this profile. Analyses have indicated that soil properties within horizon 3 and 4 differ significantly to those in horizon 2 and it is suggested that these soil horizons have developed through different processes, within different time periods in prehistory and history; as proposed by discussed models of formation and the abrupt horizon boundary between horizon 3 and horizon 2. What is unclear at present however is whether the post-depositional function of these SSBCR changed with different soil formation processes or whether both soil formation processes were employed for the same post-depositional functional purpose.

Results indicate that the properties of the anthropogenic amended horizon 2 within this deepened topsoil at this site, along with the proposed model of formation are consistent with those from deepened topsoils around Marwick, suggesting that they have also been amended to perform a similar function. Simpson (1997) used a combination of analytical techniques along with early historical documentation to identify the post-depositional arable function of these deepened topsoils which occurred within the arable tunmal (Old Norse) land. This land was held permanently by the adjacent farmstead and unlike other areas of arable land was not subject to periodic distribution (Clouston 1919). The earliest map from Marwick is from 1750 AD (Mackenzie 1750) and does demonstrate a broad division in the cultural landscape between the hill land and the agricultural land enclosed by a turf dyke. Different functional areas are evident within the enclosed land with substantial patches of arable land within a grassland matrix and areas of meadowland also evident (Simpson 1997).

The same 1750 Orcades map series (Mackenzie 1750) does not show the equivalent detail for the Bay of Skaill, although again the broad division in the cultural landscape between the hill land and the agricultural land enclosed by a turf dyke is evident. The Skaill Control profile is clearly located within agricultural land located within the turf dyke and the proximity of this location to the townships of Skail and Suthisquoy identified from the 1595 AD Rentals (Clouston 1914) contributes to the suggestion that the deepened top soil mapped by the Soil Survey Scotland (Macaulay Institute for Soil Research 1981), in which the Skaill Control profile has been located, represents the tunmal land used for arable agriculture land. The first edition of the Ordnance Survey map for Orkney also provides evidence to support the suggestion that this control profile is located within land used for arable agriculture, which by 1882 AD had become defined within regular field boundaries (Ordnance Survey 1882).

The identification of textural pedofeatures of silt coatings and silty clay coatings (Stoops 2003) within thin section samples from this horizon may also support an interpretation of a post-depositional arable function. The formation of these textural pedofeatures has been discussed within the context of cultivation where soils are exposed, lacking in permanent vegetation cover and with declining structural stability associated with a reduced surface organic matter content with the physical processes forming these features being attributed to the structural break-up of surface peds possibly by cultivation implements (Carter and Davidson 1998). Problems of equifinality concerning the formation of these textural pedofeatures do exist (section 3.2.6), but Simpson (1997) has securely interpreted similar clay and silt textural pedofeatures from deepened top soils at West Howe, Marwick within the context of known historical historical land use and agricultural practices as being indicators of ancient cultivation. The textural pedofeatures at Skaill are similar in content to those observed by Simpson (1997), including both silt coatings and silty clay coatings (Stoops 2003) with limpid clay coatings only present within the underlying glacial material. The textural pedofeatures from Skaill Control are also of a similar magnitude of size to those observed by Simpson (1997) with silty clay coatings in the region of 60-70 µm in thickness and silt coatings being up to 150 µm in thickness. These features are therefore interpreted as likely to be the result of similar cultivation practices to those exerted upon the deepened top soils of Marwick, probably involving moderately intense cultivation under the influence of the one-stilted plough (Fenton 1997, Simpson 1997).

There is therefore sufficient evidence from the soil properties within horizon 2 and the historical literature available to suggest that horizon 2 within this profile represents a deepened topsoil which formed as the result of similar cultural practices, most likely within a similar time period to the deepened topsoils identified around Marwick (Simpson 1997). It is therefore interpreted that its formation was part of deliberate land management activity designed to maintain the fertility of the arable tunmal land. A question remains however as to the function of horizons 3 and 4 which represents a clearly different process of formation to the overlying deepened topsoil and is clearly the product of much earlier, Late Bronze Age/Iron Age cultural (LBA/IA) activity.

4.5.3.2 Horizon 3 and 4

In the absence of any historical literature concerning settlement and/or any known land management activity dating to the LBA/IA within the Bay of Skaill the post-depositional function has been determined by contextualising the anthropogenic soil deposits resulting from LBA/IA cultural activity within the profile at Skaill Control with those of other anthropogenic enhanced soils resulting from Iron Age cultural activity within the Northern Isles. Research from the multiperiod site of Old Scatness, Shetland has identified distinct, multiple phases of archaeological activity including multiple buried anthropogenic amended soils over which a chronology has been established. Recent research concerning these arable soils identified their function as arable soils through the identification of ard marks and suggests that at this site the arable soils associated with the early Iron Age were fertilised with domestic waste composed almost entirely of peat ash with a minor component of fine charcoal, heated stone and animal bone (Guttmann *et al* 2006). This early Iron Age arable soil at Old Scatness is comparable in characteristics to the LBA/IA soil horizon within the Skaill Control profile which may suggest that this soil horizon within Horizon 3 and 4 at the Bay of Skaill was amended by anthropogenic activity in order to perform a function as an arable soil.

Furthermore Guttmann *et al* (2006) identify a change in cultural practices at Old Scatness between the fertilisation of early Iron Age arable soils which were amended with domestic waste almost entirely composed of peat ash and later Iron Age cultural practices which involved maintaining arable fertility within soils by the addition of significant amounts of organic matter including unburnt peat. The occurrence of peat fragments within arable soils in the Northern Isles is generally linked with the plaggen soil system (Davidson and Carter 1998), as previously discussed concerning Orkney and as suggested as being initiated around Marwick between 1242-1407 cal AD (Simpson 1993) The plaggen manuring sytem referred to here and hereafter is used to define the specific process of manuring by cutting turf, using the turf in a byre and subsequently spreading the composted turf and animal manures upon the land (Bridges 1997).

Guttmann *et al* (2006) suggest that as at Old Scatness the plaggen manuring system may have developed within the Iron Age, before becoming more widespread especially within Orkney within the Norse period. Results from Skaill Contol are remarkably similar to those from Old Scatness which have identified early Iron Age activity involving the amendment of soils with large amounts of domestic waste being superseded in time by the amendment of soils with large quantities of organic material. The similarities between results from Old Scatness and Skaill Control supports the argument that the amended soils within horizon 3 and 4 were amended in order to maintain arable fertility within these arable soils. This interpretation is further supported by the presence of *many* silty textural pedofeatures within horizon 3 and 4 of Skaill Control. Silt textural pedofeatures identified within horizon 2 of Skaill Control have been interpreted alongside historic literature as being the result of cultivation. The presence of these textural pedofeatures in the underlying horizons 3 and 4 further suggests that these amended soil horizons were used for a similar function to horizon 2 and therefore that they functioned as arable soils,

Results from Skaill Control concur with those from Old Scatness suggesting that the plaggen soil system which became dominant on Orkney in the Norse period may have originated out of an early Iron Age cultural practice of maintaining arable soil fertility through the amendment of soils with domestic waste, particularly with significant amounts of peat/turf ash. The abrupt horizon boundary between horizon 3 and horizon 2 is not interpreted as a deflation surface which may indicate that arable land management ceased for a period at this site before the commencement of the plaggen manuring system. The longevity of arable land management at this site, along with evidence from Old Scatness suggests continual arable land management but that the change from maintaining arable land fertility through the application of domestic waste, to the subsequent plaggen management may have occurred relatively quickly. Reasons proposed for the change in cultural activity and initiation of plaggen type soil systems have included the introduction of the plaggen manuring technique by monastic settlement and the need to sustain increasing population levels during a climatic optimum (Simpson 1997). This research however, suggests that at least in parts of Orkney the plaggen type land management process evolved out of existing land management activities designed to maintain fertility within soils used for arable activity. The organised settlement and land economy associated with the Norse settlers has for the most part eradicated any pre-existing land management patterns, but it is entirely feasible and indeed is now seems most likely that an organised land economy existed in the Northern Isles long before the Norse settled (Fenton 1997). Any evidence of such land management and SSBCR is likely to be identified within anthropogenic soil profiles such as this one at Skaill Control which identifies a palimpsest of land management activity associated with various societal groups within history and prehistory.

4.6 Skaill Control Conclusion

In conclusion, Skaill Control consists of anthropogenic horizons which have formed as the result of two separate, discrete formation processes. The lower anthropogenic horizon has formed as the result of LBA/IA cultural activity involving the deposition of domestic waste, predominantly peat/turf ash. The upper anthropogenic horizon is consistent with formation through the plaggen system involving the removal of turf material from the hill land, the use of this turf as animal bedding within the byre and then the composting of this turf with animal dung and a small proportion of domestic waste before being spread onto the fields. Despite different processes of formation, both of these soil horizons appear to have been amended in order to perform a post-depositional function of maintaining soil fertility for arable agriculture. As such this control profile has allowed the identification of soil properties associated with both LBA/IA and later plaggen soil cultural activities involved in maintaining arable land fertility.

4.7 *Chapter Conclusion*

This chapter has identified control profiles which have formed from different processes, and has characterised the properties of soil horizons within each control profile (Table 9). The pre-settlement control site at Finstown identifies soil properties characteristic of a glacial moraine which has not been subjected to any anthropogenic influences or amendments. The soil properties of this profile may therefore be considered as a bench mark associated with no cultural influence from which the properties of soils within the WHS IBZ can be compared to ascertain the presence and degree of any anthropogenic influences (SSBCR). The control profile at Finstown Control is not a pre-settlement soil, but a pre-settlement glacial moraine but it may be expected that any soil properties in profiles within the WHS IBZ unaffected by cultural activities may closely resemble the soil properties of Finstown Control (Table 9).

The control profile at Skaill Control has identified two discrete cultural practices which both occurred for the purpose of maintaining soil fertility for arable agriculture. The characterisation of soil properties associated with the plaggen horizon (horizon 2) has identified soil properties associated with extreme cultural amendment resulting from known cultural activities, whereas the characterisation of the soil properties in horizon 3 has allowed the characterisation of soil properties which have resulted from arguably less intensive, earlier and different cultural practices also designed to maintain soil fertility for arable agriculture (Table 9). The characterisation of soil properties within these controls and the correlation of these soil properties with specific cultural practices has allowed the properties of soils within the WHS IBZ to be compared to those resulting from known cultural practices. This has facilitated the inference of anthropogenic activites upon soil properties from soils within the WHS IBZ and has therefore facilitated the identification and interpretation of SSBCR.

The use of these control sites has allowed the processes of formation and any post-depositional function of SSBCR within the WHS IBZ to be evaluated within a control framework ranging from no anthropogenic amendment to extreme amendment within specific cultural practices involved maintaining soil fertility for arable agriculture. It was anticipated that any identified Neolithic SSBCR would exibit soil properties *within* the range of soil properties identified within these control profiles (Table 9).

Table 9 Key characteristics of control profiles

Characteristic	**Finstown Control**	**Skaill Control LBA/IA**	**Skaill Contol Plaggen**
pH range	4.2-4.9	7-7.2	6.5-6.9
Dominant PSD	Coarse sand	Coarse silt	Medium sand
Mass Susceptibility range	$0.04\text{-}01.4\text{x}10^{-6}$ m^3kg^{-1}	$2.23\text{-}3.09\text{x}10^{-6}$ m^3kg^{-1}	$2.4\text{-}3.51\text{x}10^{-6}$ m^3kg^{-1}
Total P range	43-90 mgP/100g dried soil	98-155 mgP/100g dried soil	181-206 mgP/100g dried soil
Thin section observations			
Fuel ash		Many	
Burnt peat/turf		Occasional	Rare
Bone		Occasional Unburnt	Rare Unburnt
Calcium Spherulites			
Coprolite			
Fungal Spores		Occasional	Rare
Pedofeatures: Coatings and Infillings	Many limpid clay coatings and infillings	Many silt coatings and dense incomplete silt infillings	Many clay and silt coatings. Dense incomplete silt infillings
Nodules		Many typic iron	Rare typic iron
Excremental Mamilliate and biological disturbance			Rare
Void Type	Planes and Complex Packing	Complex Packing, few planes	Complex Packing, few planes
Sorting	Poorly	Moderately well	Well
Coarse Mineral	Blocky, angular	Blocky, sub rounded	Blocky, rounded
Related distribution	Porphyric	Porphyric	Open porphyric

Chapter 5 - The Ness of Brodgar

5.1 Introduction

The initial excavation of soil profiles at the Ness of Brodgar was conducted in conjunction with archaeological excavation managed by Orkney Archaeology Trust (OAT). The excavation was designed to evaluate and assess the site in relation to results from its geophysical survey (Card 2004). Soil profiles within each archaeological trench were therefore described by archaeological context following standard soil science survey procedures (Hodgson 1997). This has resulted in all soil horizons being recorded as separate archaeological contexts, but not all contexts representing different soil horizons. Deep homogenous anthropogenic soil horizons were excavated in *c* 0.1 m spits with each spit receiving a separate context number. This resulted in multiple context numbers being assigned to the same anthropogenic soil horizon. This initial investigation was intended to investigate the nature and depth of the site stratigraphy and to obtain soil samples. As such, the majority of trenches were deliberately located away from the main structural archaeological features identified by geophysical survey (Figure 23). Results presented within this thesis are from the stratigraphy and soil based excavation results. These must be interpreted within the context of the excavated archaeological evidence identified by Card 2004, and Card and Cluett 2005.

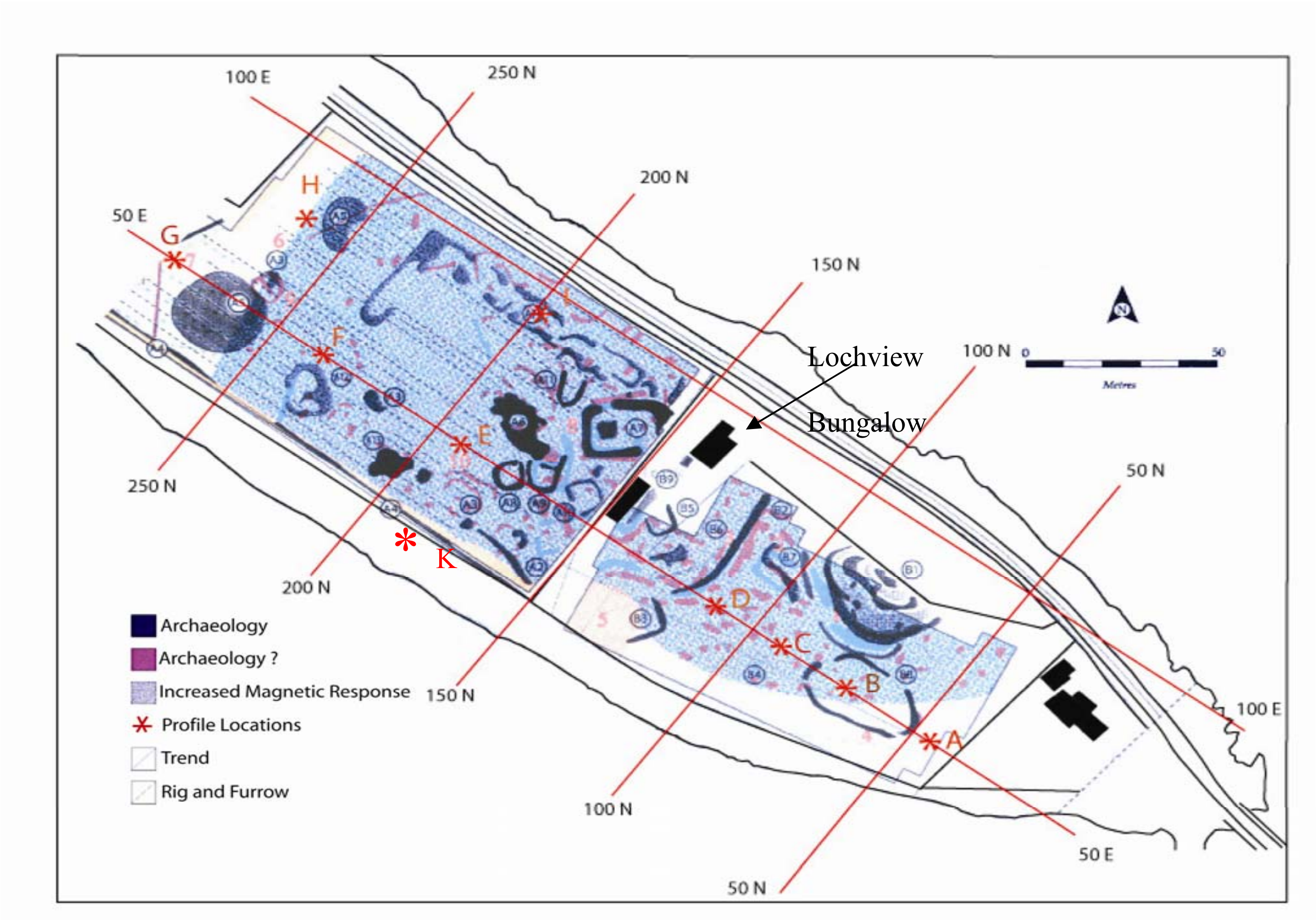


Figure 23 Combined geophysical survey results from the Ness of Brodgar and Trench locations (Card 2004)

5.2 Field Observations

Field observations were undertaken within archaeological trenches located along a transect from Trench A to Trench G. Along this transect, elevation gently increases from both Trench A and Trench G to the highest elevation of the site, a mound below Lochview bungalow. Field observations identified the presence of anthropogenic activity within every trench excavated, with structural archaeology being encountered in the majority of trenches. Very fine-fine charcoal and cremated bone were identified within soil profiles at each trench along with the occurrence of artefactual evidence of lithics and pottery. The nature of the pottery and lithics artefacts indicates that soil profiles have most probably been influenced by Late Neolithic activity associated with structural archaeology on the site (Card 2004, Card and Cluett 2005). More specifically field observations from initial field work in 2004 (Trenches A-G) observe the following. Numbers within parentheses represent archaeological contexts.

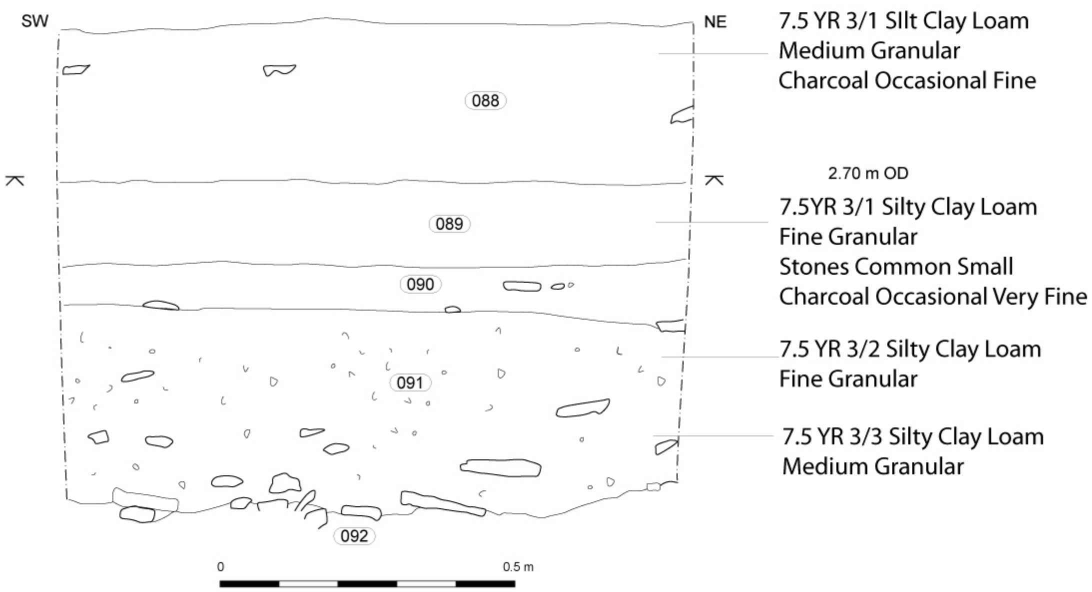
5.2.1 Trench A (Figure 24)

At a depth of *c* 0.4 m from the top of the profile, beneath the topsoil Ap horizon (088) and the ploughsoil (089) was a 0.1m thick horizon consisting of mid orange-brown (7.5YR 3/2) silty clay loam. This horizon (090) contained few, fine charcoal flecks and fragments of cremated bone. Context 090 overlay context 091 which was *c*0.35 m thick and was also a mid orange-brown (7.5 YR 3/3), containing few fine charcoal flecks and fragments of cremated bone but from which 5 lithics were also removed. The soil within this profile has clearly been influenced by anthropogenic activity although the quantities of charcoal and cremated bone within these contexts do not suggest any deliberate enhancement with the addition of household waste material. Context 091 overlay context 092 which was a loose stony layer. Excavation stopped at this level (*c*2.2 m OD) as context 092 may have been part of a larger surface associated with the finding of a 5 lithics. The C horizon presumably at the base of this soil profile was therefore not exposed.

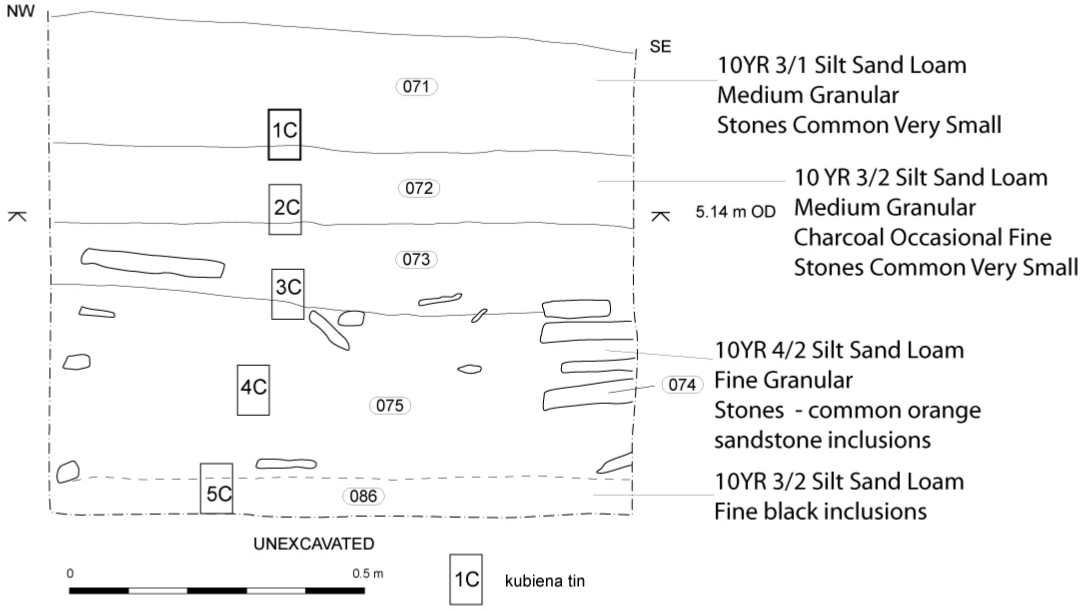
5.2.2 Trench C (Figure 24)

Below the topsoil Ap horizon (071) and the ploughsoil (072), at a depth of 0.35 m was context 073, a mid orange-brown (10YR 4/2) silty clay which was *c* 0.15 m thick. This context contained few, small stones but common fine inclusions of charcoal and cremated bone and burnt stone. This context was well homogenised and appeared very similar to the anthropogenic deposit identified within Trench E. Below context 073 was a spread or dump of medium size rubble (074) which was within a matrix of anthropogenic deposits (075), again identified by the common fine occurrence of inclusions of cremated bone and charcoal. These anthropogenic deposits in context 075 (10YR 4/2 silt sand loam) were slightly less homogenised than those in 073 and also contained inclusions of undisturbed white clay. The rubble (074) had no structure to it and may have been a dump as opposed to a collapse from structural archaeology. Context 075 was removed from out of context 074 to reveal more anthropogenic deposits below (086) which appeared similar to context 074 but also appeared to contain slightly more grey material. Excavation was halted at this level (*c*4.6 m OD) due to the potential complexities of stratigraphy being revealed within this trench which could not be resolved within the limits of this test trench (Card 2004).

Trench A and C



Trench A - SE facing Section.



Trench C SW facing Section

Figure 24 Trench A and Trench C. Adapted from Card 2004

5.2.3 Trench D (Figure 25)

The Ap horizon (079) and the ploughsoil (080) within this trench were shallower than in the other trenches with a thickness of c 0.15 m and were composed of silt clay loam (7.5 YR 3/1) containing many fine roots. This is probably a result of the location of this trench on the upper south eastern slope of the Lochview mound (Figure 23) and the movement of soil downslope, probably enhanced by the predominant direction of ploughing which has been up and down the slope (Thomas 1849, Mr Slater *pers comm.*). Contexts 079 and 080 sealed a greyish-brown silt (7.5YR 3/2) clay loam, context 080, which contained common, fine inclusions of cremated bone and charcoal along with few flecks of ash. This context is very similar to the anthropogenic deposits identified within other trenches along this transect, although context 081 appears to contain fewer inclusions of anthropogenic deposits than the other anthropogenic horizons identified upon this site. Below context 081 (082) medium angular stones are present set within a shaley, silty clay matrix (083). These two contexts abutted some large well fitted blocks of sandstone (087) within the trench. These blocks are interpreted as being part of a collapsed wall with contexts 082 and 083 being interpreted as being collapse from this wall (Card 2004). Excavation was halted at this depth, as again the archaeology could not be resolved within the size of this test trench.

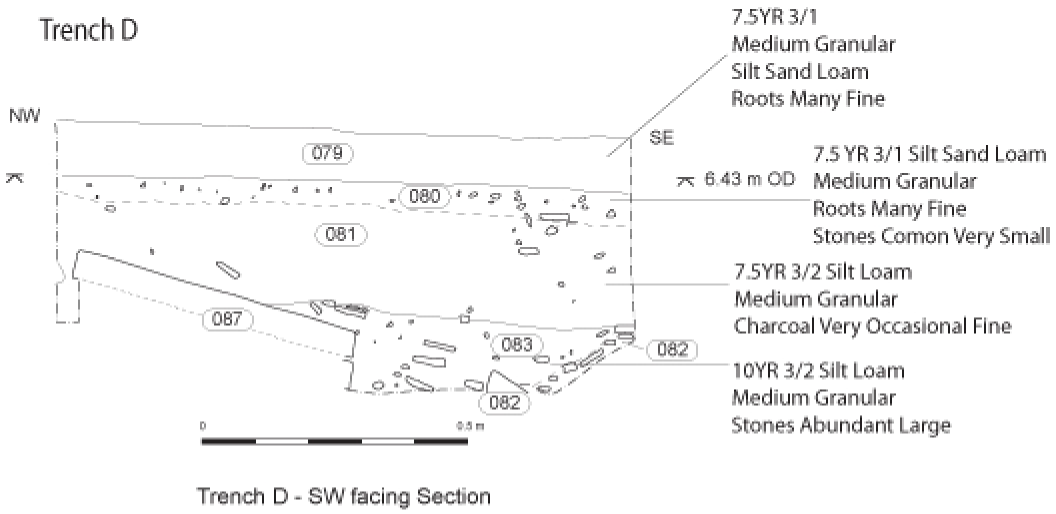
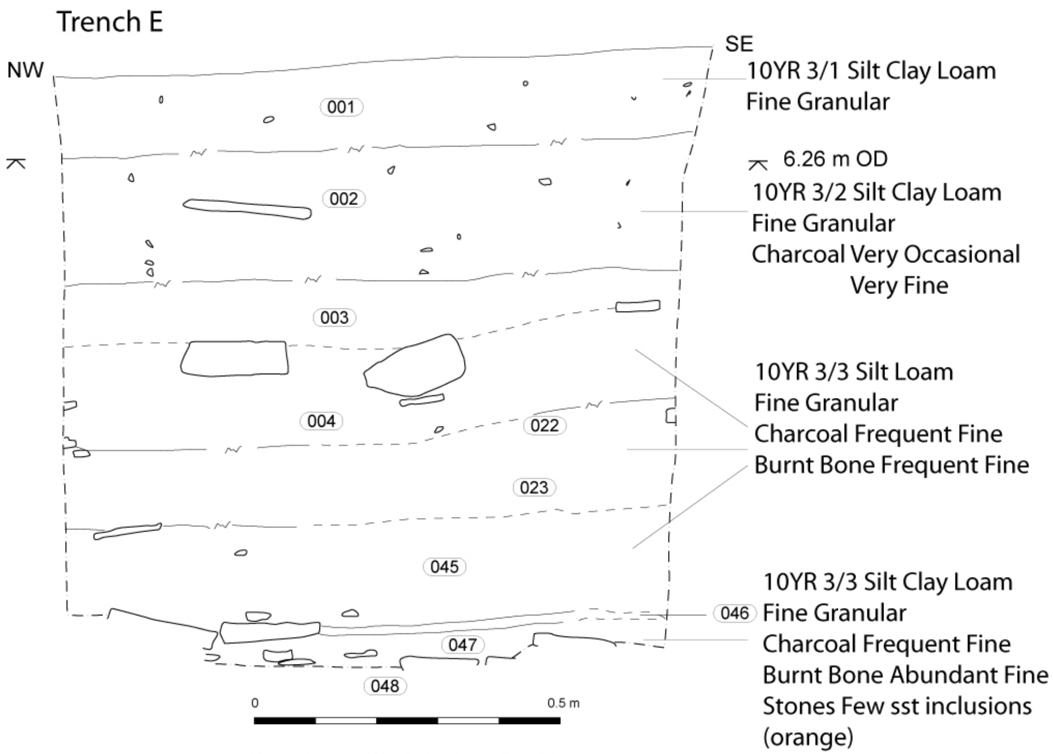


Figure 25 Trench D. Adapted from Card 2004

5.2.4 Trench E (Figure 26 and 27)

Removal of the Ap horizon (001) and the ploughsoil (002) which contained common, very fine-fine inclusions of charcoal, revealed at a depth of *c*0.35 m the top of a mid orange-brown (10YR 3/3) silty clay horizon (context 003) which contained many very fine-fine inclusions of charcoal, burnt stone, cremated bone and pot. It is anticipated that this horizon represents the anthropogenic material identified as midden and forming 'the majority of the surface of the trench and lying between and around the two features' partly excavated in 2003 (Ballin Smith and Petersen 2003).

Context 003 represents only the uppermost part of the anthropogenic horizon within Trench E. Over the *c*0.5 m depth very little change was noted in the excavated material apart from some subtle changes in colour so this was removed as a series of *c*0.1 m thick spits (003, 004, 022, 023, and 045). These contexts are therefore interpreted as being the same pedological horizon (Figure 27) with field observations suggesting they are the result of the same formation processes. At the base of this anthropogenic horizon was a thin *c*0.02 m layer of mid dark greyish-brown silty clay which may represent a buried vegetation horizon (046). Context 046 sealed a spread of medium sized, flaggy rubble (048) with patches of creamy-brown clay within it (Figure 27). This stone spread was interpreted as structural debris, possibly in situ with context 049 being used as bonding. Excavation stopped at this level (*c*5.5 m OD) since an understanding of this possible structure was not possible within the spatial constraints of this trench. An auger survey around Trench E confirmed that the anthropogenic horizon with Trench E extends to an area of at least 10 m (NW-SE and NE-SW) at a similar thickness to that observed within Trench E (Figure 28).



Trench E - SW facing Section

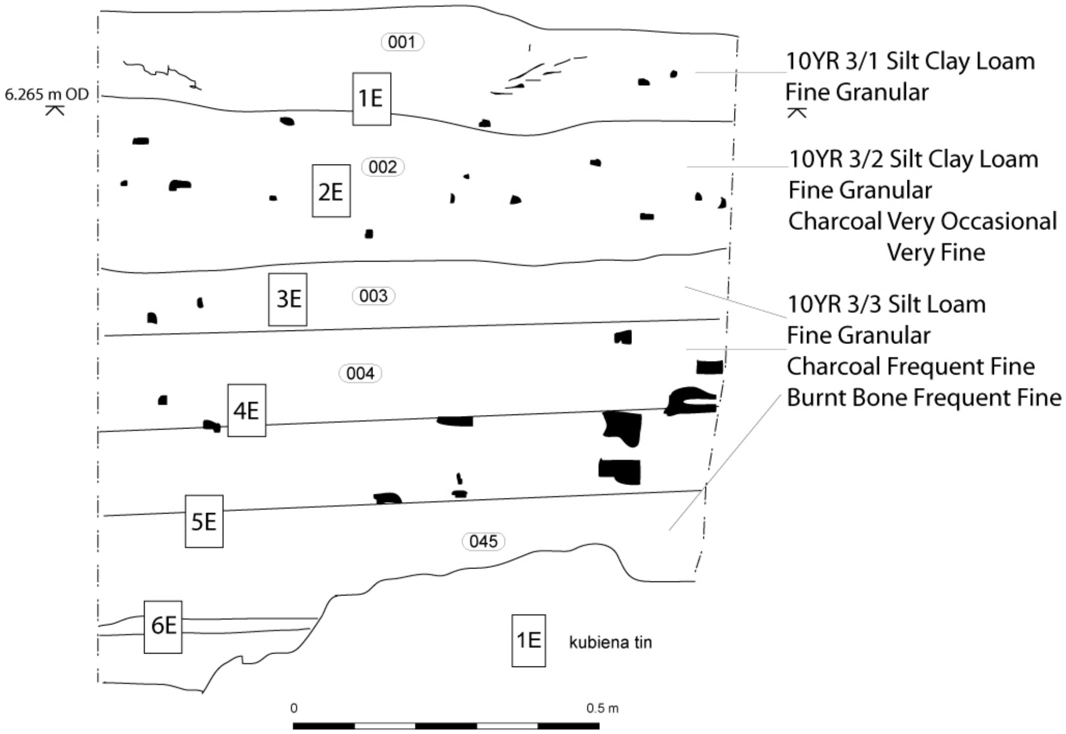


Figure 26 Trench E. Adapted from Card 2004

Figure 27 Trench E. Adapted from Card 2004

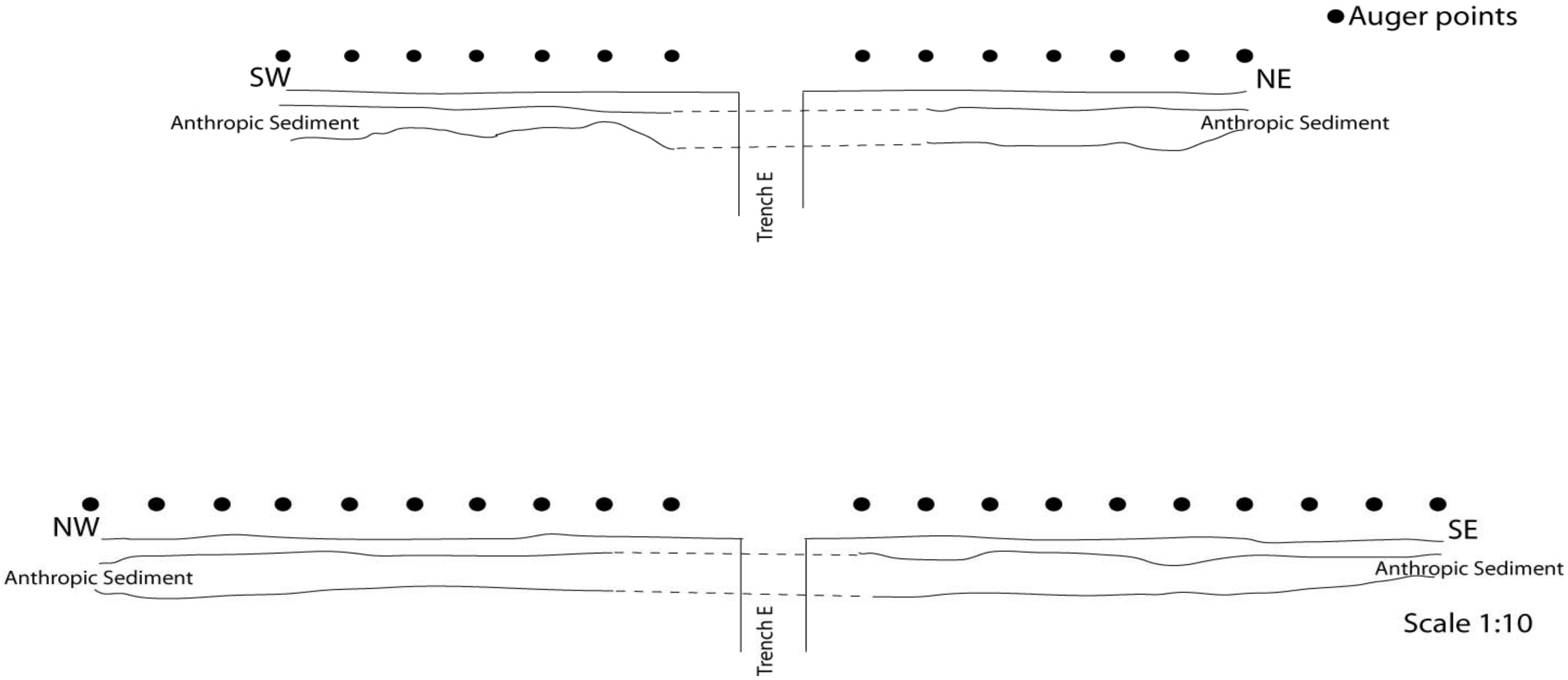
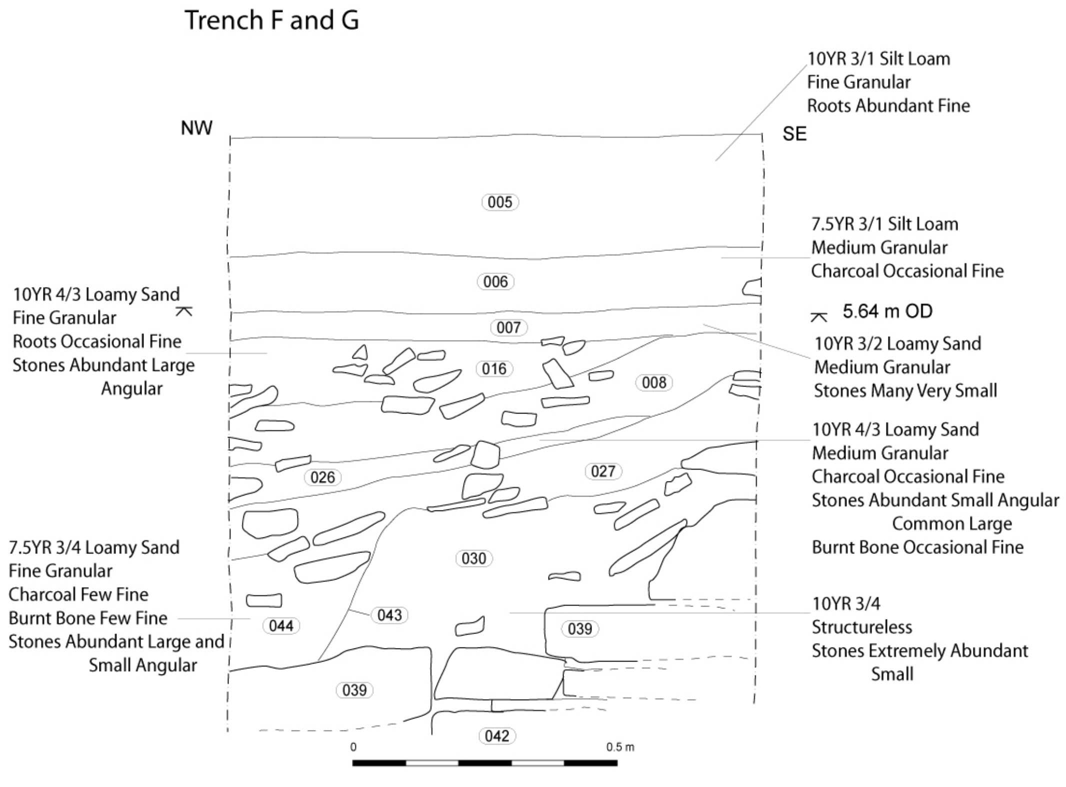


Figure 28 Stratigraphy identified around Trench E by auger survey

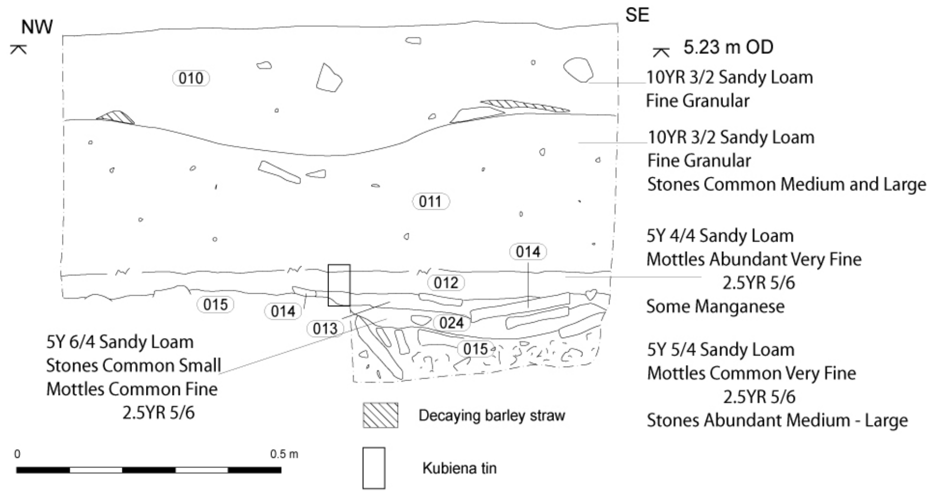
5.2.5 Trench F (Figure 29)

At a depth of *c*0.3 m below the Ap horizon (context 005, 10YR 3/1 silt loam) and the ploughsoil (context 006, 10YR3/1 silt loam with few, fine charcoal inclusions) context 007 was uncovered. Context 007 was a thin (*c*0.05 m) layer of mid orange-brown (10YR 3/2) silty clay which contained common, fine inclusions of charcoal, burnt stone and cremated bone. The deposit within context 007 is interpreted as being the same anthropogenic deposit present within Trench C, D and E. Excavation of 007 revealed a spread or dump of non structured, mainly medium sized stones (009) over the western half of the trench, sitting on a compact 'surface' of sandy, silt loam (10YR 4/3). Layer 016 did not extend across the entire trench. Beneath context 016 is a complexity of layers containing rubble and silty clay material including occasional isolated patches of white clay material until excavation was stopped at a layer of large rubble/building stone (039) (*c*5.0 m OD) which was lying mainly horizontal within a matrix of loose shale and silty clay. This rubble was on a more massive scale (up to 0.5 m by 0.5 m by 0.15 m) than that found in the bottom of Trench E.

Card (2004) suggests that both the size of the masonry observed within Trench F, along with the overlying shales is inconsistent with Neolithic domestic activity. Card (2004) concludes by postulating whether the massive rubble in the base of this trench form an outlying deposit of structural rubble associated with a chambered cairn at least 25 m in diameter possibly identified within geophysical surveys.



Trench F - SW facing Section



Trench G - SW facing Section

Adapted From Card 2004

Figure 29 Trench F and Trench G.

5.2.6 Trench G (Figure 29)

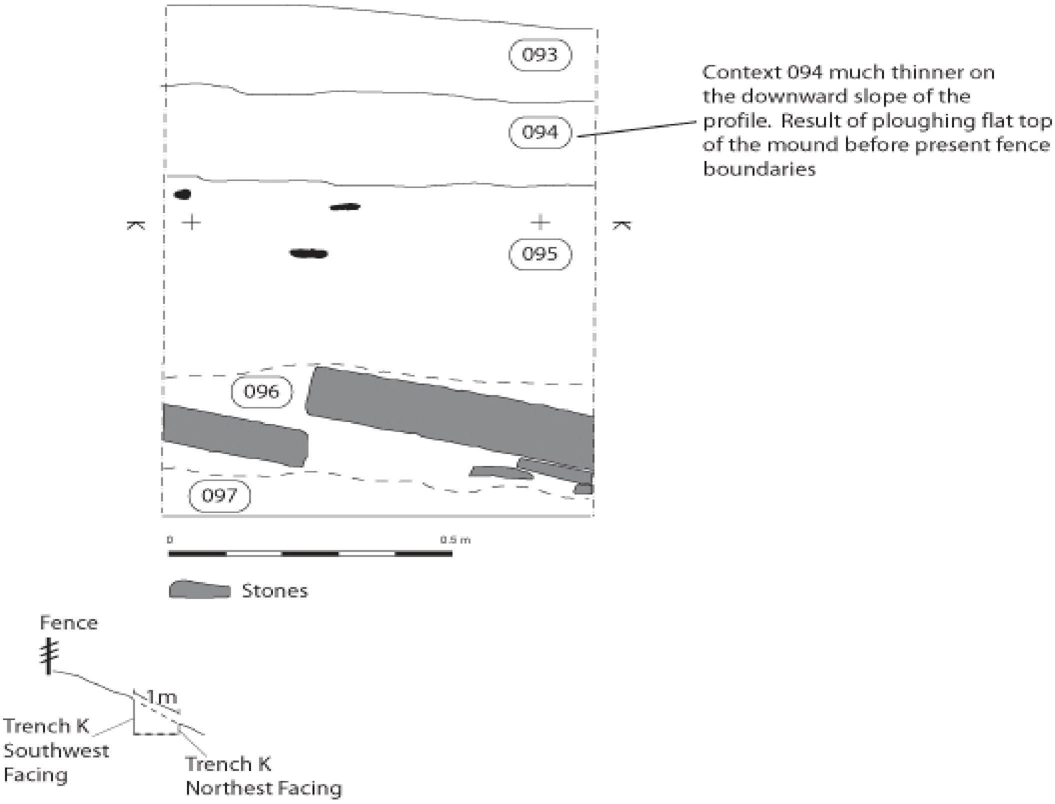
Beneath the Ap horizon (010, 10YR 3/2) and the ploughsoil (011) at a depth of *c*0.4 m, a sealed thin band of stony clay (012) was identified. This appeared to have been derived from the C horizon, perhaps derived from plough disturbance. Significantly for this research, decaying barley straw was observed at a depth of *c*0.15 m which indicates the depth of the last ploughing episode upon this land. In the eastern corner of this trench layer 012 sealed a patch of red, possibly heat-effected soil (013) *c*0.5 m in extent. This was associated with some small flattish flags (014) sitting within and at the base of 013. Sealed beneath 013 and 014 was a pale cream brown material (024). Context 024 is interpreted as the result of soil mineralisation processes including gleying of the underlying C horizon. The C horizon (015) was identified within the base of this trench at a height of *c*4.8m OD. The C horizon within this trench appears extremely comparable to the glacial C horizon observed and recorded at Finstown Control. Significantly the C horizon was only identified within Trench G on the Ness of Brodgar. Within every other trench structural archaeology was encountered which prevented the excavation down to the underlying C horizon.

5.2.7 Trench K (Figure 30 and 31)

Subsequent to initial excavation at this site it was decided to excavate further during 2005. The aim of this subsequent fieldwork was first to investigate the nature and spatial extent of the anthropogenic deposit identified within Trench E. Second it was anticipated that this field work would establish the relationship between this anthropogenic deposit and the pre-settlement glacial moraine dominated landscape, further contributing to the discussion concerning land management, resource utilisation and cultural organisation within the Orcadian Neolithic.

Trench K was deliberately located near to the shore of the Loch of Stenness where glacial drift had previously been identified. This trench was located outside of present day field boundaries but was parallel to Trench E at 19E/199N; 19E 198N; 18E/199N; 18E198N (Figure 23). Previous fieldwork confirmed the anthropogenic deposit identified within Trench E extended at least 10 m towards the field boundary at site grid south and it was considered probable that the extent of the anthropogenic material associated with Neolithic settlement activity would not be constrained by present day field boundaries. Geophysical survey has not been conducted outside of present day field boundaries and there was therefore no indication as to whether structural archaeology would be encountered within this trench.

Trench K was located upon a slope descending from the present day field boundary to the shore of the Loch of Stenness. As such the profile on the upward part of the slope, facing southwest has a much greater depth of stratigraphy than the profile down slope which faces northeast. It is the profile on the upward part of the slope which faces southwest which will be described and discussed in detail. The Ah horizon (093) was dominated by thick vegetation and the rooting zone of this vegetation. The dense vegetation and location of the profile outside of the present day field boundary suggest that this topsoil has not been cultivated within recent agricultural history.



Context 094 much thinner on the downward slope of the profile. Result of ploughing flat top of the mound before present fence boundaries

Figure 30 Trench K. Northeast facing

Figure 31 Trench K. Southwest facing

Below the Ah horizon to a depth of *c*0.25 m was located the ploughsoil (094). The ploughsoil within Trench K shows similar field characteristics to the ploughsoil identified within Trench E (10YR 3/1 silty clay loam), with the common occurrence of fine charcoal and fine cremated bone and two fine flints (Card 2004). It is apparent that the thickness of the ploughsoil, (094) decreases down slope, as evidenced in Trench K. It is unlikely that the thinning of the ploughsoil down slope is the result of natural pedogenic processes. It is suggested that the ploughsoil towards the top of the slope, just outside the present field boundary has been thickened as a result of cultivation practices moving soil material from field systems on the Ness of Brodgar onto the top of the slope leading to the Loch of Stenness.

The ploughsoil overlies an obvious anthropogenic amended horizon referred to as context 095. Context 095 is more orange in colour (10YR 3/3) than the overlying ploughsoil and A horizon and contains common, very fine-fine inclusions of charcoal and cremated bone. The material within this context appears to be well sorted with the charcoal being poorly preserved. Field evidence suggests that context 095 represents the same anthropogenic deposit evident within Trench E (Card 2004). An interesting observation from context 095 is the presence of a piece of bone which has not been cremated along with a tooth, preliminary interpreted as a sheep tooth. It is suggested that this non cremated bone and tooth have been preserved by localised favourable site conditions and are unlikely to represent different cultural practices than those associated with the formation of the anthropogenic deposit in Trench E.

Field based profile descriptions suggest that the anthropogenic deposit within Trench E (Card 2004) extends further than the preliminary auger survey suggests, extending at least to Trench K a horizontal distance of 27 m. Furthermore, as in Trench E there is also an extensive depth of this anthropogenic deposit within Trench K, with the anthropogenic deposit also being present between the large stones comprising context 096. Context 096 is composed of large interconnecting stones which have the anthropogenic deposit of context 095 between them. The large stones do not appear to show any general orientation trend and have been interpreted as being rubble associated with some structural archaeology. Context 097 lies beneath context 096, at a depth of *c*1.53 m (3.20 m OD) and is also composed of many large stones which in part are interconnected but are also interpreted as rubble. The material associated with context 097 is also obviously anthropogenic containing many fine cremated bone and charcoal inclusions. However, this material is less well sorted than in contexts 095 and 096 and contains patches of grey and red ash along with patches of yellow clay. It is entirely possible that this material represents material that was incorporated along with the large rubble material into the construction of some structure, although it is not possible to identify any such structure within the spatial constraints of this trench.

The presence of structural archaeology within the base of Trench K (Figure 31) prevented the relationship between the anthropogenic deposit and the pre-settlement glaciated landscape from being established. Figure 32 shows results of an auger survey which indicates the potential altitude of glacial moraine within the stratigraphy along a transect from the present day field boundary to the shore of the Loch of Stenness. While subject to interpretation in part, it does indicate the great depth of stratigraphy associated with the archaeological deposits further confirming the extensive nature of the archaeology at this site (Card 2004).

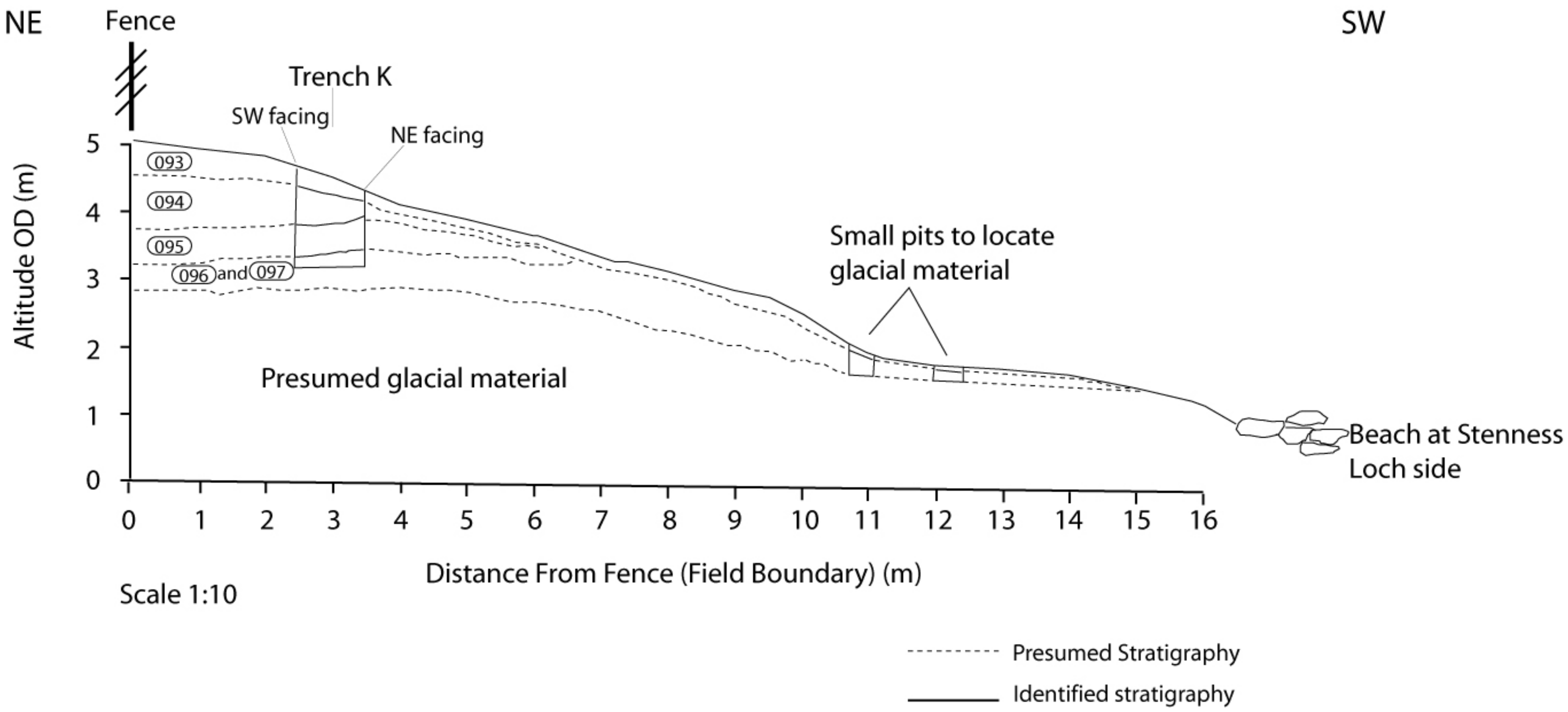


Figure 32 Profile of the Ness of Brodgar from the field boundary to the Loch of Stenness

5.2.8 Summation of Field Results

Field observations indicate a deep, complex stratigraphy of anthropogenic deposits and structural archaeology at the Ness of Brodgar which artefactual evidence and archaeological structural evidence suggests is all related to Late Neolithic activity (Card 2004). Of particular interest to this research is the deeply stratified anthropogenic deposit identified on the site, which field observations including auger survey, suggest is one deposit which extends from Trench E to at least Trench K and Trench C (Figure 23).

5.3 *Analytical Results*

Bulk samples have been obtained from Ap horizons, from the anthropogenic deposit in each trench and from the C horizon in Trench G. Kubiena tin samples for thin section analyses were obtained from Trench C, Trench E, Trench K and from the C horizon in Trench G. Table 10 shows a complete list of the contexts sampled.

Table 10 Ness of Brodgar contexts sampled

	Context Bulk Sampled	**Context Kubiena Tin Sample**
Ap Horizon	A088, C071, D079, E001, F005, G010, K093	C071 (Trench C sample 1) E001 (Trench E sample 1)
Anthropogenic Deposit	A090, A091 C072, C073, C075, C086 E002, E003, E004, E023, E045, E046, E047 F006, F007, F016, F026, F030, F044 K094, K095, K096, K097	C072, C073, C075, C086 (Trench C samples 1,2,3,4,5) E002, E003, E004, E023, E045, E046, E047 (Trench E samples 1,2,3,4,5,6) K094, K095, K096, K097 (Trench K samples 1,2,3,4,5,6)
C Horizon	G012, G015	G012, G013, G015, (Trench G sample 1)

5.3.1 Chronology

All charcoal recovered from Trench E context 047, and Trench C contexts 075 and 086 was identified (Ramsay *pers comm.)*, and the percentage weight distribution of charcoal species was calculated *(*Figure 33). A single entity *Ericales* charcoal sample weighing 0.05 g was submitted from Trench E, context 047 along with a single entity sample of Betula weighing 0.05 g from Trench C, context C 075. Single entities of cremated bone from the Ness of Brodgar Trench E, context 047 and 003 and Trench C context 086 were also submitted for radiocarbon analysis. Samples of charcoal within Trench C context 086 were not of sufficient weight to be single entities; therefore a single entity charcoal sample from the overlying context 075 was submitted for analysis. These contexts both represent the same pedological unit. Bulk soil samples were submitted from the Ness of Brodgar Trench E context 047 and Trench C 075 for radiocarbon analysis of the humic fraction of the soil organic matter. Table 11 and Figure 34 show radiocarbon results. All calibrated radiocarbon ages were calibrated using the university of Oxford Radiocarbon Accelerator Unit calibration programme (OxCal3).

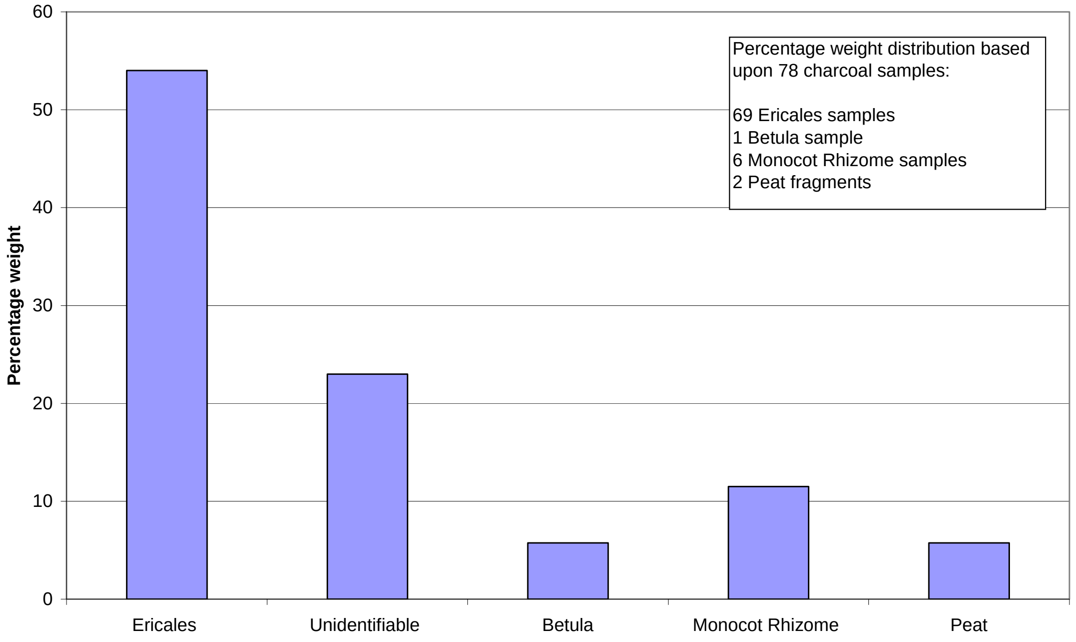


Figure 33 Percentage weight distribution charcoal species

Table 11 Radiocarbon results

Lab Number	**Reporting Number**	**Sample type**	**Context**	**δ13C**	**14C Age (yr BP ± 1 σ)**	**Calibrated Age Ranges (yr B.C to 2 σ)**
GU-12946	SUERC-6191	Charcoal: Ericales	NOB E 047	-25.0	4280 ± 35	3020-2860
GU-12947	SUERC-6684	Humic acid	NOB E 047	-27.2	3160 ± 40	1520-1370
GU-13117	SUERC-6762	Cremated mammal bone	NOB E 047	-22.4	4225 ± 40	2910-2830
GU-13199	SUERC- 6764	Charcoal: Betula	NOB C 075	-26.0	4320 ± 40	3080-3060
GU-12949	SUERC-6685	Humic acid	NOB C 075	-27.4	4085 ± 40	2870-2800
GU-13116	SUERC-6761	Cremated mammal bone	NOB C 086	-27.0	4185 ± 45	2900-2620
GU-13806	SUERC-9542	Cremated mammal bone	NOB E 003	-20.4	4285 ± 35	3020-2870

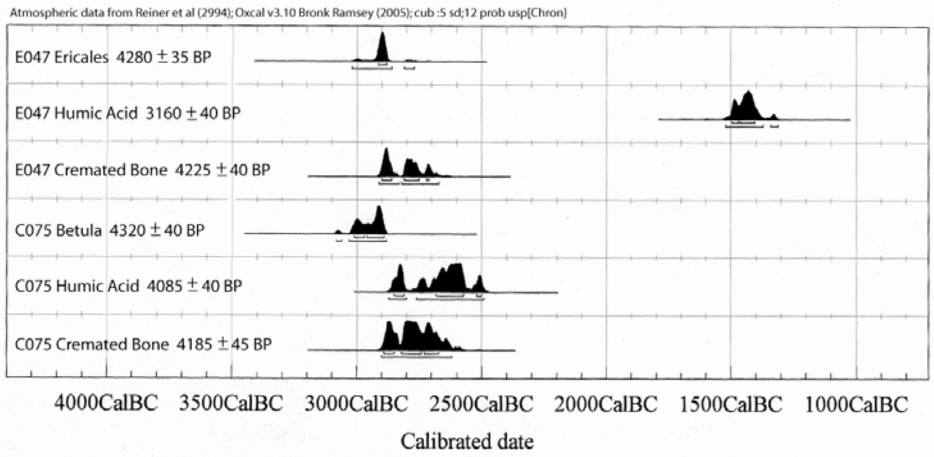


Figure 34 Radiocarbon results

5.3.2 pH and Soil Organic Matter

pH of the contexts at the Ness of Brodgar ranges from 5.7 to 6.4. pH from the uppermost Ap horizons are generally slightly lower than the pH from the anthropogenic deposit samples, although there is no clear pattern of changing pH within profiles (Table 12, full results available Appendix B page 304).

Table 12 Ness of Brodgar summary pH results

	Minimum	Maximum	Mean
A Horizon	5.7	6.1	5.9
Anthropogenic Horizon	5.8	6.4	6.2

Loss on ignition (LOI) results range from 13% associated with Ap horizons to 2.07% and 3.16% associated with the glacial C drift horizon exposed in Trench G (Table 13), which are comparable to results from the glacial moraine C horizon from Finstown Control. LOI results indicate that the organic matter content decreases down profile from surface horizons in each trench despite the increase of anthropogenic inclusions of charcoal and cremated bone in the anthropogenic deposit (Table 13, full results available Appendix B page 304).

Table 13 Ness of Brodgar summary LOI results

	Minimum	Maximum	Mean
A Horizon	11%	13%	12%
Anthropogenic Horizon	2%	9%	6%

5.3.3 Particle Size Distribution (PSD)

Ap horizons from each trench indicate a PSD dominated by silt and containing a little clay and very little sand material. The anthropogenic deposit containing obvious anthropogenic inclusions of cremated bone and charcoal does not appear to have a significantly different PSD to the surface Ap contexts (Figure 35). The contexts within the anthropogenic deposit also have a PSD dominated by silt, with a little clay and very little sand material. Figure 35 illustrates the mean particle size distribution for Ap horizons and for the anthropogenic deposit, full results available Appendix C page 307.

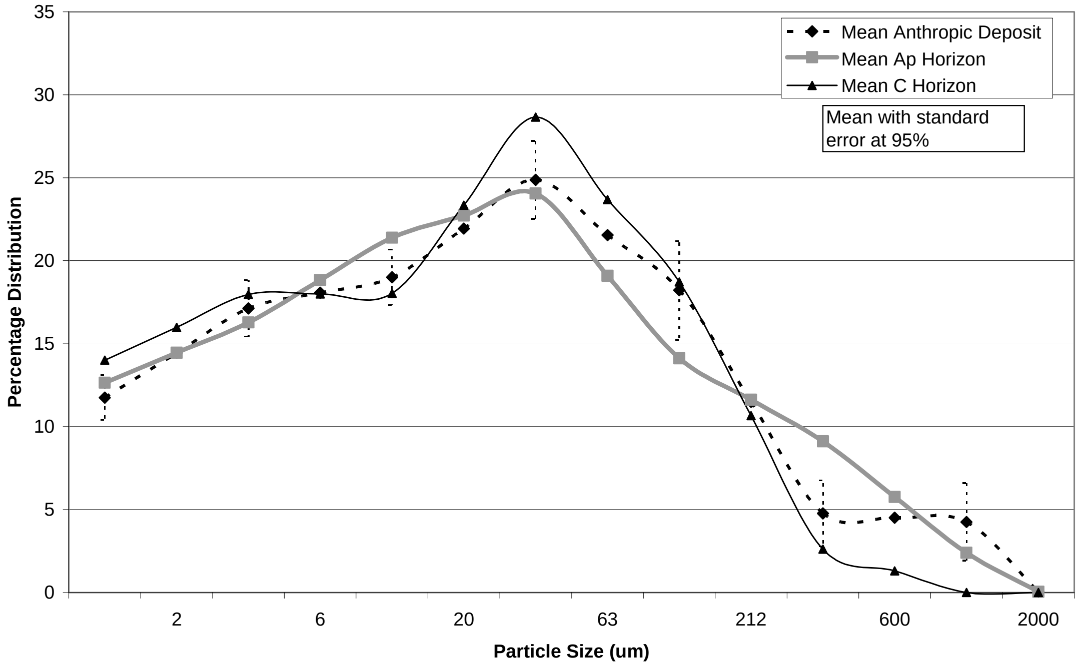


Figure 35 Ness of Brodgar mean PSD SSBCR

5.3.4 Total Phosphorus

The results of total phosphorus analysis by fusion with NaOH clearly indicate that contexts within the anthropogenic deposit are enhanced with phosphorus relative to the glacial drift C horizon identified within Trench G (015) which has a total phosphorus concentration of 85 mg/100g oven dried soil and is comparable to the mean total phosphorus concentration from Finstown Control of 54 (±2) mg/100g oven dried soil. Full results available see Appendix D. Patterns of phosphorus concentration within individual trenches are complicated by the presence of structural archaeology and rubble. However, it is clear that contexts identified as containing anthropogenic inclusions including cremated bone and charcoal are generally phosphorus enhanced relative to surface Ap horizons where total phosphorus concentrations range from 118-196 mgP/100g oven dried soil (for example see Figure 36, Trench E). A slight exception to this is observed in the base of Trench E where contexts 045, 046 and 047 all appear to have lower mean concentrations of phosphorus than is observed within the Ap horizon (Figure 36).

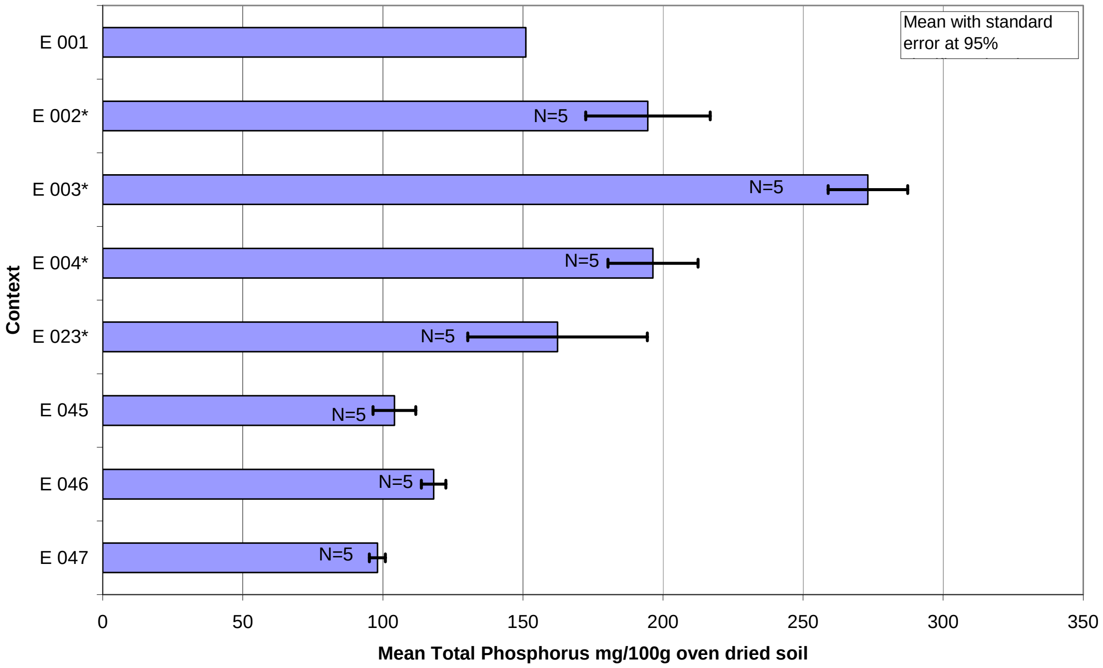


Figure 36 Ness of Brodgar total P trench E

Despite the variability of phosphorus concentration between contexts, at depth, within and between trenches, field observations supported by thin section micromorphology suggest that the deepened anthropogenic deposit identified within Trenches C,D,E,F and K has resulted from the same formation processes including the addition of the same anthropogenic inclusions (Table 10). The average total phosphorus concentration from this anthropogenic deposit was therefore calculated in order to easily compare the total phosphorus concentration of the anthropogenic deposit at the Ness of Brodgar (NoB) with the total phosphorus concentrations of control profiles and with total phosphorus concentrations published from Orcadian Late Neolithic SSBCR. This facilitates addressing the initial research questions. Mean total phosphorus concentration for the anthropogenic horizon was calculated as being 250 mg/100g oven dried soil. As expected total phosphorus concentration of the anthropogenic deposit on the Ness of Brodgar is significantly greater than total phosphorus concentration associated with the pre-settlement Finstown Control. Total phosphorus concentration from the anthropogenic deposit on the Ness of Brodgar is statistically greater than total phosphorus concentration associated with Late Bronze Age/Iron Age amended soils within Skaill Control but there is no evidence to suggest that total phosphorus concentration from the anthropogenic deposit on the Ness of Brodgar differs statistically from the total phosphorus concentration of the later plaggen soil within Skaill Control (Table 19).

Comparison of results of total (inorganic) phosphorus from contexts within Trench E using NaOH fusion with total phosphorus results based upon extraction of the phosphorus with 10 molar H_2SO_4 shows that concentrations of phosphorus determined by extraction with 10 molar H_2SO_4 are consistently greater than total phosphorus concentrations determined through NaOH fusion.

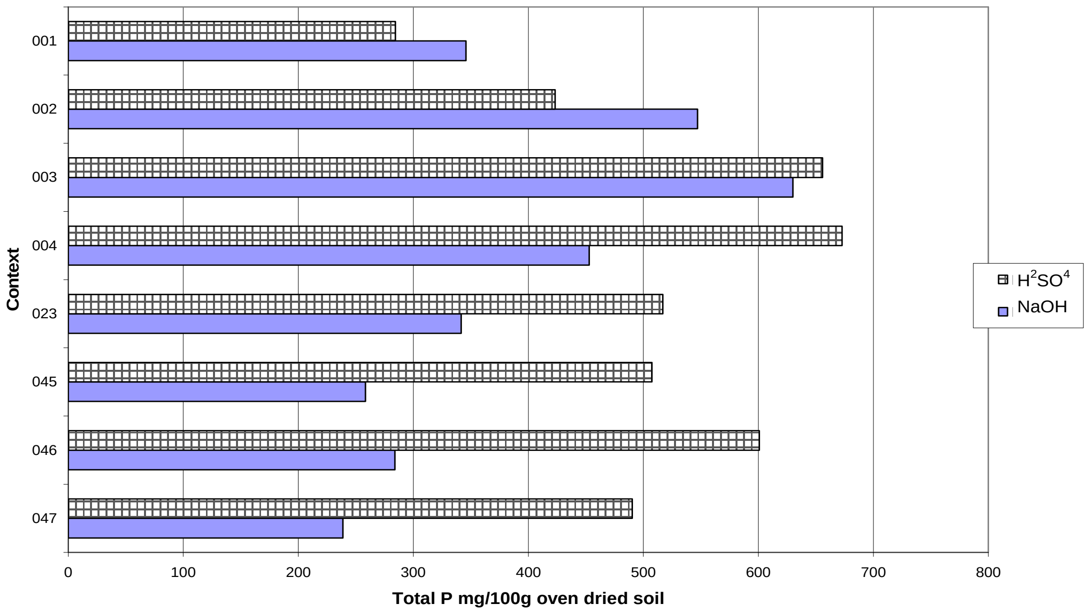


Figure 37 Comparison of Total P NoB Trench E

This is not necessarily problematic for this research as it is well understood that laboratory protocols for quantifying soil phosphorus vary widely, making comparisons of soil phosphorus data problematic (Heron 2001). Of more significance is that results from both methodologies exhibit similar trends of total phosphorus concentration with the anthropogenic deposit identified at depth within Trench E being phosphorus enhanced relative to the surface Ap horizon. Results for the phosphorus fractionation within Trench E suggest that the majority of phosphorus present within each horizon is in the form of inorganic phosphorus. There is a relatively greater proportion of organic phosphorus in the surface Ap and ploughsoil horizons with the anthropogenic deposit within Trench E dominated by inorganic phosphorus (Table 14).

Table 14 NoB Phosphorus fractionation Trench E

Context	Total P (H_2SO_4) mg/100g oven dried soil	% of Organic P	% of Inorganic P
NOB E 001	284.4	36.9	63.1
NOB E 002	423.3	29.7	70.3
NOB E 003	655.8	20.6	79.4
NOB E 004	672.8	12.6	87.4
NOB E 023	516.8	4.4	95.6
NOB E 045	507.8	1.9	98.1
NOB E 046	600.9	0	100
NOB E 047	490.4	5.4	94.6

5.3.5 Mass Susceptibility (χ)

Mass susceptibilities from the anthropogenic deposit samples are generally high although there is a large range with results ranging from 0.67×10^{-6} m^3kg^{-1} to 12.63×10^{-6} m^3kg^{-1} (Table 15). Results associated with the anthropogenic deposit at depth within each trench are greater than mass susceptibilities associated with surface Ap horizons which probably reflects the greater concentration of burnt material within the stratigraphy of the anthropogenic deposit. Mean mass susceptibility of this anthropogenic deposit is 6.96×10^{-6} m^3kg^{-1} (Table 15). There is statistical evidence to suggest that mass susceptibilities of the anthropogenic deposit on the Ness of Brodgar is greater than the mass susceptibility of Finstown Control and of both amended soil horizons within Skaill Control (Table 19). Full results available Appendix E Mass Susceptibility Results.

Table 15 NoB Summary mass susceptibility result (χ $\times 10^{-6} m^3kg^{-1}$)

	Minimum	Maximum	Mean (SD to 95%)
Ap	1.38	4.13	2.67 (± 0.89)
Anthropogenic Deposit	0.67	12.63	6.19 (± 1.17)
Glacial Drift (Tr G)	0.09	0.6	N/A

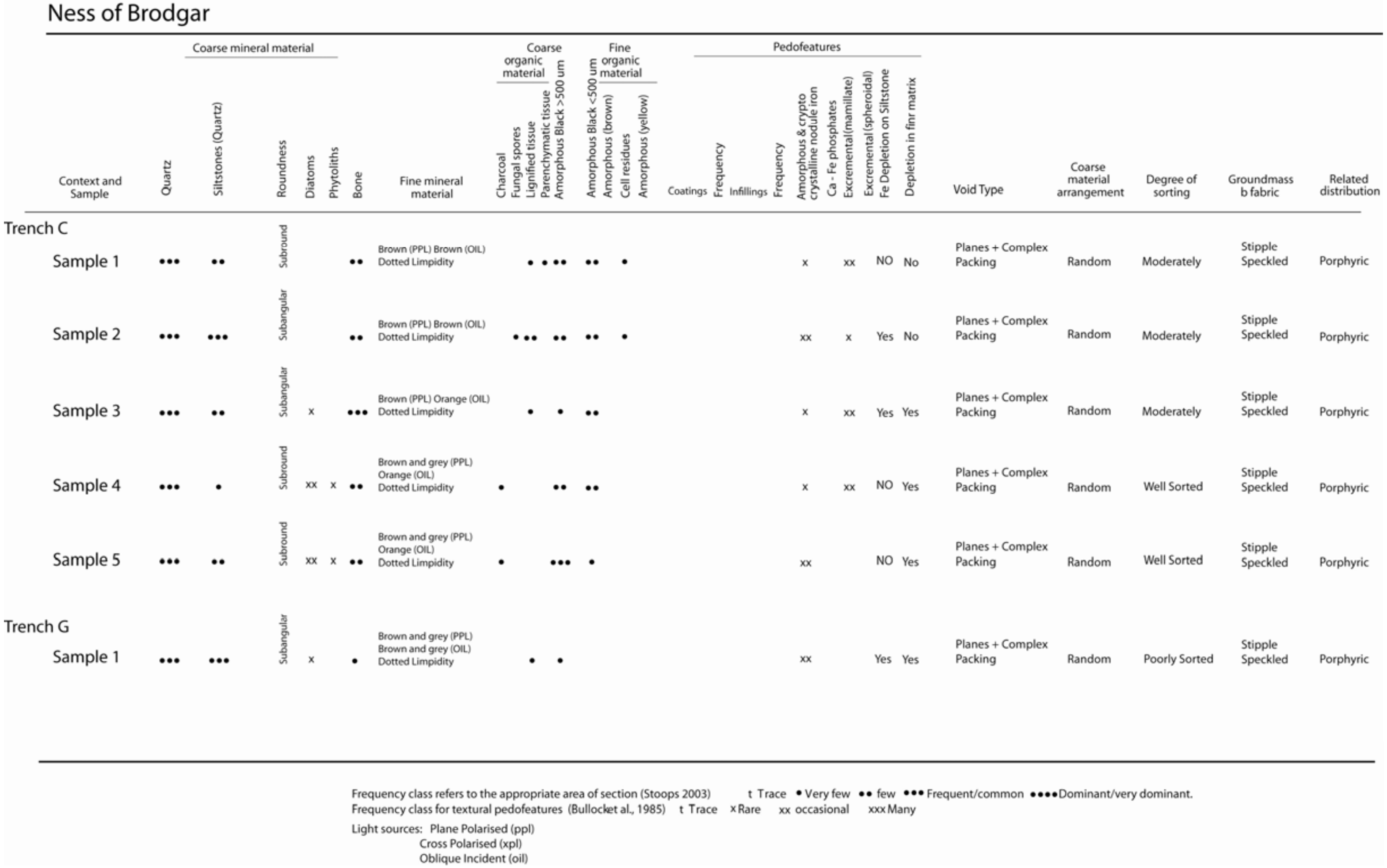
5.3.6 Thin Section Micromorphology

Samples for thin section micromorphology analyses were taken from the anthropogenic deposit from Trenches C, E and K (Tables 16, 17 and 18). A further sample was taken from Trench G in order to ascertain any anthropogenic impact within this trench (Table 16). All thin section samples from the Ness of Brodgar are characterised by containing a coarse mineral component of quartz with a common to frequent abundance (25-35%). Siltstones are also present within all samples and the abundance of siltstones does not appear to change significantly within the anthropogenic deposit within Trenches C and K where abundance ranges from few to common (10-30%). The abundance of siltstones within Trench E appears to decrease down the profile with very few (>5%) being observed with slides 3,4,5,6 (contexts 002, 003, 004, 023. 045, 046 and 047**)**. Iron depletion stone rim features are not present upon every siltstone but within each trench they are present at depth. Typic iron nodules are also identified at depth within each trench with a frequency of rare to common. The coarse mineral component within each sample is blocky in shape, subangular-subrounded with a smooth surface roughness.

Anthropogenic inclusions of cremated bone and charcoal within this deposit identified at the Ness of Brodgar were also identified within thin section. Charcoal appeared to be relatively rare within the anthropogenic deposit with an abundance in thin section ranging from very few to few (<5-5%, Figure 38). The presence of black amorphous material appeared more abundant ranging from very few to common (>5-15%). Black amorphous material within each profile was characterised as containing mineral inclusions and as such has been interpreted as turf (Figure 38). Unburnt turf was also identified as brown amorphous material again containing mineral inclusions (Figure 38). Bone material with an abundance of very few to common (>5-15%) has been identified within every thin section sample. The majority of the bone material within this deposit is very fine-fine in size and is also identified as being cremated (Figure 38). All profiles also contain a very small quantity of non-cremated bone which may exist as a result of favourable localised taphonomic conditions. Very few (<5%) bone fragments were also identified within the thin section sample from Trench G, confirming anthropogenic influence on the soil within this trench.

Other features including fungal spores, phytoliths and diatoms which may indicate amendment by anthropogenic activity were also identified within each profile. Phytoliths and diatoms were observed with a frequency of rare to occasional within all thin section samples and were observed as being present with a frequency of occasional to many within Trench E context 003. It appears that as at Skaill Control, the greater frequency of phytoliths and diatoms correlates well with the presence of grey features within the fine matrix which, as at Skaill Control are also interpreted as fuel ash residues (Figure 38). Field observations identified the anthropogenic deposit on the Ness of Brodgar as being a mid orange-brown in colour (10YR 3/3). This colour was also obvious in thin section under PPL but was a bright orange under OIL. Mamilliate excrement was observed with a frequency of rare to many within thin sections throughout the depth of each Trench which suggests a reasonably high degree of biological activity within the deposit.

Table 16 Thin section micromorphology results



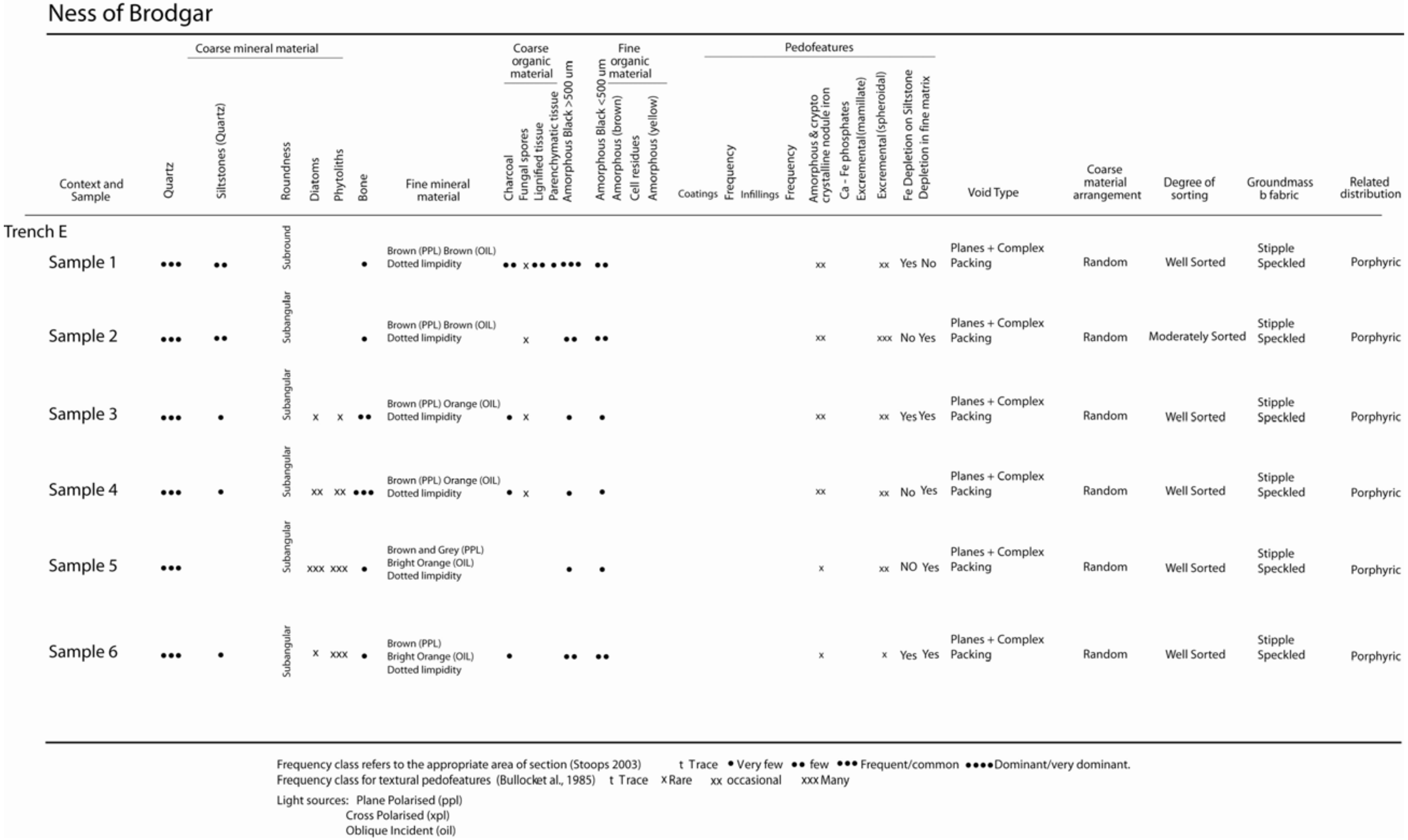
Ness of Brodgar

	Coarse mineral material							Coarse organic material					Fine organic material				Pedofeatures														
Context and Sample	Quartz	Siltstones (Quartz)	Roundness	Diatoms	Phytoliths	Bone	Fine mineral material	Charcoal	Fungal spores	Lignified tissue	Parenchymatic tissue	Amorphous Black >500 um	Amorphous Black <500 um	Amorphous (brown)	Cell residues	Amorphous (yellow)	Coatings	Frequency	Infillings	Frequency	Amorphous & crypto crystalline nodule iron	Ca - Fe phosphates	Excremental (mamillate)	Excremental (spheroidal)	Fe Depletion on Siltstone	Depletion in finr matrix	Void Type	Coarse material arrangement	Degree of sorting	Groundmass b fabric	Related distribution
Trench C																															
Sample 1	•••	••	Subround			••	Brown (PPL) Brown (OIL) Dotted Limpidity			•	•	••	••		•						x		xx		NO	No	Planes + Complex Packing	Random	Moderately	Stipple Speckled	Porphyric
Sample 2	•••	•••	Subangular			••	Brown (PPL) Brown (OIL) Dotted Limpidity		•	••		••	••		•						xx		x		Yes	No	Planes + Complex Packing	Random	Moderately	Stipple Speckled	Porphyric
Sample 3	•••	••	Subangular	x		•••	Brown (PPL) Orange (OIL) Dotted Limpidity			•		•	••								x		xx		Yes	Yes	Planes + Complex Packing	Random	Moderately	Stipple Speckled	Porphyric
Sample 4	•••	•	Subround	xx	x	••	Brown and grey (PPL) Orange (OIL) Dotted Limpidity	•				••	••								x		xx		NO	Yes	Planes + Complex Packing	Random	Well Sorted	Stipple Speckled	Porphyric
Sample 5	•••	••	Subround	xx	x	••	Brown and grey (PPL) Orange (OIL) Dotted Limpidity	•				•••	•								xx				NO	Yes	Planes + Complex Packing	Random	Well Sorted	Stipple Speckled	Porphyric
Trench G																															
Sample 1	•••	•••	Subangular	x		•	Brown and grey (PPL) Brown and grey (OIL) Dotted Limpidity			•		•									xx				Yes	Yes	Planes + Complex Packing	Random	Poorly Sorted	Stipple Speckled	Porphyric

Frequency class refers to the appropriate area of section (Stoops 2003) t Trace • Very few •• few ••• Frequent/common ••••Dominant/very dominant.
Frequency class for textural pedofeatures (Bullocket al., 1985) t Trace ×Rare xx occasional xxx Many

Light sources: Plane Polarised (ppl)
Cross Polarised (xpl)
Oblique Incident (oil)

Table 17 Thin section micromorphology results



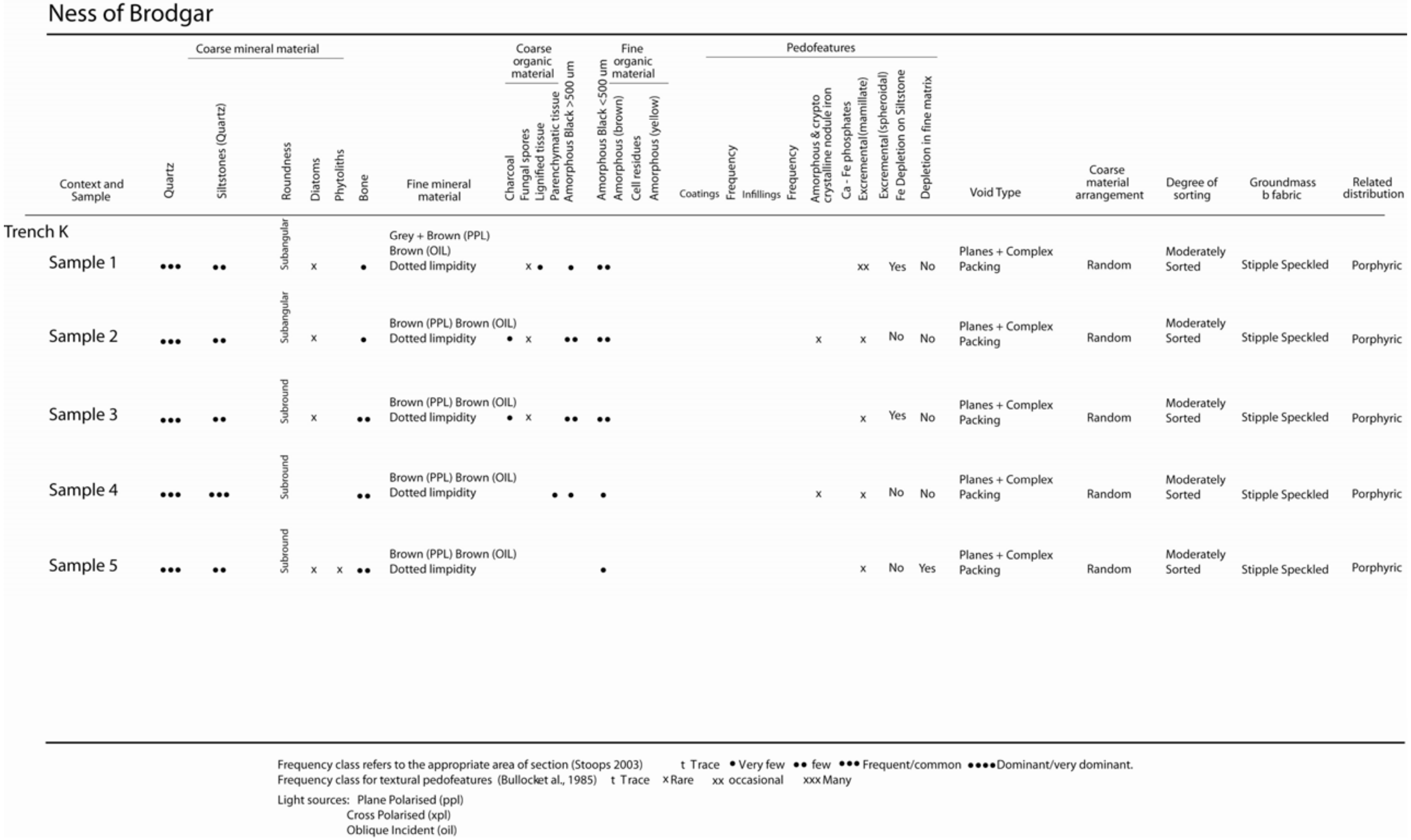
Ness of Brodgar

	Coarse mineral material							Coarse organic material					Fine organic material				Pedofeatures														
Context and Sample	Quartz	Siltstones (Quartz)	Roundness	Diatoms	Phytoliths	Bone	Fine mineral material	Charcoal	Fungal spores	Lignified tissue	Parenchymatic tissue	Amorphous Black >500 um	Amorphous Black <500 um	Amorphous (brown)	Cell residues	Amorphous (yellow)	Coatings	Frequency	Infillings	Frequency	Amorphous & crypto crystalline nodule iron	Ca - Fe phosphates	Excremental(mamillate)	Excremental (spheroidal)	Fe Depletion on Siltstone	Depletion in fine matrix	Void Type	Coarse material arrangement	Degree of sorting	Groundmass b fabric	Related distribution
Trench E																															
Sample 1	•••	••	Subround			•	Brown (PPL) Brown (OIL) Dotted limpidity	••	x	••	•	•••	••								xx			xx	Yes	No	Planes + Complex Packing	Random	Well Sorted	Stipple Speckled	Porphyric
Sample 2	•••	••	Subangular			•	Brown (PPL) Brown (OIL) Dotted limpidity		x			••	••								xx			xxx	No	Yes	Planes + Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample 3	•••	•	Subangular	x	x	••	Brown (PPL) Orange (OIL) Dotted limpidity	•	x			•	•								xx			xx	Yes	Yes	Planes + Complex Packing	Random	Well Sorted	Stipple Speckled	Porphyric
Sample 4	•••	•	Subangular	xx	xx	•••	Brown (PPL) Orange (OIL) Dotted limpidity	•	x			•	•								xx			xx	No	Yes	Planes + Complex Packing	Random	Well Sorted	Stipple Speckled	Porphyric
Sample 5	•••		Subangular	xxx	xxx	•	Brown and Grey (PPL) Bright Orange (OIL) Dotted limpidity					•	•								x			xx	NO	Yes	Planes + Complex Packing	Random	Well Sorted	Stipple Speckled	Porphyric
Sample 6	•••	•	Subangular	x	xxx	•	Brown (PPL) Bright Orange (OIL) Dotted limpidity	•				••	••								x			x	Yes	Yes	Planes + Complex Packing	Random	Well Sorted	Stipple Speckled	Porphyric

Frequency class refers to the appropriate area of section (Stoops 2003) t Trace • Very few •• few ••• Frequent/common ••••Dominant/very dominant.
Frequency class for textural pedofeatures (Bullock et al., 1985) t Trace x Rare xx occasional xxx Many

Light sources: Plane Polarised (ppl)
Cross Polarised (xpl)
Oblique Incident (oil)

Table 18 Thin section micromorphology results



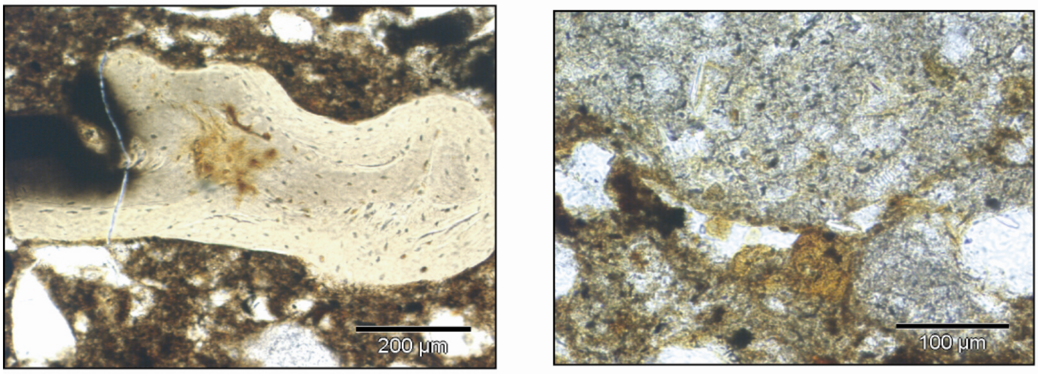
Ness of Brodgar

Context and Sample	Coarse mineral material: Quartz	Coarse mineral material: Siltstones (Quartz)	Coarse mineral material: Roundness	Coarse mineral material: Diatoms	Coarse mineral material: Phytoliths	Coarse mineral material: Bone	Fine mineral material	Coarse organic material: Charcoal	Coarse organic material: Fungal spores	Coarse organic material: Lignified tissue	Coarse organic material: Parenchymatic tissue	Coarse organic material: Amorphous Black >500 um	Fine organic material: Amorphous Black <500 um	Fine organic material: Amorphous (brown)	Fine organic material: Cell residues	Fine organic material: Amorphous (yellow)	Pedofeatures: Coatings	Pedofeatures: Frequency	Pedofeatures: Infillings	Pedofeatures: Frequency	Pedofeatures: Amorphous & crypto crystalline nodule iron	Pedofeatures: Ca - Fe phosphates	Pedofeatures: Excremental(mamillate)	Pedofeatures: Excremental (spheroidal)	Pedofeatures: Fe Depletion on Siltstone	Pedofeatures: Depletion in fine matrix	Void Type	Coarse material arrangement	Degree of sorting	Groundmass b fabric	Related distribution
Trench K																															
Sample 1	•••	••	Subangular	x		•	Grey + Brown (PPL) Brown (OIL) Dotted limpidity		x	•		•	••										xx		Yes	No	Planes + Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample 2	•••	••	Subangular	x		•	Brown (PPL) Brown (OIL) Dotted limpidity	•	x			••	••								x		x		No	No	Planes + Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample 3	•••	••	Subround	x		••	Brown (PPL) Brown (OIL) Dotted limpidity	•	x			••	••										x		Yes	No	Planes + Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample 4	•••	•••	Subround			••	Brown (PPL) Brown (OIL) Dotted limpidity				•	•	•								x		x		No	No	Planes + Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample 5	•••	••	Subround	x	x	••	Brown (PPL) Brown (OIL) Dotted limpidity						•										x		No	Yes	Planes + Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric

Frequency class refers to the appropriate area of section (Stoops 2003) t Trace • Very few •• few ••• Frequent/common ••••Dominant/very dominant.
Frequency class for textural pedofeatures (Bullocket al., 1985) t Trace x Rare xx occasional xxx Many

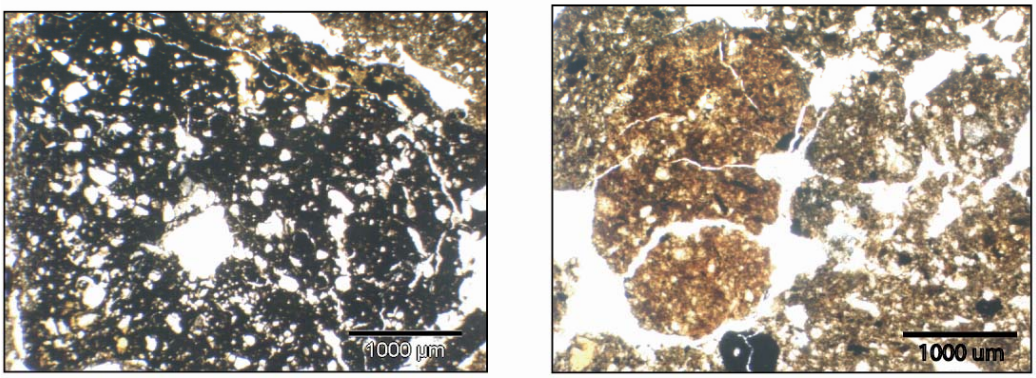
Light sources: Plane Polarised (ppl)
Cross Polarised (xpl)
Oblique Incident (oil)

Key micromorphological features from the anthropic sediment on the Ness of Brodgar (PPL)



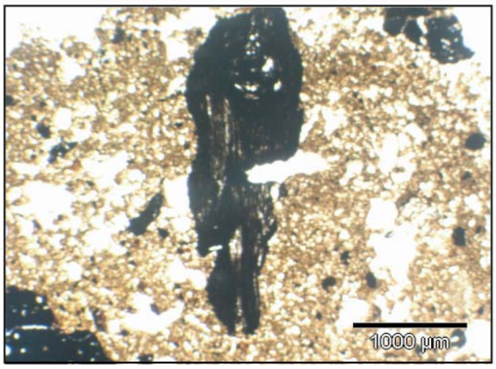
Cremated bone. Bone identified by presence of haversian canals. Cremated state of bone evidenced by black edge.

Turf grey fuel ash. Fuel ash contains occasional - many diatoms and rare - occasional phytoliths. Bright orange under OIL.



Burnt Turf. Black amorphous feature containing mineral inclusions under cross polars.

Unburnt Turf. Brown amorphous feature containing mineral inclusions under cross polars.



Charcoal evidence of internal cellular structure.

Figure 38 Key micromorphological features NoB Trench C and Trench E (PPL)

5.4 Discussion

5.4.1 Period of Formation

At the Ness of Brodgar a stratigraphic relationship has been inferred between the anthropogenic deposit and the Late Neolithic house partly excavated by Ballin Smith and Petersen (2003). Stratigraphic interpretation suggests that the Late Neolithic house is mostly above the anthropogenic deposit identified within Trench E and is therefore of a later date than the formation of the anthropogenic deposit. However; this stratigraphy has mostly been inferred due to the archaeological sensitive nature of the landscape where the complexities of the known structural archaeological record and the probable structural archaeological record identified through geophysical survey have prevented further excavation. With regards to the relative chronology of this site it is entirely feasible that the anthropogenic deposit identified within Trench E was formed before, was contemporaneous with or was formed after the Late Neolithic archaeological structures. For the purposes of this research it is sufficient to recognise that the anthropogenic deposit identified, at least within Trench E is intimately associated with the Late Neolithic house and it is therefore anticipated that it would be integrally associated with Neolithic settlement activity.

Despite the potential problems and limitations inherent within the attempt to provide radiocarbon dates for periods of cultural activity involved in anthropogenic soil and sediment formation, the use of multiple samples of different origin from each context along with the sum of stratigraphic relationships does allow confidence in the general interpretation which follows. It is also worth noting that the individual precision of the calibrated radiocarbon dates for single entities is enhanced as they do not suffer from being within the plateau of the radiocarbon calibration curve generally accepted as being between 3100 cal BC and 3400 cal BC (Ashmore and Sanderson 2005).

5.4.1.1 Initiation Anthropogenic Deposition, Trench E

Calibrated radiocarbon dates for the single entities of *Ericales* charcoal (3020-2860 cal BC) and cremated mammal bone (2910-2830 cal BC) expressed to two standard deviations indicate that the death of both of these organisms occurred within a similar time period, that of the Late Neolithic. It is suggested that the death and use of these organisms occurred as part of Late Neolithic cultural activity associated with settlement at the Ness of Brodgar. The Late Neolithic calibrated radiocarbon date of death of these organisms does not necessitate that these single entities were buried as part of Neolithic cultural activity. However, the calibrated radiocarbon age ranges of these single entities are similar and indeed overlap (Figure 34). The identification of similar calibrated radiocarbon age ranges within single entities from different organisms within the same archaeological context suggests that these single entities were deposited together, soon after the point of death and as the result of Late Neolithic domestic cultural activity. If the formation of this anthropogenic deposit had occurred significantly later than the age of death of the organisms used as single entities for radiocarbon dating it would be more likely that the calibrated radiocarbon date ranges from these single entities would reflect this and would not be contemporaneous.

Results from radiocarbon analyses of a single entity of cremated bone along with a single entity of charcoal further contributes to the security of the conclusion that the anthropogenic deposit in Trench E was formed from Neolithic cultural activity. Cremated bone material is generally good material to use to provide single entity radiocarbon dates, having a maximum inherited age of 15-20 years (Lanting *et al* 1998), although some research has shown that cremated bone may still inherit carbon from other sources (Lanting *et al* 2001, Ashmore and Sanderson 2005). The similarity of calibrated radiocarbon age ranges from the single entity *Ericales* charcoal and the cremated mammal bone suggest that this is not the case within this context. Also the use of *Ericales* charcoal to provide radiocarbon dates may be problematic as the *Ericales* may have been incorporated, preserved and later burnt within peat material. This would potentially give the *Ericales* a significantly inherited age, for example see Simpson *et al* (2000). Again the similarity of calibrated radiocarbon age ranges between the single entity *Ericales* charcoal and the cremated mammal bone suggest that the *Ericales* is not likely to have been incorporated into peat material and is more likely to have been from turf material. This conclusion is supported through the identification of turf within thin section (Figure 38) and through the humic acid radiocarbon results which are contemporaneous with, and younger than the single entity *Ericales* and do not have a significant inherited age which may be expected if they derived from peat.

5.4.1.2 Initiation Anthropogenic Deposition, Trench C

As in Trench E, calibrated radiocarbon dates for the single entity *Betula* charcoal (3080-3060 Cal BC) and the cremated mammal bone (2900-2620 cal BC) expressed to two standard deviations indicate that the death of these organisms occurred within the Late Neolithic period. The calibrated age range of the single entity *Betula* charcoal and the single entity cremated mammal bone at the base of the anthropogenic deposit in this trench do not overlap but are very similar and both calibrated date ranges are similar to the total date range of the dates provided for the single entities identified at the base of the anthropogenic deposit in Trench E (3020-2830 cal BC). As in Trench E it is suggested that the death and use of the cremated bone and charcoal material in the base of Trench C is the result of Late Neolithic cultural activity associated with settlement at the Ness of Brodgar (*Betula* charcoal was identified as being a maximum of 5 years old at age of death, Ramsey *pers comm.*). It is again suggested that the cremated mammal bone and the *Betula* charcoal were deposited together within Trench C soon after death and use, as evidenced by the similarity in dates and discussed previously.

5.4.1.3 Contribution of Humic Acid

Calibrated radiocarbon age ranges for the humic acid content of the soil organic matter (1520-1379 cal BC from the base of Trench E and 2870-2800 cal BC from the base of Trench C) are both younger than the calibrated age ranges of single entities from the same contexts. This is to be expected as research demonstrates that measured ^{14}C ages of soil organic matter are frequently younger than the true ages of soil formation due to the continuous input of organic matter into soils (Wang *et al* 1996) and that movement of organic material within soil horizons can serve to blur ages of soil formation (Simpson *et al* 2000). Despite this blurring, calibrated radiocarbon age ranges for the humic acid fraction of the soil organic matter within Trench C are reasonably coherent with those of the single entities from Trench C and support the previous discussion and conclusions concerning the period of anthropogenic deposition. The calibrated radiocarbon age range from the humic acid fraction of the soil organic matter within Trench E however is significantly younger than those provided by the single entities of the same context and requires further discussion.

The radiocarbon analysis conducted on the humic acid fraction of the soil organic matter is not conducted upon a single entity but upon all the alkali soluble, acid insoluble material extracted from soil material. As such the calibrated radiocarbon date range from the humic acid analysis actually represents the mean ^{14}C of this material. When compared with the single entity ^{14}C from the same context it is evident that the mean ^{14}C of the humic acid of the soil organic matter has been significantly skewed by the addition, or contamination of more recent carbon. This has produced a significantly younger calibrated radiocarbon age range, suggesting a much younger period of soil formation than would be expected from results of the single entities.

It is possible that carbon within the humic acid fraction of the soil organic matter has been leached down the profile, although this process is the least favoured in explaining the source of the contamination of more recent carbon into the humic acid fraction of the soil organic matter within this context. Humic acid is generally regarded as being acid insoluble and is assumed to be immobile within the pH range associated with peat material, typically in the order of pH 4 (Simpson *et al* 2000, Brady and Weil 2002). The pH within profiles at the Ness of Brodgar is only slightly acidic (around pH 6), and it may be expected that some humic acid has leached within this profile but it has been demonstrated that at pH 6 only limited movement of the humic acid may be expected (Ulrich and Khanna 1968 in Russell 1973). It is considered unlikely that this process is solely responsible for the incorporation of enough more recent carbon to account for the much younger radiocarbon date observed. Also, climatic, biotic and physical and chemical conditions do not appear to alter significantly between Trench E and Trench C and it would be expected that any conditions favouring the leaching of humic acid down the profile within Trench E would also be prevalent upon the profile in Trench C. Results indicate that this is unlikely to be the case.

Another source of contamination by recently introduced ^{14}C into the base of Trench E could be by the penetration of more recent plant roots. Field observations did not observe fine roots within this context but some research has demonstrated that apparent ages deduced from the ^{14}C content of the humic acid fraction of the soil organic matter have been recognised as being too young because of contamination through recent plant roots which may be too fine to identify within field observations and remove by hand (Hormes *et al* 2004, Shore *et al* 1995). It is also possible that the contamination by more recent carbon is the result of processes involved in the formation processes or subsequent function of the anthropogenic deposit. Field based observations identified only fine inclusions of charcoal and fine bone within a well sorted soil matrix. It is apparent that the homogeneity of this anthropogenic deposit is a product of its anthropogenic formation processes and possibly a product of any post-depositional function to the Neolithic community. The proximity of the calibrated radiocarbon ranges from single entities of differing organisms within the same context of this homogenised anthropogenic deposit may suggest that the homogeneity is more likely to be the result of depositional processes than of any post-depositional function. If the homogeneity was the result of any post-depositional function then it might be expected that there would be discrepancy between the calibrated radiocarbon ranges of single entities within the same context. Field observations suggest that the homogenous nature of this deposit results from its formation and possibly function within Neolithic settlement activity and not as the result of recent cultivation practices at this site. It is doubtful whether recent cultivation practices have significantly contributed to the contamination of this context with more recent carbon.

As anticipated the ^{14}C measurements of the humic acid fraction of the soil organic matter mostly support the conclusions from single entities. The ^{14}C analyses of the humic acid fraction of the soil organic matter can also contribute to the understanding of the material inputs associated with the formation of this anthropogenic deposit. Extracted humic acid concentrations from bulk samples were extremely low (Cook *pers comm.*) and loss on ignition values were within the range of 3-7%. This indicates relatively low soil organic matter content of the soils more comparable to turf material from grasslands than to peat material (Bohn *et al* 1985). This low soil organic matter content may reflect the combusted turf component of the deposit, also evidenced by thin section micromorphology results.

5.4.1.4 Cessation of Anthropogenic Deposition

Radiocarbon analysis for the cremated bone at the top of Trench E (context 003), suggests a calibrated age range of the death of the mammal as being 3020-2870 cal BC. This is comparable to the calibrated radiocarbon ranges obtained from the single entities within the base of both Trench E and Trench C. It has been argued that the proximity of calibrated radiocarbon ranges of different organisms within the same context at the base of the anthropogenic deposit within Trench E is evidence that the single entities were deposited soon after death and initial use in settlement activity. If there was significant time between death and deposition of these single entities larger discrepancies would be expected between the calibrated radiocarbon ages of different single entities. There is no evidence to suggest that the nature of the anthropogenic deposit within Trench E or the processes responsible for its formation, change within the stratigraphic unit of anthropogenic deposit within Trench E (Figure 27). It is therefore suggested that the single entity of cremated bone within context 003 was deposited by the same process as the single entities of cremated bone and charcoal analysed within context 047. This suggests that the date of death of the mammal which provided the single entity of cremated bone within context 003 is also a reasonable date to use for the date of the addition of this single entity of cremated bone to the anthropogenic deposit; and therefore that the calibrated radiocarbon date of 3020-2870 cal BC is also a reasonable date to use to infer the date of the cessation of the formation of this anthropogenic deposit upon the Ness of Brodgar.

5.4.1.5 Conclusion

The calibrated radiocarbon age ranges of the single entities and the humic acid fraction of the soil organic matter suggest that anthropogenic deposition on the Ness of Brodgar is the result of anthropogenic activities which occurred during the Late Neolithic and more specifically is likely to have formed as the result of a single, specific cultural practice between *c*3000 BC and *c*2800 BC. This Late Neolithic interpretation is consistent with that of the archaeological evidence from the wider Ness of Brodgar site which has identified only Late Neolithic artefactual evidence (Card 2004, Card and Cluett 2005), although the structural archaeology underlying this anthropogenic deposit may indicate earlier cultural activity. Further excavation to investigate this was not possible within Trench E.

The confirmation of this Late Neolithic landscape allows the Ness of Brodgar to be evaluated within the broader context of known settlements within the Orcadian Neolithic. The Knap of Howar on Papa Westray is generally regarded as the earliest Orcadian excavated settlement with a series of radiocarbon dates placing the occupation period between about 3700 and 2800 cal BC (Sharples 2000). At Pool on Sanday a sequence of Grooved Ware middens and houses has been partially dated with 68% confidence that twigs within this sequence, above earlier houses died between 3040 and 2780 cal BC (Ashmore 2005). Radiocarbon dates from the two main phases at Skara Brae have also been analysed with conclusions that occupation started at the earliest

3360 and at latest at 2920 cal BC and most likely that occupation occurred between 3100 and 3000 cal BC, and radiocarbon dates from settlement at the Links of Noltland, Westray suggest settlement started around, but not before 3000 cal BC and continued until after 2500 cal BC (perhaps as late as 2400 cal BC, Ashmore and Macsween 1998). More recently radiocarbon analyses from Barnhouse Neolithic Settlement suggest settlement some time between 3400 and 2900 cal BC and abandonment some time within the same period. The best estimate of the duration of the excavated part of the settlement is that it was founded nearer to 3100 cal BC and it went out of use around 2900 cal BC (Ashmore 2005).

Two early radiocarbon dates are available for the WHS monument The Stones of Steness (Ritchie 1976). The earliest of these dates (4310±70 BP) comes from animal bone from the base of the henge ditch with the other sample from wood charcoal from the large hearth feature in the centre of the henge. Radiocarbon analysis was undertaken on these samples when actual errors were larger than previously thought, but after appropriate correction the earliest date from the Stones of Stenness lies between true dates of 3400-2500 cal BC while the date from the central hearth lies between 3350-2350 cal BC (Ashmore 2005). The archaeological site of the Ness of Brodgar clearly demonstrates that the cultural activity, including the formation of this anthropogenic deposit at this site in the Late Neolithic was contemporaneous, at least in part with settlement at Barnhouse and may have been contemporaneous with the construction of the Stones of Stenness.

5.4.2 Materials and Processes of Formation

The field observations identified an anthropogenic deposit at the Ness of Brodgar containing inclusions consistent with those of household waste (midden) deposits associated with other Late Neolithic settlements on Orkney including charcoal, pottery, bone and burnt stone (Renfrew 1985). Results have characterised the properties of this anthropogenic deposit, and an integrated discussion of these results elucidates the materials and processes of its formation. The importance of this site and this anthropogenic deposit to the further interpretation of the WHS is further discussed in Chapter 9. The location of this anthropogenic deposit above structural archaeology (Trench E) suggests that deposition was entirely the product of anthropogenic sedimentation processes including the deposition of material which has been transported from elsewhere. There is no evidence, as present at Skaill Control, for the influence of anthropogenic activity upon a soil which formed before being amended by anthropogenic activity. Any existing evidence of pedogenesis prior to settlement presumably remains beneath the structural archaeology.

Thin section results identified that the coarse mineral component of this anthropogenic deposit contains 25-30% quartz material with a relatively uniform size and degree of sorting, suggesting that the material forming the anthropogenic deposit has originated from the same geographic location. Typically between 5 and 30% of the coarse organic material in thin section is amorphous black material containing mineral inclusions obvious under cross polars, which has been interpreted as burnt turf. The presence of occasional typic iron nodules and the uniformity of iron depletion features upon siltstones at depth within the deposit suggest that the turf material forming the basis of this anthropogenic deposit originated from the upper horizons of a moderately well developed podsol. These depletion features occur in the uppermost horizons of well developed podsols as the result of the very active organic compounds produced by litter causing acidification and the weathering and translocation of materials including iron. Such depletion features are unlikely to occur at depth within this anthropogenic deposit (Romans and Roberson 1985, Simpson 1997). The presence of occasional-many diatoms indicates that the most likely source for this deposit as being formed upon a poorly drained, wet substrate (Simpson and Barrett 1996). This is perhaps unsurprising considering the location of this site between the Loch of Harray and the Loch of Stenness with low lying poorly drained land to the northwest. The turf base to this anthropogenic deposit would presumably have been removed and deposited by hand with such a significant volume of this deposit suggesting its source as being in close proximity to the settlement site upon the Ness of Brodgar.

The turf material has been stripped from the wet substrate and has been burnt prior to deposition, fulfilling a function within domestic activity consistent with the archaeological interpretation of this site, including observations of cremated mammal and non-cremated sheep bone, charcoal, pot and flint. The burning of this material is evidenced by the common abundance of burnt turf material within thin section, although charcoal is relatively rare. Furthermore the identification and quantification of charcoal from bulk samples obtained from Trench E (047) and from Trench C (086 and 075) for the purpose of radiocarbon analysis identify *Ericales* species as comprising 54% of the charcoal species by weight (Figure 33 page 141). This is consistent with the interpretation that turf was the dominant fuel resource utilised within the Late Neolithic by settlers at the Ness of Brodgar.

An adequate supply of fuel is a prerequisite for a sustainable settlement and it is well documented that generally by the Late Neolithic on Orkney that birch-hazel woodlands had been replaced by more herbaceous vegetation (Davidson and Jones 1985, De La Vega Veinart *et al* 2000). Results from the Ness of Brodgar are consistent with those from Barnhouse Neolithic settlement where *Calluna* species were dominant comprising 33.1% by weight of the total charcoal retrieved (Cartwright 2005). It is clear from both of these results both that the dominant vegetation in the immediate vicinity of these two sites during the Neolithic closely resembles the *Calluna vulgaris-Erica cinerea* type of present day heathland vegetation community (Rodwell 1991) and that this heathland was heavily utilised as a fuel resource. Further evidence for the burning of this turf material prior to deposition is the presence of grey features within the fine matrix observed within thin section (Figure 38). As at Skaill Control these features are bright orange under OIL and contain many diatoms and phytoliths and are interpreted as being fuel ash residues.

The extent of burning upon this site is evidenced within particle size distribution (PSD) and mass susceptibility results. PSD is dominated by silt which is consistent with anthropogenic sediments dominated by peat/turf fuel ash within the Northern Isles (Guttmann 2001, Simpson *et al* 2006). Mass susceptibility results identify a wide range of mass susceptibilities associated with the anthropogenic deposit with a mean mass susceptibility of 6.19 $x10^{-6}$ m^3kg^{-1}. These results support those from magnetometry survey and suggest that the anthropogenic deposit has formed from moderate to high intensity burning which has been sufficient to reduce haematite or goethite to magnetite under the heating and reducing conditions engendered by the combustion of soil organic matter associated with surface fire. The magnetite has been reoxidised to maghaemite. Mass susceptibility results from the anthropogenic deposit at the Ness of Brodgar are statistically greater than from both anthropogenic horizons within Skaill Control (Table 19). This suggests that the anthropogenic deposit from the Ness of Brodgar contains more burnt material than the anthropogenic soil horizons within Skaill Control and/or that the deposit upon the Ness of Brodgar has been burned more intensively than the material within the anthropogenic soil horizons within Skaill Control. The high mass susceptibility results from the Ness of Brodgar are more akin to sites involving industrial metal working activities than just domestic activities (Ovenden *pers comm*) and while such activities seem improbable within the context of this Late Neolithic site, the intensity and extent of this burning does pose further questions concerning the formation and function of this deposit. Further evidence for the extent and intensity of burning is evident within the cremated bone in which the carbonate has undergone structural changes consistent with those observed at cremation temperatures between 525^{o}C and 625^{o}C (Mays 1998). This suggests that the turf material and associated anthropogenic inclusions have been burnt up to temperatures of 525-625^{o}C, although such temperatures may still be consistent with those associated with the burning of fuel resources within domestic cultural activity (Simpson *et al* 2003).

Statistical comparison of total phosphorus results suggests that the intensity of amendment associated with the formation of the anthropogenic deposit upon the Ness of Brodgar is comparable to that associated with the later plaggen soils within Skaill Control (Table 19). However, thin section results identify different anthropogenic inclusions within these two anthropogenic deposits. The relative abundance of bone, charcoal and ash inclusions within the deposit upon the Ness of Brodgar may be represented within the fractionated phosphorus results which identify a significant proportion of the phosphorus within Trench E as being inorganic phosphorus. These results should be interpreted cautiously however, as the greater proportion of inorganic phosphorus within the anthropogenic deposit does not necessitate that all of the inputs into this deposit were predominantly in the form of inorganic phosphorus such as bone and ash.

Organic phosphorus such as present within manure is mineralised into inorganic phosphorus by the action of microbes within the soil environment and the rate of any mineralisation is therefore a product of soil environmental factors which affect biological activity (Brady and Weil 2002, See section Soil Phosphorus 3.2.4). It is entirely possible therefore that any organic phosphorus originally present within this deposit has been mineralised into inorganic phosphorus. Despite this cautionary approach it is apparent that bone, fuel ash and charcoal form a significant input into this anthropogenic deposit.

A distinct feature of this anthropogenic deposit both within field observations and in thin section is the homogenous nature of the deposit. All of the anthropogenic inclusions are very fine-fine in size and are well homogenised within the anthropogenic material which is moderately-well sorted. This deposit is significantly more homogenised and well sorted than both amended soil horizons within Skaill Control and this characteristic of this deposit is anomalous within the context of other investigated Late Neolithic anthropogenic sediments containing similar anthropogenic inclusions (Card *pers comm.*). It is apparent that there has been significant mixing of the anthropogenic inclusions within the turf material burnt within domestic activity which is evidenced by the well sorted nature of this deposit. If no deliberate mixing had taken place it would be expected that the deposit would be more poorly sorted containing inclusions of various sizes and that the deposit would not be homogenous. This mixing could have occurred during burning as evidenced by cremated bone, but it seems more likely to have occurreds immediately prior to, or contemporaneous with deposition of this deposit.

The deposition of this anthropogenic deposit has occurred within a discrete geographical location within the overall archaeological site at the Ness of Brodgar and is only found between

Trenches C and F, (a distance of *c*150 m) and Trench K (a distance of *c*30 m). The mean depth of this deposit within these trenches is 0.4 m with estimates based upon these observations suggesting that it is possible that 1338 m^3 of this turf based deposit has been deposited at this site, suggesting that much of the extensive mound below Lochview bungalow at the Ness of Brodgar is the result of anthropogenic formation processes. This significant volume of anthropogenic deposit within this discrete geographical location may emphasise the importance of this deposit and any cultural activities associated with its pre and/or post-depositional function in further interpreting the WHS. The lack of microhorizons and the lack of textural pedofeatures within thin sections suggest that its accumulation was persistent and rapid with no standstill phases where the deposit could have been exposed to surface weathering (Simpson *et al* 1999b). As such it is suggested that this deposit be classified as an anthropogenic sediment which has been transported and deposited through anthropogenic activity and that it does not represent a soil amended through subsequent anthropogenic activities (Brady and Weil 2002).

This research has identified the pre-depositional function of this anthropogenic sediment as being utilised within domestic Late Neolithic cultural activity presumably for heat and light involved with domestic activities. Research from excavation of Barnhouse Neolithic Settlement does suggest deliberate resource selection of fuel resources utilised for specific tasks such as firing pottery (Cartright 2005), this may also have been the case upon the Ness of Brodgar although the limited excavations and the homogeneity of the anthropogenic sediment identified prevent this hypothesis from being tested within this research. The sediment has formed as the result of the deposition of a significant volume of turf material which was stripped from a wet substrate, burnt within domestic settlement activity, mixed with aspects of household waste (midden) and which was then deposited within a geographically discrete area of the site.

5.4.3 Post-depositional Function

Recent publications draw attention to the importance of anthropogenic sediments to Neolithic settlement activity, and there is an increasing awareness that the character of anthropogenic sediments may be intimately linked to post-depositional functions and used to define Neolithic cultural activities (Guttmann *et al* 2005, Simpson *et al* 2006). Here, the post-depositional function of this Late Neolithic anthropogenic sediment is discussed within the context of multiple working hypotheses. These hypotheses are developed from post-depositional functions of anthropogenic soils and sediments identified within excavations of Late Neolithic settlements on Mainland Orkney and the outer Isles, as previously identified in chapter 1.

Discussion concerning the multiple working hypotheses of post-depositional function relies predominantly on observations from field work and thin section micromorphology, as thin section micromorphology analysis has the potential to identify post-depositional pedological processes as well as the anthropogenic amendments added to the sediment (Carter and Davidson 1998). Table 20 compares the key thin section characteristics of the anthropogenic sediment at the Ness of Brodgar with those of anthropogenic soils from other secure archaeological contexts. Total phosphorus and mass susceptibility results from the anthropogenic sediment upon the Ness of Brodgar are also compared to results from anthropogenic sediments from known archaeological contexts (Table 20). Such comparisons however, are likely to be less useful in determining any post-depositional function as total phosphorus results indicate only the intensity of anthropogenic amendment of a sediment, with mass susceptibility results indicating the intensity of burning and/or amount of burnt material present within the anthropogenic sediment. The intensity of organic material amendment and the intensity and/or amount of burnt material within anthropogenic sediments may be independent of the post-depositional function of that sediment and the use of the comparison of these results to establish post-depositional function of the anthropogenic sediment upon the Ness of Brodgar is therefore problematic. Furthermore, no typical Neolithic midden or anthropogenic sediment exists, as any such deposit is likely to reflect a sites economic base which is dependant at least upon geographical location and the choice of resources utilised within settlement.

Table 19 Comparison of characteristics

Control sites				**Anthropogenic sediments from Neolithic excavations**	
Ness of Brodgar (NoB) Anthropogenic sediment property	Finstown Control	Skaill Control LBA/IA Arable function	Skaill Control Plaggen Arable function	Skara Brae Construction Function (Trench 2)	Pool Possible arable function
Total P Mg/100g oven dried soil **Mean 250** **Median 216**	NoB significantly greater. (Mann Whitney P=0.0000)	NoB significantly greater. (Mann Whitney P=0.0002)	NoB not significantly different (Mann Whitney P=0.1981)	Skara Brae significantly greater than NoB (Mann Whitney P=0.000)	Pool significantly greater than NoB (Mann Whitney P=0.0039)
Magnetic Susceptibility **Mean 6.19 $\times10^{-6}$(m^3kg^{-1})**	NoB significantly greater. (Mann Whitney P=0.0001)	NoB Significantly greater. (Mann Whitney P=0.0150)	NoB Significantly greater. (Mann Whitney P=0.0251)	*unknown*	*unknown*

All statistical tests carried out to 95% significance

Table 20 Comparison of micromorphological features with those from secure archaeological contexts

	Ness of Brodgar (This volume)	**Finstown Control (This volume)**	**Skaill Iron Age (This volume)**	**Skaill Later Plaggen (This volume)**	**Skara Brae (Simpson 2006)**	**Skara Brae (Simpson 2006)**	**Tofts Ness (Guttmann 2006)**
Post-depositional Function	Unknown	None glacial deposit	Arable agriculture	Arable agriculture	Construction	Possible compost	Arable agriculture
Fuel ash residues	Many		Many		Rare-Many	Occasional	Occasional
Burnt peat/turf	Many		Occasional	Rare	Occasional	Occasional	Occasional
Bone	Many Cremated		Occasional Unburnt	Rare Unburnt	Rare	Many some decayed	Occasional
Calcium Spherulites						Rare	
Coprolite						Occasional	
Fungal Spores	Occasional-Many		Occasional	Rare	Rare	Rare	Rare
Pedofeatures: Coatings and Infillings		Many limpid clay coatings and infillings	Many silt coatings and dense incomplete silt infillings	Many clay and silt coatings. Dense incomplete silt infillings	Rare iron hypocoatings and clay coatings		Rare Fe Hypocoatings
Nodules	Many Typic Iron		Many typic iron	Rare typic iron			
Excremental Mamilliate and biological disturbance	Occasional-Many			Rare			Occasional-many-high biological activity
Void Type	Planes and complex packing	Planes and Complex Packing	Complex Packing, few planes	Complex Packing, few planes	Cracks, rare vughs and channels	Crack	Spongy, some channel and chamber
Sorting	Very well	Poorly	Moderately well	Well	Unknown	Unknown	Unknown
Coarse Mineral	Blocky, sub rounded	Blocky, angular	Blocky, sub rounded	Blocky, rounded	Blocky	Blocky, sub angular	Unknown
Related distribution	Porphyric	Porphyric	Porphyric	Open porphyric	Close porphyric	Lose porphyric	Porphyric

5.4.3.1 Working Hypothesis 1 – A Waste Deposit, No Post-depositional Function

This hypothesis seems to be the least plausible explanation for the post-depositional function of the anthropogenic sediment identified upon the Ness of Brodgar. There is sufficient evidence from secure archaeological contexts within the Orcadian Late Neolithic to suggest that anthropogenic sediments were retained within cultural activities as having significant value associated with their post-depositional function. Literature review of these secure archaeological contexts suggests at least post-depositional functions associated with settlement and ritual monument construction or the management of arable land (section 1.3, page 8). Furthermore, the identification by recent research of specific resource selection of different anthropogenic sediments dependant upon their post-depositional function further contributes to the value attributed to anthropogenic sediments by settlers within the Late Neolithic (Simpson *et al* 2006).

Evidence from the Ness of Brodgar identifies the anthropogenic sediment as being defined within a discrete geographical location within the overall Late Neolithic archaeological complex. This suggests that this anthropogenic sediment has been deliberately deposited by anthropogenic activity within this part of the site, within an area of up to 3125 m^2. Such a deliberate, geographically defined deposition pattern suggests the importance of this anthropogenic sediment and its specific deposition to the Neolithic cultural activities being undertaken at this location and within the wider landscape. Further evidence of the value attributed to this anthropogenic sediment is the stratigraphic location of the sediment above structural archaeology which may remain *in situ* (Trench E). The location of this structural archaeology below a significant depth of this anthropogenic sediment may indicate that the anthropogenic sediment and its post-depositional function became more valuable to Neolithic settlers than the underlying archaeological structure.

The anthropogenic sediment at the Ness of Brodgar also possesses characteristics inconsistent with an interpretation that this sediment only represents discarded waste which had no post-depositional function. The homogeneity and well sorted nature of this deposit are more indicative of a post-depositional function than of just discarded waste which would be expected to be poorly sorted. Furthermore, observations within thin section of many mammilliate excrement suggests a high degree of biological activity within the sediment. This high biological activity within the sediment must be a product of its post-depositional state as organisms would be unable to survive burning temperatures of 525-625^{o}C associated with the burning of this sediment (Mays 1998). Peat/turf ash dominated Iron Age middens of no post-depositional function and anthropogenic sediments associated with Neolithic settlement construction contain no evidence of biological activity (Guttmann 2001, Simpson *et al* 2006). This suggests that the high biological activity identified within the anthropogenic sediment upon the Ness of Brodgar which is also dominated by turf fuel ash is more likely to be associated with a post-depositional function.

5.4.3.2 Working Hypothesis 2 – Pastoral Land Management

The Neolithic period has been characterised by the domestication of cattle, pigs and sheep/goats and the utilisation of new resources of cultivated cereals principally wheat and barley (Murray and Wintle 2000). There is sufficient evidence from Neolithic Orkney to identify that food production came from mixed agricultural practices, perhaps with a pastoral bias although the differential survival of evidence is heavily biased towards the products of animal husbandry (Clarke and Sharples 1985). Despite this bias there is sufficient evidence from Neolithic Orkney to suggest the deliberate management of livestock for the production of food within settlement.

Research from Barnhouse Neolithic Settlement does draw attention to pastoral land use. French (2005) has identified that the turfs associated with settlement construction were probably removed from pre-existing pasture land either on the site or in its close vicinity, therefore facilitating its construction. This is indicated by the observation of biological activity and the presence of amorphous iron and phosphatic or coprolitic material within thin section which is interpreted as being the result of the grazing of animals on turf (French 2005). It is suggested that this grazing of animals occurred upon pasture land prior to the construction of settlement and perhaps also from subsequent grazing on re-deposited turfs used within the settlement (French 2005).

Results of analytical experiments of the anthropogenic sediment upon the Ness of Brodgar do not necessarily preclude a post-depositional pastoral function but neither do they strongly support such an interpretation as any pastoral and livestock management may leave little or no micromorphological evidence of its existence (Carter and Davidson 1998). The observation of *sclerotia* fungal spores has been proposed as evidence of grazing (Romans and Robertson 1985) and while fungal spores are present within the sediment upon the Ness of Brodgar these features need to be interpreted cautiously because of problems concerning equifinality. It has been suggested that the grey features observed in thin section containing occasional-many diatoms and phytoliths and interpreted as fuel ash deposits may be interpreted as the result of cattle trampling. Macphail (*pers comm.*) suggests that the grey fabric unit may actually represent the incorporation of lake shore sediments into the pasture land which may have occurred as the result of animals being taken to the water edge to drink and then being returned to pasture with lake shore sediments attached to their hooves and becoming trampled into the pasture. Such an explanation does seem unlikely where the anthropogenic sediment contains significant quantities of burnt material. Furthermore, the features interpreted as fuel ash features within thin section from the sediment at the Ness of Brodgar differ significantly from the lacustrine silts identified within thin section samples from excavations around the edge of the Loch of Harray (Chapter 7, Figure 65).

Other characteristics of the anthropogenic sediment upon the Ness of Brodgar are difficult to explain through an interpretation of post-depositional pastoral function. These characteristics include the significant volume and depth of the anthropogenic sediment which has accumulated persistently and rapidly which may be unexpected from any pastoral post-depositional function where cattle would have presumably been grazing. The sediment contains a significant proportion of household waste of probably a greater concentration than would be expected from a pastoral land use. Results do not preclude a post-depositional pastoral function but neither do they support such a post-depositional function. It seems unlikely that that the anthropogenic sediment upon the Ness of Brodgar was utilised within any direct pastoral land management system.

5.4.3.3 Working Hypothesis 3 – Utilisation within Construction

The use of anthropogenic sediments utilised within Neolithic settlement construction was recognised during excavation of Skara Brae where structures were identified as being embedded within domestic waste material (Childe 1931). Childe (1931) identified a significant volume of anthropogenic sediment associated with the construction of Skara Brae and suggested that any Neolithic visitor to the settlement ‘approaching from the southeast would have been faced with a great slope of refuse culminating in hut 1 where some projecting walls would have been visible’.

There is a suggestion based upon interpretations from Skara Brae that the creation of a midden mound (anthropogenic sediment) containing a significant volume of domestic waste represented the first stage in the construction process of the settlement and that the material within the midden mound was left to consolidate before finally having houses set into depressions within it. This concept of a large midden mound utilised in construction possibly finds parallels with the west midden at Links of Noltland which may represent midden material stored for construction but which was never used (Clarke and Sharples 1985).

Further excavations of Skara Brae during 1972-1973 revealed a more complex relationship between construction and waste materials, with the foundations of both earlier and later structures countersunk in anthropogenic sediments, double dry stone walling packed with waste mixtures and evidence of anthropogenic sediment accumulating against structures (Clarke 1976). These anthropogenic sediments were clearly used within settlement construction but it is only recently that these sediments have been characterised using thin section micromorphology supplemented by total phosphorus and particle size analysis. Research has identified deliberate resource selection in construction materials with peat/turf fuel residues dominating the foundation and construction of the earliest phases of settlement. The later settlement also used a wide range of household waste materials which may have been used to help stabilise continuing and possibly increasing sand blow. Silty clay material mixed with a very small amount of household waste is associated with wall construction and may have been used for both its structural and insulating properties within the double stone walls. Sediments not directly associated with construction were identified as containing a significant amount of household waste but the identification of calcium spherulites within these samples also suggests a significant herbivore dung component leading to the suggestion that animal manures may have been composted on the edge of the settlement (Simpson *et al* 2006).

Total phosphorus concentration of the anthropogenic sediment associated with the construction of Skara Brae is significantly greater than total phosphorus concentration associated with the anthropogenic sediment at the Ness of Brodgar (Table 19). This suggests that the anthropogenic sediment associated with construction at Skara Brae contains a greater concentration of household waste than the anthropogenic sediment identified at the Ness of Brodgar, which contains a significant input of turf. This does not necessarily preclude a post-depositional construction function of the anthropogenic sediment at the Ness of Brodgar, as it is considered possible that as at Skara Brae any construction within other Neolithic settlement activity would utilise various anthropogenic sediments in a variety of ways. The interpretation of the anthropogenic sediment at the Ness of Brodgar possessing a post-depositional construction purpose is further complicated by the implications of recent research from Barnhouse Neolithic Settlement. Excavation identified house structures which would have been free standing with turf material being banked up against their outer walls (Richards 2005). Such settlement construction provides a stark contrast to Skara Brae where settlement was countersunk into anthropogenic sediments. Further characterisation of the deposit surrounding the structures at Barnhouse Neolithic Settlement using thin section micromorphology has identified the material as being a heterogeneous mixture of predominantly turf material with the addition of lacustrine silt and only a minor amount of household waste (midden) (French 2005). These examples demonstrate the variability of anthropogenic sediments utilised within settlement construction.

The excavated archaeological structures on the Ness of Brodgar bear close resemblances to the structures excavated at Barnhouse Neolithic Settlement (Card and Cluett 2005) which may be expected due to the proximity of these two settlement sites to one another. The anthropogenic sediment at the Ness of Brodgar also appears to have similar characteristics to the deposit identified as being stacked around the structures at Barnhouse Neolithic Settlement. Both deposits are predominantly turf based with inclusions of household domestic waste, both deposits contain mamillate excrement features which are indicative of high biological activity which at Barnhouse Neolithic Settlement is interpreted as being the result of being taken from pasture. The similarity between these two deposits located at settlement sites within close proximity of each other may suggest that the anthropogenic sediment at the Ness of Brodgar had a post-depositional construction function within settlement and that the significant volume of this anthropogenic sediment represents a mound deliberately constructed for later use within construction as would have been present at Skara Brae and may have been present at the Links of Noltland (Clarke and Sharples 1985). However, such an interpretation does not account for the well sorted, homogenised nature of the anthropogenic sediment, and the high fuel residue content interpreted as being a result of post-depositional function. Furthermore field evidence from the Ness of Brodgar identified this anthropogenic sediment as being stratigraphically above structural archaeology and there is no evidence that this anthropogenic sediment was intimately associated with settlement construction (although this does not preclude the sediment from being incorporated into a midden heap which was incorporated into later construction).

What can be rigorously interpreted from the discussion concerning the post-depositional construction function of anthropogenic sediments within Late Neolithic construction is that the incorporation of soils, sediment and anthropogenic sediments varied significantly throughout

Late Neolithic construction including both domestic and ritual constructions. The resource selection of soils and sediments incorporated into construction is likely to have been determined by local geographic conditions but also appears to be the product of differing knowledge and practices across Neolithic Orkney. The large variation in sediments utilised within Late Neolithic construction precludes a post-depositional construction function of the anthropogenic sediment upon the Ness of Brodgar from being totally discarded. However, such an interpretation does not fully account for several of the key micromorphological characteristics of this anthropogenic sediment including the well sorted, homogenised nature of the sediment and the high degree of biological activity. It is still feasible, although it does seem unlikely, that the anthropogenic sediment upon the Ness of Brodgar had a post-depositional construction function.

5.4.3.4 Working Hypothesis 4 – Arable Land Management

Comparison of total phosphorus results from the anthropogenic sediment at the Ness of Brodgar with total phosphorus results from anthropogenic sediments and amended soils associated from known archaeological contexts suggests that the total phosphorus concentration of the anthropogenic sediment at the Ness of Brodgar is significantly lower than the total phosphorus concentration of the anthropogenic sediments associated with construction at Skara Brae (Table 19). This does not suggest an arable function for the anthropogenic sediment at the Ness of Brodgar but it does validate the thin section observations that the anthropogenic sediment is not entirely the product of domestic waste material but also contains a significant input of turf material.

The identification of this turf based sediment containing a significant volume of anthropogenic inclusions does not necessarily indicate a post-depositional arable function, but characteristics of this sediment are consistent with those observed within cultivated anthropogenic sediments (middens) from other Neolithic settlements within the Northern Isles. The post-depositional arable function of these middens has been ascertained through the observation during excavations of ard marks (Guttmann *et al* 2006). Ard marks were not observed to be present within the sediment at the Ness of Brodgar but the absence of ard marks within the excavated trenches does not necessitate an interpretation of the absence of agricultural activities. Ard marks are usually identified within sandy soils, as at Tofts Ness (Guttmann *et al* 2006) and not within the silt loam of the Ness of Brodgar where it is also likely that the spatial constraints of the excavated area may have prevented their observation. Guttmann (2001 and *et al* 2006) identified a Neolithic arable land management system at Tofts Ness probably based upon the flattening and cultivation of domestic waste material (midden) rather than the addition of midden material onto surrounding arable areas. The cultivated middens at Tofts Ness were composed predominantly of domestic waste including peat ash, animal bone and organic material with evidence suggesting that this midden material had been flattened and cultivated in situ to create what may have been small garden size plots used for early cereal cultivation (Guttmann *et al* 2006).

Thin section results suggest that the anthropogenic sediment upon the Ness of Brodgar is very similar to that observed within the cultivated middens at Tofts Ness (Guttmann 2001 and *et al* 2006). Both deposits contain significant volumes of domestic waste, predominantly peat/turf fuel ash and bone. Occasional fungal spores are present within both deposits which may indicate the addition of animal manures. Calcium spherulites which are the unequivocable evidence of animal manures (Canti 1998) were not present, although this may be because they are prone to dissolution within acidic soils such as upon the Ness of Brodgar (Simpson *et al* 2006). Other significant similarities between these two deposits are the well sorted homogenous nature of the deposits and relatively high degree of biological activity associated with both deposits. The homogenisation may have resulted from soil biota but it is also possible that deposits were physically reworked by cultivation.

Significantly, the only Neolithic anthropogenic sediment from a secure archaeological context with a high degree of biological activity is from the cultivated midden material at Tofts Ness. Uncultivated ash middens at Tofts Ness and anthropogenic sediments utilised in construction at Skara Brae contain no evidence of any biological disturbance (Simpson *et al* 2006). Biological activity has been an important indicator of ancient cultivated soils and in certain situations has been demonstrated to positively correlate with cultivation (Davidson and Carter 1992). These observations suggest that it is most likely that the anthropogenic sediment upon the Ness of Brodgar had a post-depositional arable function. Further evidence to support this is present from field based observations which identify this sediment within a geographically discrete part of the archaeological landscape. It is possible that this discrete geographical location represents an arable field system which as at Links of Noltland and possibly Barnhouse Neolithic was defined by constructed features such as ditches and walls (Clarke and Sharples 1985, Richards 2005). Further excavation would be required to test this hypothesis.

The only observation from the anthropogenic sediment at the Ness of Brodgar which is inconsistent with those of the cultivated midden at Tofts Ness is the volume of anthropogenic sediment. The cultivated midden material identified at Tofts Ness was *c*0.3 m in thickness whereas a greater depth and volume of anthropogenic sediment was identified at the Ness of Brodgar. This does not preclude a post-depositional arable function at the Ness of Brodgar, with differences in the volume of anthropogenic sediment potentially easily explained by factors such as differences in populations between settlement sites. It is interesting that the textural pedofeatures were not identified within either the anthropogenic sediment at the Ness of Brodgar or the cultivated middens of Tofts Ness. This suggests that as within the anthropogenic sediment upon the Ness of Brodgar the midden material at Tofts Ness accumulated rapidly and persistently but that such a depositional pattern did not preclude its post-depositional arable function. The rapid persistent accumulation of the anthropogenic sediment upon the Ness of Brodgar would not therefore necessarily preclude any post-depositional arable function.

It is apparent that as with the incorporation of sediments into Late Neolithic construction, some variation exists in the management of arable land between settlement sites in Neolithic Orkney. A management practice which does appear to be common to sites excavated and possessing evidence of agricultural practices is the incorporation of household waste for the specific purpose of maintaining the fertility of arable land. The incorporation of household waste into soils such as at the Links of Noltland, and the cultivation of household wastes as at Tofts Ness has been identified within the literature review and within this discussion and is further supported from other excavation including those at the Bay of Stove (Bond *et al* 1995). The characteristics of the anthropogenic sediment at the Ness of Brodgar most closely resemble those of the anthropogenic sediments of known post-depositional arable function, suggesting that its most probable post-depositional function is that of an arable function within Late Neolithic settlement activity. This interpretation may become more secure through any post excavation analysis undertaken upon bulk samples of the anthropogenic sediment retained within storage by

Orkney Archaeological Trust. Analysis may include the potential identification of charred weed seeds which grow alongside cereal crops through archaeobotany and the identification of land snails (Carter and Davidson 1998).

5.4.3.5 Conclusion

While evidence clearly supports a post-depositional function associated with the anthropogenic sediment at the Ness of Brodgar there is no apparent reason which precludes either an as yet unknown post-depositional function or the possibility of multiple post-depositional functions. Furthermore it must be recognised that any value attributed to this anthropogenic sediment by Neolithic settlers may not have been solely, or in anyway associated with its post-depositional function. This research has identified a significant volume of anthropogenic sediments upon the Ness of Brodgar along with structural archaeology within a deeply stratified archaeological site. Prior to excavation it was presumed that the topography of the land at the Ness of Brodgar was primarily the result of glaciation processes. This research however suggests that much of the extensive mound below Lochview bungalow is the result of anthropogenic sedimentation processes, with field obervations suggesting that at least 2 m of anthropogenic stratigraphy exists in places (Card 2004). Indeed, the mound may have been even more pronounced prior to more recent agricultural practices associated with Orkney’s mid nineteenth century Agricultural Revolution (Card and Cluett 2005).

Despite these considerations, there is sufficient evidence to suggest that whatever societal values were associated with this anthropogenic sediment that a post-depositional function existed, which in all probability had significant value for the functioning and sustenance of settlement.

Results of analytical analyses and subsequent discussion within the context of the post-depositional function of known Late Neolithic anthropogenic sediments suggest that the most likely post-depositional function of the anthropogenic sediment upon the Ness of Brodgar was that of an arable function.

5.5 Chapter Conclusion

In relation to the original research questions this research has identified a deeply stratified anthropogenic sediment upon the Ness of Brodgar which represents a SSBCR. Radiocarbon analysis has confirmed the formation of this SSBCR within the Late Neolithic, most probably between *c*3000 and 2800 cal BC. The specific formation of this SSBCR by Late Neolithic cultural activities involved the removal of a significant volume of turf material presumably from within close proximity to the settlement and the burning of this turf within domestic activites presumably for heat and light. This turf fuel ash was then mixed with other domestic waste including sherds of pot and cremated animal bone before being deposited within a geographically discrete area of the archaeological site. Any post-depositional function attributed to this SSBCR has been evaluated within the framework of multiple working hypotheses which identify the probable post-depositional function as being that of an arable function.

Chapter 6 - Wasbister

The complex nature of the relationship between the geophysical survey and the associated structural archaeology within the WHS IBZ suggested a cautious approach be taken to the locating of soil profiles within the geophysical anomalies surrounding the probable double Bronze Age house at Wasbister. Soil profiles (A-D) were located on a transect, at a distance of 35 m from the road in order to purposefully avoid any archaeological structures (Figure 39). Subsequent to the excavation of these initial profiles, further profiles were excavated in closer proximity to the structural archaeology associated with the probable double Bronze Age house (Profiles E-H, Figure 39). Care was taken not to infringe upon the Scheduled Area associated with this archaeological monument with profiles being deliberately located away from potential structural archaeology as identified through magnetometry survey. The resulting profile locations have allowed the characterisation of soil properties within a complex archaeological landscape dominated by Bronze Age settlement and ritual structural archaeology.

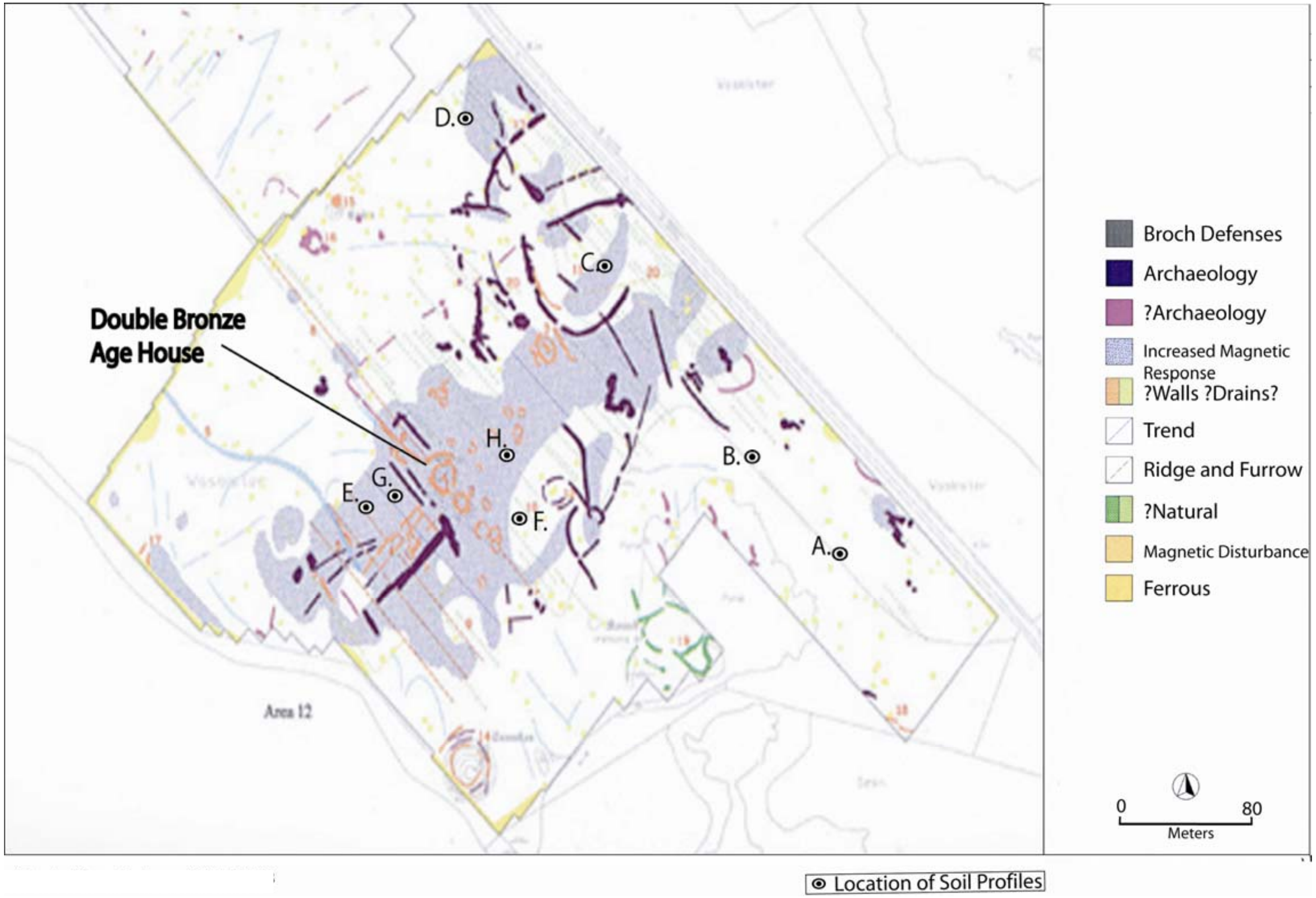


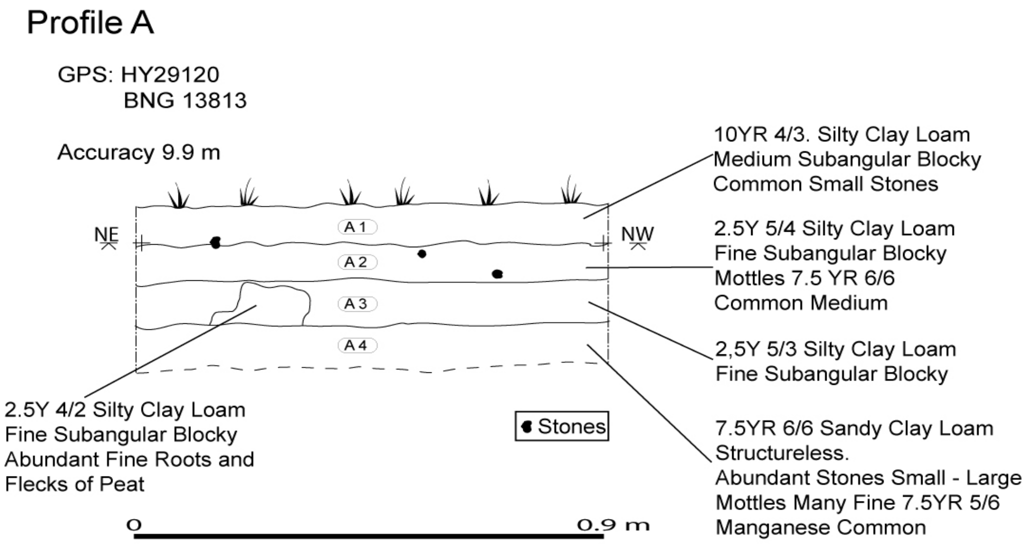
Figure 39 Wasbister magnetometry interpretation and profile locations (Gater and Sheil 2002)

6.1 Field Observations

6.1.1 Profiles Without Anthropogenic Inclusions: Profiles A, B, D and G

Excavation of Profile A and Profile B (Figure 40, Figure 41) reveal simple profiles consisting of A,AC,C horizons and which lack a characteristic B horizon. Both of these profiles were excavated to a shallow depth with the C horizon being encountered at a depth of 0.24 m within Profile A and Profile B (Figure 40, Figure 41). Soil horizons within both profiles exhibit evidence of gleying processes and contain common-many, fine-medium mottles (7.5YR 5/6) along with common manganese inclusions and common flecks of peat. These soil characteristics may be interpreted as being the result of natural pedological processes associated with these hydromorphic soils, which are characterised by the chemical reduction of iron due to the waterlogging of the soil pores, which causes a lack of oxygen over a long period of time (Duchaufour 1982). These hydromorphic conditions are evident within the profiles and these associated characteristic pedological processes are unsurprising given the low altitude of this part of the site and its proximity to the water table as evidenced by its close proximity to the pond and location between the lochs of Harray and Stenness. Soil horizons within both profiles were found to contain few-many, small-medium angular stones. These profiles are interpreted as being the result of natural pedological processes involving soil formation upon the glacial drift C horizon.

No anthropogenic inclusions were observed within these profiles which suggests that the soil within these profiles has not been deliberately amended with the addition of anthropogenic inclusions such as bone and charcoal, although it is entirely feasible that these soils have been utilised within history and even prehistory without being amended, as evidenced from recent pastoral land management (Mr Bain *pers comm.*). The lack of field evidence associated with amendment and/or utilisation of the soils within these profiles resulted in no samples being taken for further analysis from these profiles.



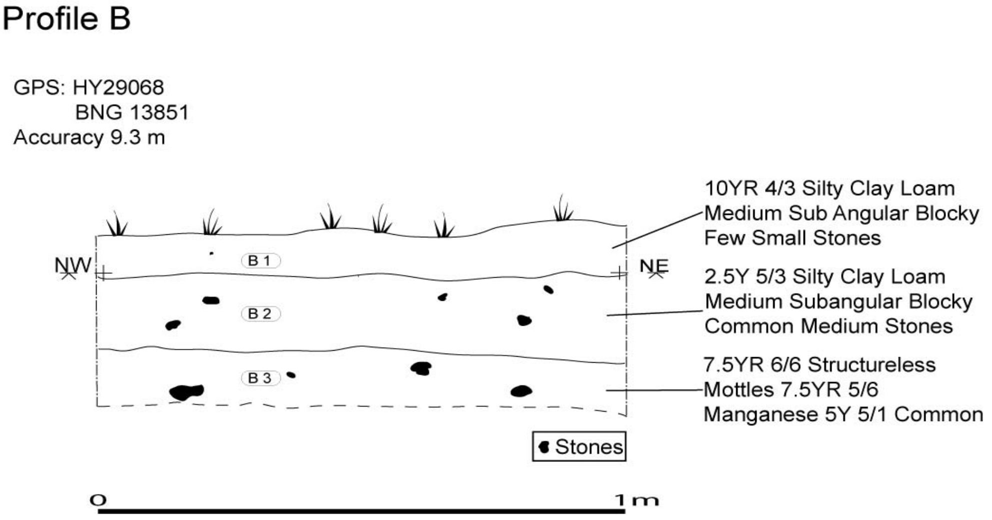


Figure 40 Wasbister Profile A and Profile B

Figure 41 Wasbister Profile A

Profile D (Figure 42) was also deliberately located upon the area of magnetometry survey which indicated an increased magnetic response (Figure 39). The soil profile however showed no evidence of anthropogenic amendment. Profile D was very similar to profiles A and B and consisted of an A horizon, an AC horizon and a glacial drift C horizon. As within profiles A and B the glacial drift C horizon was encountered at a relatively shallow depth of 0.25 m and bulk samples were not obtained from this profile for further analyses.

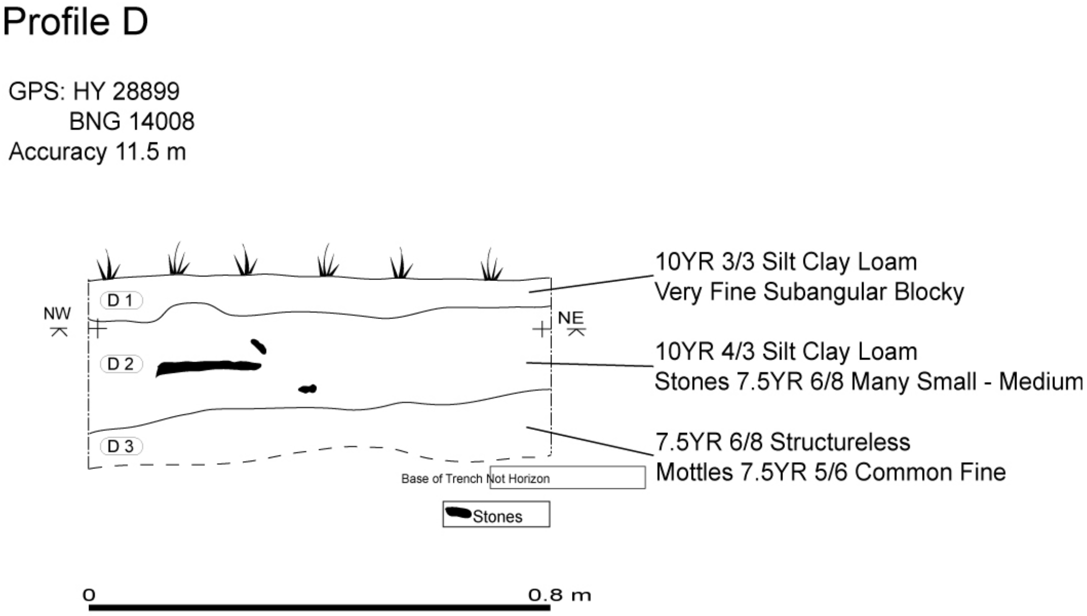


Figure 42 Wasbister profile D

Profile G was deliberately located in close proximity to the double Bronze Age house, just outwith the Scheduled Area, upon the increased magnetic response identified though magnetometry survey (Figure 39). Profile G was excavated subsequent to Profile E and it was expected that the profile exposed would be similar to that excavated within Profile E. Profile G was however very different to that excavated within Profile E. Profile G is akin to profiles excavated in profiles A,B and D. The profile is a simple A, AC, C profile with the glacial C horizon being excavated at a very shallow depth of 0.2 m (Figure 43).

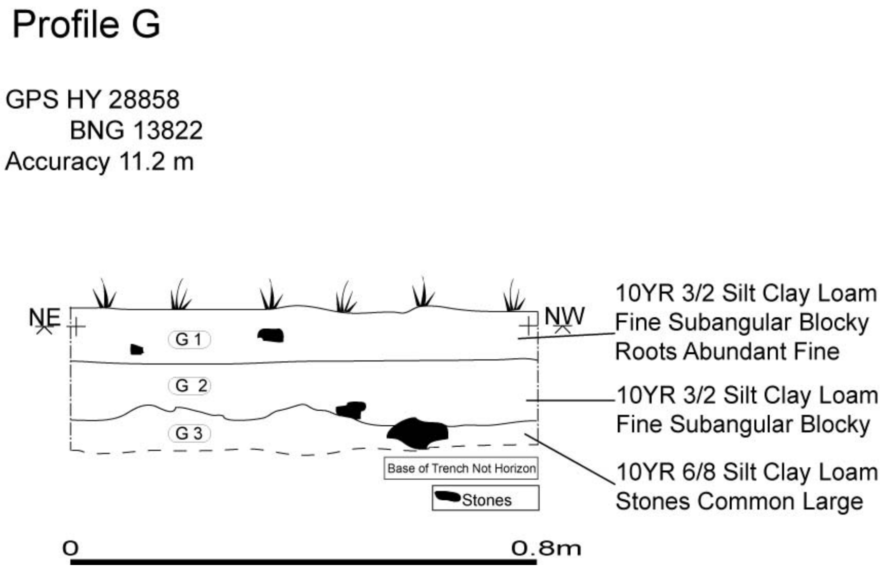


Figure 43 Wasbister profile G

6.1.2 Profiles Containing Anthropogenic Inclusions;

6.1.2.1 Profiles C (Figure 44)

Profile C was deliberately located upon an area of magnetometry survey which indicated an increased magnetic response (Figure 39). Excavation of Profile C identified a soil profile which was significantly deeper than Profiles A and B, with the glacial drift C horizon excavated at a depth of 0.4 m (Figure 44). Soil horizons within this profile had a silt clay loam texture and common very small-small angular stones were present within each soil horizon. Between the surface A horizon and the glacial C horizon a horizon was identified as containing common, fine charcoal inclusions. This soil horizon was dark greyish brown in colour (10YR 4/2) and had evidence of deliberate amendment of the soil profile through the addition of charcoal material. This profile was sampled with bulk soil samples for further analysis.

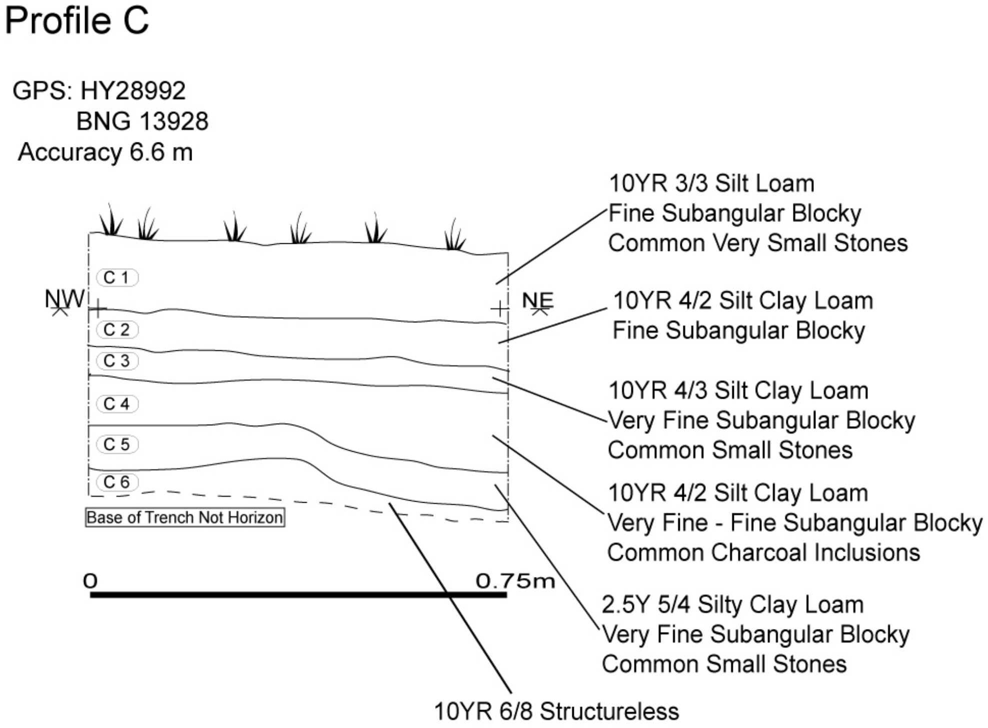


Figure 44 Wasbister Profile C

6.1.2.2 Profile E (Figure 45)

Profile E was located to the southwest of the probable double Bronze Age house again upon the increased magnetic response identified by magnetometry survey (Figure 39). Profile E appears to be very similar to Profile C with an A horizon overlying a horizon containing anthropogenic inclusions of charcoal which overlies the glacial drift C horizon excavated at a depth of 0.45 m (Figure 45). As within Profile C the horizon containing anthropogenic inclusions was brown in colour (10YR 4/3) and contained common, fine inclusions of charcoal. A few small stones were also identified within this horizon. This profile was sampled with bulk samples and Kubiena tins for further analyses.

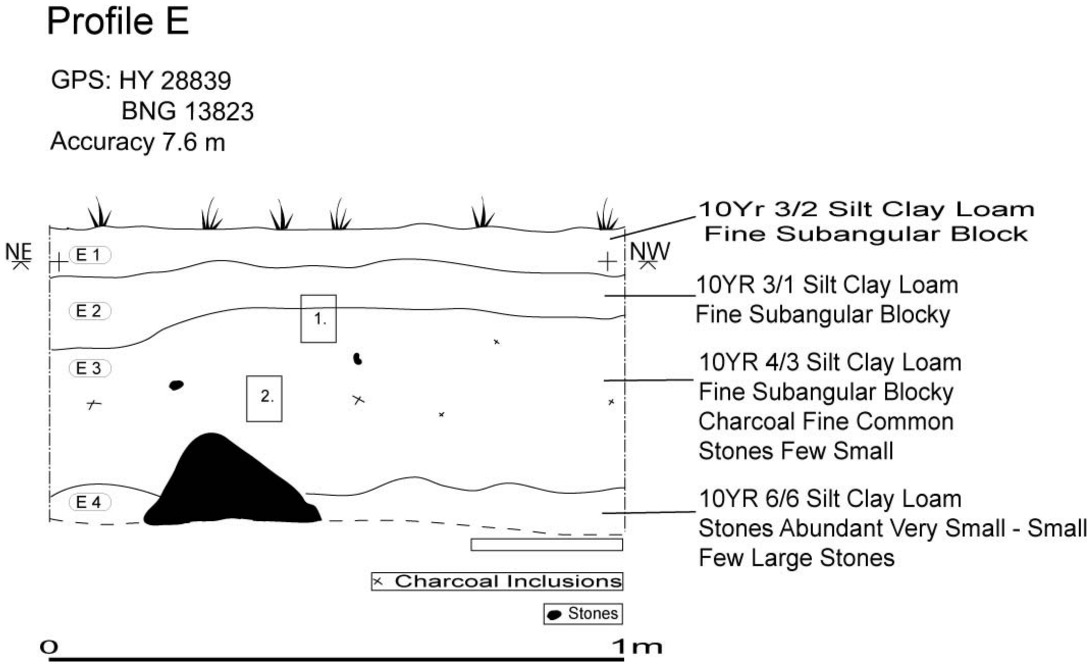


Figure 45 Wasbister Profile E

6.1.2.3 *Profile F (Figure 46)*

Profile F was located to the west of the probable double Bronze Age house and the profile within this trench was identified as similar to those in profile C and Profile E. Profile F consists of an A horizon which overlies a horizon containing inclusions of charcoal which overlies the C horizon excavated at a depth of 0.31 m (Figure 46). As with the other anthropogenic horizons identified upon this site, the horizon containing anthropogenic inclusions within this trench is dark greyish brown in colour (10YR 4/2) and contains occasional, very fine charcoal inclusions along with common small stones. This profile was also sampled with bulk samples and Kubiena tins for further analyses.

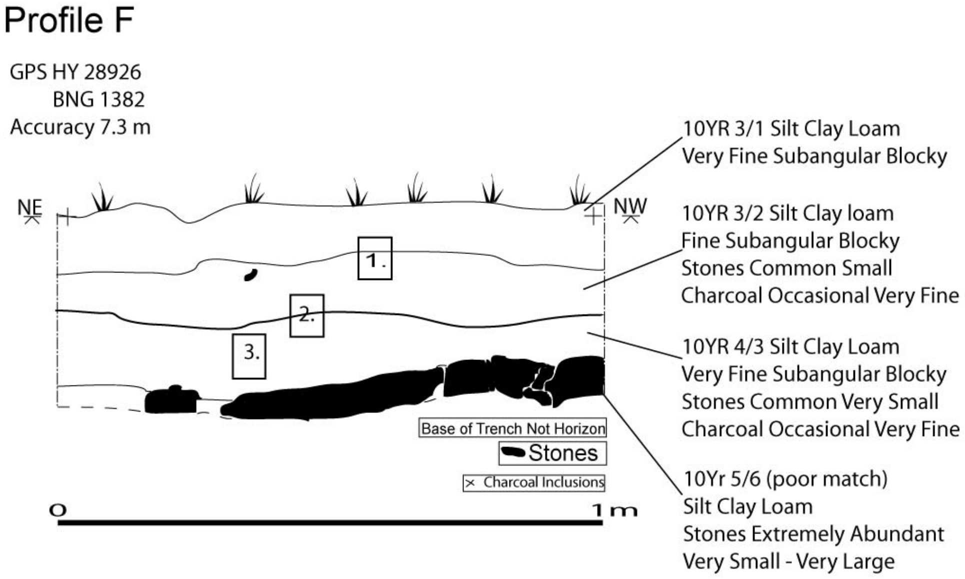


Figure 46 Wasbister profile F

6.1.2.4 Profile H (Figure 47 and 48)

Profile H was located to the east of the probable double Bronze Age house and was also located upon the increased magnetic response identified though magnetometry survey (Figure 39). Beneath the A horizon, a horizon was encountered which was similar to those within Profiles C, E, and F as being dark brown (10YR 3/3) and containing common, fine-very fine charcoal inclusions (Figure 47). An interesting observation towards the base of this horizon was the identification of a linear ferrous feature running through the base of the trench along an orientation of northeast to northwest (Figure 48). This ferrous feature was present across the entire trench and prevented complete excavation down to the glacial drift C horizon which was identified as being directly beneath it. Common, very small-medium stones were observed within the A horizon. The horizon containing charcoal inclusions also contained many, very fine stones. The stones within this horizon were identified as being a pale yellow sandstone and these differed in colour to the stones observed within the overlying A horizon.

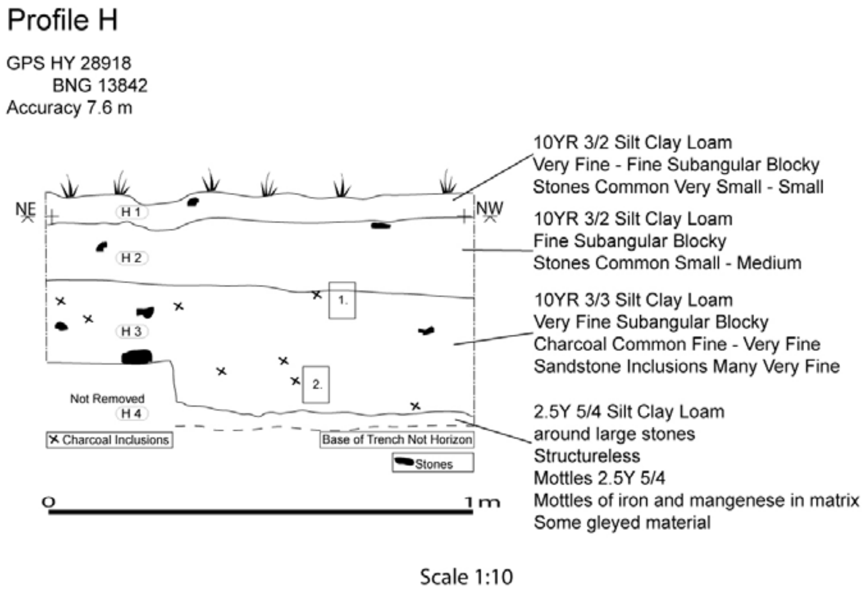


Figure 47 Wasbister profile H

Figure 48 Wasbister ferrous feature profile H

6.1.3 Summation of Field Results

Field observations have identified soil horizons which contain anthropogenic inclusions and have clearly been augmented through anthropogenic activities. These horizons were identified by the presence of occasional-common, very fine-fine charcoal inclusions within horizons which appear to have been deepened as a result of anthropogenic sedimentation processes. The location of these anthropogenic soil horizons within this landscape is complex and does not necessarily correlate with the increased magnetic response as identified through magnetometry survey. The lack of stratigraphic relationships between these amended soils and structural archaeology and their dissociated geographical distribution (in part a product of the sampling strategy), allows slight ambiguity into the interpretation of the anthropogenic horizons and associated SSBCR. It is entirely feasible that the anthropogenic soils identified within each profile actually represents different SSBCR associated with this palimpsest landscape and its use throughout history and prehistory. However there is sufficient field based evidence including the similarity of the key characteristics of colour and the depth of stratigraphy and the presence of only charcoal anthropogenic inclusions within the anthropogenic soil horizon associated in Profiles C, E, F and H to suggest that these anthropogenic soil horizons have resulted from the same formation processes. As such these anthropogenic soil horizons and associated bulk and thin section samples will be discussed as representing one anthropogenic horizon and associated SSBCR. An absence of charcoal samples of sufficient size for AMS and the complicated nature of the stratigraphy have prevented the determination of a radiocarbon chronology for the anthropogenic horizon development at Wasbister.

6.2 *Analytical Results*

Laboratory analyses were undertaken on samples from Profile C, Profile E, Profile F and Profile H. Table 21 provides a summary of the samples obtained:

Table 21 Wasbister horizons sampled

	Horizon Bulk Sampled	**Horizon Kubiena Tin Sample**
A Horizon	Profile C, Profile E, Profile F, Profile H (all horizon 1)	Profile F (sample F1)
Anthropogenic Horizon	Profile C- horizons 3,4 and 5 Profile E-horizons 2 and 3 Profile F-horizons 2 and 3 Profile H- horizons 2 and 3	Profile E (samples E1 and E2) Profile F (samples F1, F2, F3) Profile H (sample H1 and H2)
C Horizon	Profile C (horizon 6), Profile E, F and H (all horizon 4)	

6.2.1 pH

pH results from the soil horizons within profiles Wasbister containing anthropogenic inclusions are acidic ranging from 4.2 to 5.4 (Table 22). There is no clear obvious pattern of changing pH at depth within the profile although there is an indication that pH may increase slightly in subsurface horizons. Full results available Appendix B, Soil Organic Matter and pH Results.

Table 22 Wasbister summary pH results

	Minimum	**Maximum**	**Mean**
A Horizon	4.4	5.0	4.7
Anthropogenic Horizon	4.4	5.3	5.0
C Horizon	4.2	5.3	4.9

6.2.2 Soil Organic Matter Content

Loss on ignition (LOI) results indicate that the soil organic matter content ranges from 9-17% associated with surface A horizons down to 3-4% associated with glacial drift C horizons (Table 23), which are comparable to the glacial moraine at Finstown Control. Soil organic matter results indicate that within each profile the organic matter content decreases down profile from surface horizons. Full results available in Appendix B, Soil Organic Matter and pH Results.

Table 23 Wasbister summary LOI results from profiles containing anthropogenic inclusions

	Minimum	**Maximum**	**Mean**
A Horizon	8%	17%	12%
Anthropogenic Horizon	4%	6%	5%
C Horizon	3%	4%	4%

6.2.3 Particle Size (PSD)

The mean A horizon particle size distribution is dominated by a coarse silt component with a large fine and medium silt component, a relatively large clay component and a very minor sand component (Figure 49) . The mean anthropogenic horizon PSD is comparable to the PSD of the mean A horizon, also containing a large silt component. The mean C horizon PSD is also dominated by a coarse silt component but is found to contain less coarse silt material and a greater percentage of sand than the overlying horizons (Figure 49). See Appendix C, Particle Size Distribution Results for full results.

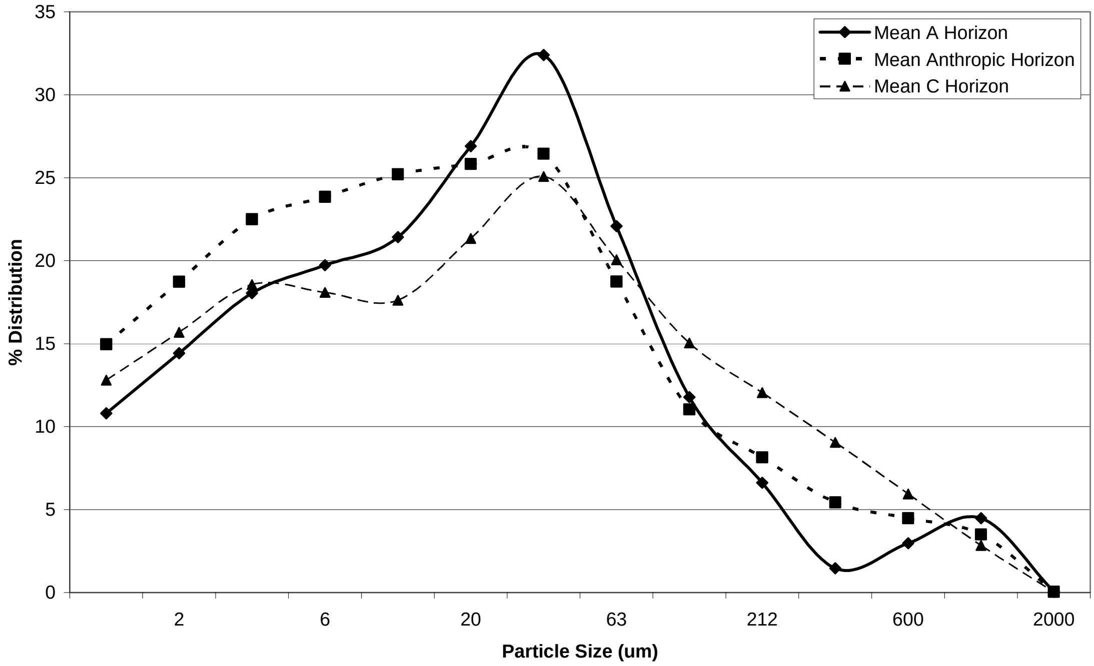


Figure 49 Wasbister PSD

6.2.4 Total Phosphorus

Total phosphorus concentrations associated with the anthropogenic horizons within profiles C, E, F and H range from 90 to 180 mgP/100g oven dried soil. A general pattern exists within each profile which demonstrates that surface A horizons contain the greatest concentration of total phosphorus and that total phosphorus concentrations generally decrease down profiles until the glacial drift C horizon. This can clearly be seen for example in profile F (Figure 50).

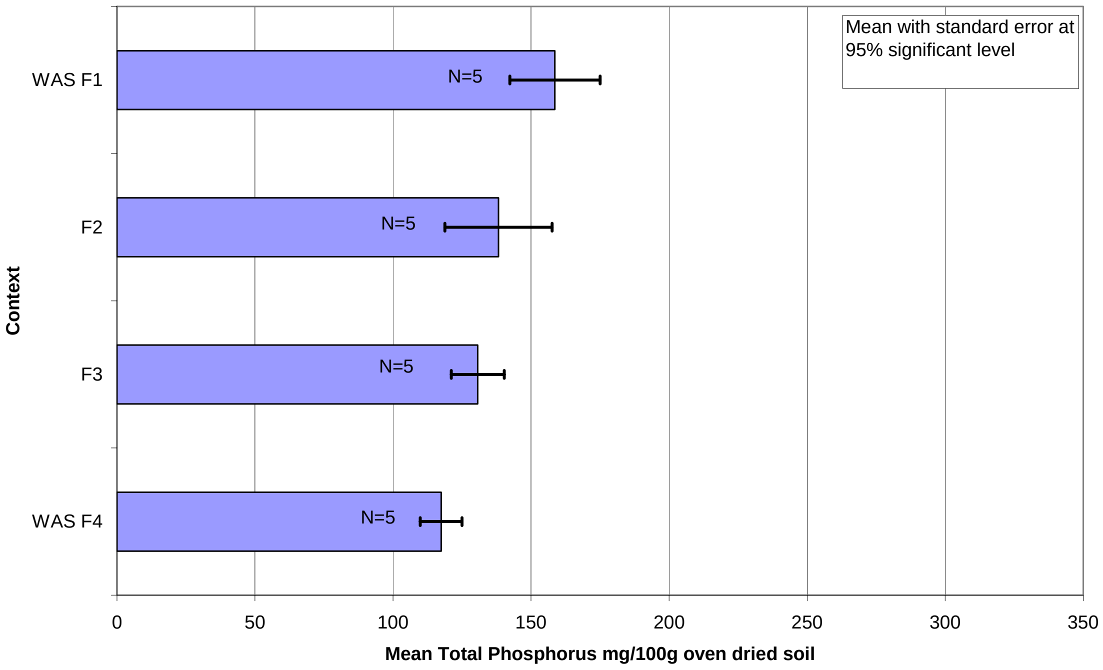


Figure 50 Wasbister Profile F Total Phosphorus

Concentrations of total phosphorus in surface A horizons ranges from 190 mg/100g oven dried soil (Profile H) to 116 mg/100g oven dried soil (Profile C) with the concentration of total phosphorus in the glacial drift C horizon of each profile ranging from 134 mg/100g oven dried soil (Profile H) to 97 mg/100g oven dried soil (Profile E). It is apparent within each profile that subsurface horizons identified as containing inclusions of charcoal do not contain a greater concentration of total phosphorus than associated overlying A horizons. Full results available Appendix D The average total phosphorus concentration was calculated for the soil horizons containing charcoal inclusions, mean 137 mgP/100g oven dried soil and median 130 mg/100g oven dried soil. These will be used to compare these results with control sites and with results from other field sites.

6.2.5 Mass Susceptibility (χ)

Mass susceptibility results from each profile clearly identify that subsurface horizons identified as containing charcoal inclusions have an enhanced mass susceptibility relative to both surface A and subsurface C horizons (Table 24). The mass susceptibility of horizons containing charcoal inclusions ranges from $1.39\text{x}10^{-6}$ m^3kg^{-1} (Profile E) to $10.51\text{x}10^{-6}$ m^3kg^{-1} (Profile F) with the mean mass susceptibility for these horizons being $6.4\text{x}10^{-6}$ m^3kg^{-1}. Full results available Appendix E Mass Susceptibility Results.

Table 24 Wasbister Summary Mass Susceptibility Results (χ x10^{-6} m^3kg^{-1})

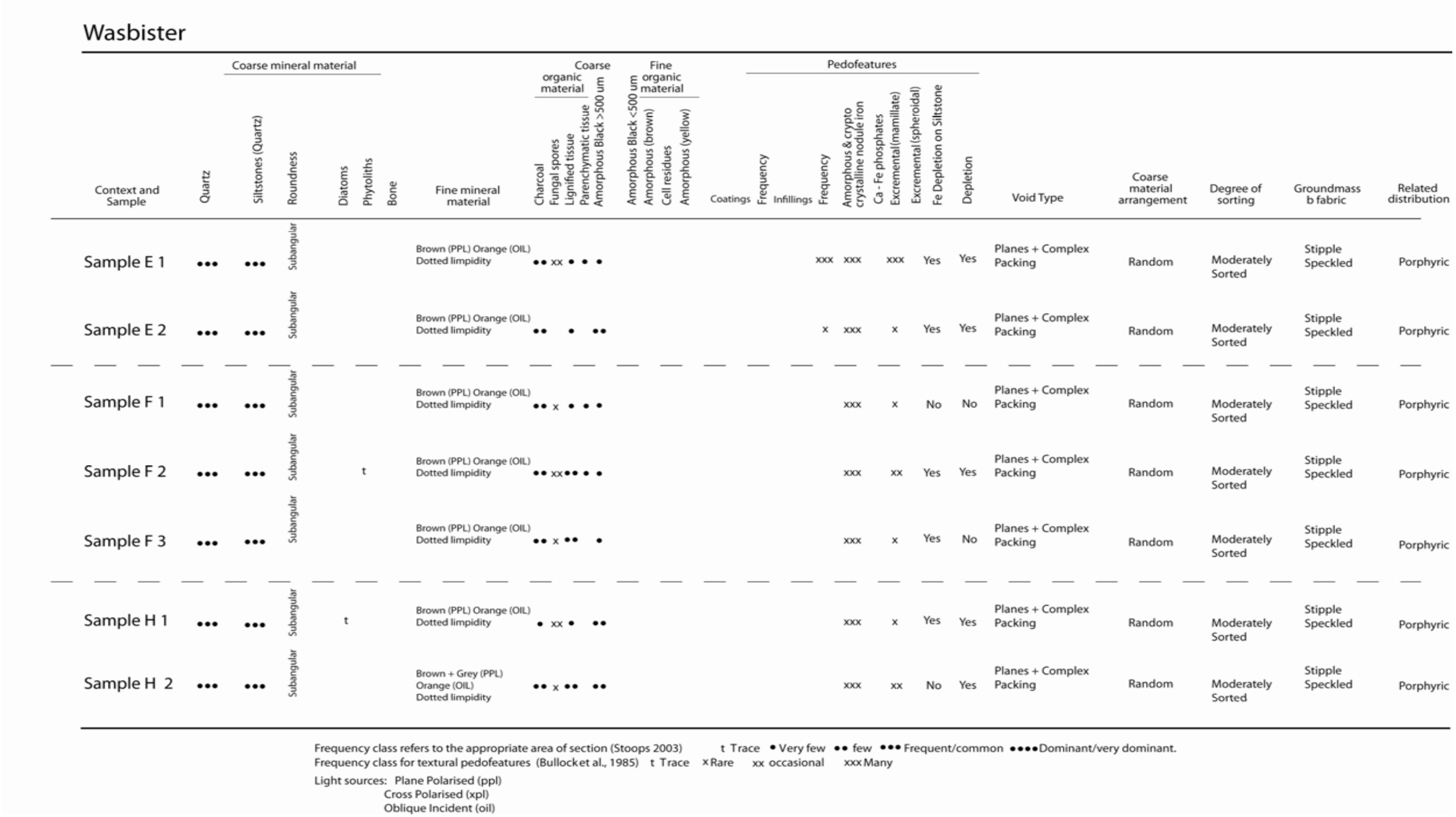
	Minimum	**Maximum**	**Mean (SD to 95%)**
Ap	1.8	7.9	4.8
Anthropogenic Deposit	1.4	10.5	6.4
Glacial Drift	0.4	1.6	0.8

6.2.6 Thin Section Micromorphology

Thin section samples were obtained from Profiles E, F and H where the subsurface horizons were identified as containing inclusions of charcoal. The coarse mineral component of each thin section sample is dominated by quartz which occurs with an abundance of common-frequent (15-30%). Siltstones are also present within all samples with an abundance of common-frequent and exhibit iron depleted stone rims in all samples except from Profile H. The coarse mineral component of the thin section samples from these horizons is blocky in shape and has a subangular degree of roundness with samples being overall moderately sorted. Many typic iron nodules were present within each thin section sample (Figure 51).

Charcoal inclusions occur within each thin section with an abundance of few (5-15%), except within sample H1 where an abundance of very few (<5%) was observed (Figure 51). Amorphous black material was also present within all slides with an abundance of very few-few (<5%-15%). A minor component of this black amorphous material contains mineral inclusions (identified under cross polars) and is interpreted as turf material (Figure 51). The majority of this black amorphous material appears to be more solid and maybe more likely to be more charcoal material. Fungal spores are present within each sample with a frequency of rare-occasional and biological activity is also indicated within each sample by the occurrence of mammilliate excrement with a frequency of rare-occasional. The absence of bone was apparent within all thin sections and supports field observations. Diatoms and phytoliths were also noticeably absent from these samples with the exception of a trace of diatoms within sample H1 and a trace of phytoliths within sample F2.

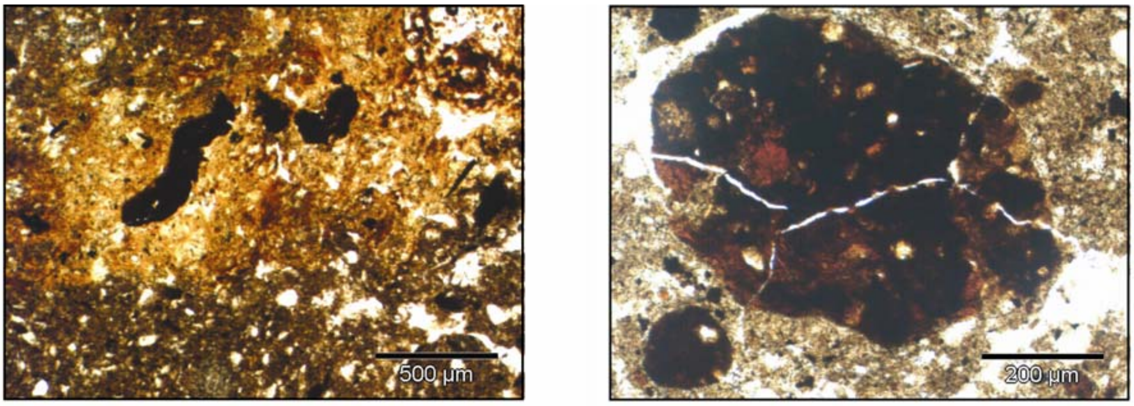
Table 25 Wasbister thin section micromorphology results



Wasbister

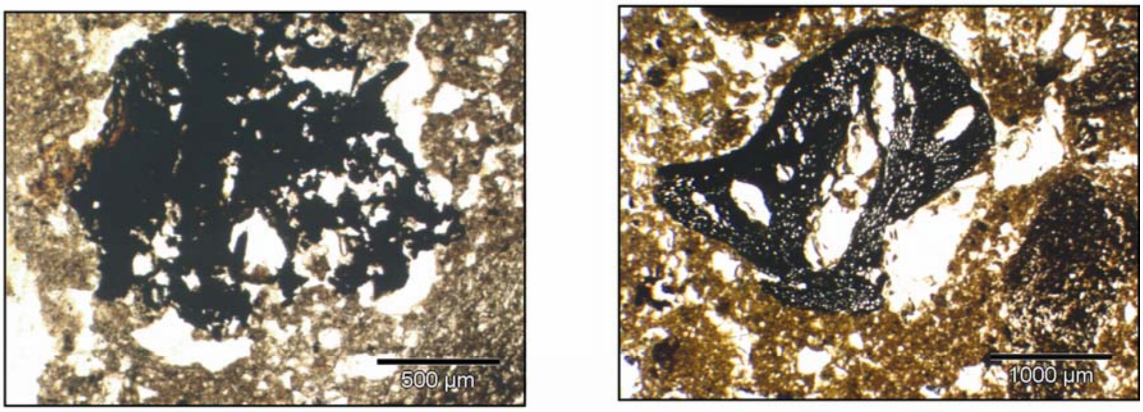
		Coarse mineral material						Coarse organic material					Fine organic material					Pedofeatures													
Context and Sample	Quartz	Siltstones (Quartz)	Roundness	Diatoms	Phytoliths	Bone	Fine mineral material	Charcoal	Fungal spores	Lignified tissue	Parenchymatic tissue	Amorphous Black >500 um	Amorphous Black <500 um	Amorphous (brown)	Cell residues	Amorphous (yellow)	Coatings	Frequency	Infillings	Frequency	Amorphous & crypto crystalline nodule iron	Ca - Fe phosphates	Excremental(mamillate)	Excremental (spheroidal)	Fe Depletion on Siltstone	Depletion	Void Type	Coarse material arrangement	Degree of sorting	Groundmass b fabric	Related distribution
Sample E 1	●●●	●●●	Subangular				Brown (PPL) Orange (OIL) Dotted limpidity	●●	xx	●	●	●								xxx	xxx		xxx		Yes	Yes	Planes + Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample E 2	●●●	●●●	Subangular				Brown (PPL) Orange (OIL) Dotted limpidity	●●		●		●●								x	xxx		x		Yes	Yes	Planes + Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample F 1	●●●	●●●	Subangular				Brown (PPL) Orange (OIL) Dotted limpidity	●●	x	●	●	●									xxx		x		No	No	Planes + Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample F 2	●●●	●●●	Subangular		t		Brown (PPL) Orange (OIL) Dotted limpidity	●●	xx	●●	●	●									xxx		xx		Yes	Yes	Planes + Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample F 3	●●●	●●●	Subangular				Brown (PPL) Orange (OIL) Dotted limpidity	●●	x	●●		●									xxx		x		Yes	No	Planes + Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample H 1	●●●	●●●	Subangular	t			Brown (PPL) Orange (OIL) Dotted limpidity	●	xx	●		●●									xxx		x		Yes	Yes	Planes + Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample H 2	●●●	●●●	Subangular				Brown + Grey (PPL) Orange (OIL) Dotted limpidity	●●	x	●●		●●									xxx		xx		No	Yes	Planes + Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric

Frequency class refers to the appropriate area of section (Stoops 2003) t Trace ● Very few ●● few ●●● Frequent/common ●●●● Dominant/very dominant.
Frequency class for textural pedofeatures (Bullocket al., 1985) t Trace × Rare xx occasional xxx Many
Light sources: Plane Polarised (ppl)
Cross Polarised (xpl)
Oblique Incident (oil)



Profile E Slide 2
Iron accumulation within the fine matrix.

Profile F Slide 1
Typic iron nodule indicative of iron translocation.



Profile H Slide 2
Black amorphous organic material, possibly turf showing evidence of iron enrichment.

Profile E Slide 2
Charcoal idenitifed with internal cellular structure.

Figure 51 Wasbister key micromorphological characteristics (PPL)

6.3 Discussion

6.3.1 Period of Formation

The identification of the chronology of the anthropogenic activities responsible for the formation of this anthropogenic horizon has proved to be problematic and it remains difficult to attribute its formation to a specific period and people group within history or prehistory. Stratigraphic relationships between the anthropogenic horizon and any structural archaeology have been unable to be identified due to the archaeological sensitivity of this landscape including the Scheduled Monuments and associated area and any stratigraphic relationship must therefore be inferred from the complex stratigraphy. There are inherent weaknesses in any such inference, perhaps best highlighted by field observations of Profile E and Profile G. It may be that the anthropogenic horizon identified within Profile E is the result of cultural activity associated with the probable double Bronze Age house. However, the lack of anthropogenic horizons, representing this SSBCR within Profile G prevents any stratigraphic relationship from being established between the anthropogenic horizon within Profile E and the probable double Bronze Age house. Equally, the lack of any anthropogenic horizon within Profile G does not totally preclude the possibility that the anthropogenic horizon identified within Profile E has resulted from Bronze Age cultural activity associated with the probable double Bronze Age house.

The determination of the chronology of the formation of the anthropogenic horizon at this site is further complicated by the field observation of a ferrous feature identified stratigraphically beneath the anthropogenic horizon and above the glacial drift C horizon within profile H (Figure 48). This ferrous feature is clearly not associated with Bronze Age cultural activity and preliminary suggestions of its origin include a possible field drain or the burial of a purposefully discarded ferrous object. The identification of this ferrous feature underlying the anthropogenic horizon implies either that the anthropogenic horizon is relatively modern and has been deposited *in situ* upon the ferrous feature or that the anthropogenic horizon formed before the deposition of this ferrous feature and has been disturbed in order to place the ferrous feature directly upon the glacial drift C horizon with the anthropogenic horizon being back filled on top of the ferrous feature.

Evidence suggests that it is more likely that the anthropogenic horizon was formed before the deposition of the ferrous feature and was then subjected to significant post-depositional disturbance. The location of the ferrous feature immediately overlying the glacial drift C horizon and the identification of sandstone inclusions interpreted as originating from the C horizon within the overlying anthropogenic horizon suggest that such an explanation is more probable. Such an explanation does not however necessitate that the formation of this anthropogenic horizon is contemporaneous with the Bronze Age cultural activity evident upon the site. This ferrous object could feasibly have been deposited within relatively recent history (post *c*1850 agricultural intensification), without any reference being made to it within farm records. In such case the anthropogenic horizon may potentially be the result of relatively recent agricultural practices. The complexities involved in determining the period of formation of this anthropogenic horizon have been further investigated using a framework of multiple working hypotheses:

6.3.1.1 Hypothesis 1 –Post Agricultural Intensification (c1850 AD)

A post agricultural intensification, post-depositional arable functional interpretation of this anthropogenic horizon is problematic when examined within the context of the available literature. Thomas in 1849 records the land at Wasbister as being swampy and does not identify any arable agricultural land use associated within this area. This is in direct contrast to the arable rigs recorded by Thomas (1849) upon the same map upon the Ness of Brodgar and around the Stones of Stenness. Furthermore, the current land owner's private farm records along with local historical knowledge suggest that within living memory that this land was not used for arable production until the 1970s (Mr Bain *pers comm.*). These records identify that the north-eastern half of this field was cultivated for barley cultivation between the 1970s and 1980s along with the occasional barley cultivation post 1999 (Mr Bain *pers comm.*). This recent, post industrialised cultivation is unlikely to have resulted in the formation of this anthropogenic horizon, although it is likely to have been sufficient to produce the ridge and furrow anomalies identified within magnetometry survey (Gater and Shiel 2003) and may have increased biological activity identified by the presence of occasional mammilliate excrement features within thin section.

6.3.1.2 Hypothesis 2 – A Bronze Age SSBCR

It also remains difficult to securely attribute this anthropogenic horizon to Bronze Age cultural activities associated with this site although recent research may lend weight to such an interpretation. Further magnetometry survey has been conducted upon the north side of the road on the Ness of Brodgar as part of the ongoing WHS geophysical survey conducted by Orkney College Geophysics Unit. This research identifies archaeological structural features which are interpreted as the continuation of settlement part of which is represented by the probable double

Bronze Age house within this field site. The identification of such a large settlement site within this landscape containing evidence of complex habitation, burial, monuments and possible enclosures (Robertson 2005) must have significantly influenced the landscape. It is anticipated that such settlement would produce a large, complex associated SSBCR as may be demonstrated by the geographical dissociated anthropogenic horizons identified at this site. Furthermore, the depth and the width of the walls of the probable double Bronze Age house and the field observation of ash material incorporated into its construction imply significant labour inputs and are interpreted as evidence for long term habitation at this site (the probable double Bronze Age house is a Scheduled Monument and excavations were not undertaken. Cattle trampling had produced scars upon the monument through which it was possible to identify peat/turf ash incorporated into its construction). It may be expected that any significant long term habitation would necessarily include activities such as arable food production and pastoral land management which would be expected to produce a SSBCR.

Despite its location within an apparent significant Bronze Age settlement, the characteristics of the anthropogenic horizons at Wasbister differ significantly from known amended arable, Bronze Age soils. Bronze Age amended soils at both Tofts Ness and within Skaill Control contain a large quantity of domestic waste including peat/turf ash and bone (Guttmann *et al* 2006). The anthropogenic horizon at Wasbister contains no peat/turf ash yet the identification of peat/turf ash incorporated into the construction of the probable double Bronze Age house identifies that this fuel resource was utilised within Bronze Age cultural activity both as a fuel resource and also with regards to a post-depositional construction function. It may be expected that as at other Bronze Age sites that this peat/turf fuel ash resource would have also been utilised as a resource within arable food production and would therefore be present within the anthropogenic horizon. In contrast to known Bronze Age amended arable soils, bone inclusions were not identified within the anthropogenic horizon at Wasbister. It is possible that the diagnetic microbial and chemical processes associated with this site, and enhanced by the low pH would have been sufficient to weather any bone inclusions into solution, although this would be unlikely with cremated bone (Millard 2001). The absence of any bone material and any phosphatic features within the fine matrix of thin section samples suggest it is more likely that bone inclusions were not incorporated into the formation of this anthropogenic horizon.

6.3.1.3 Conclusion

Assigning the formation of this anthropogenic horizon to a specific period and people group within history or prehistory is therefore problematic. The inference from the archaeological landscape is that the anthropogenic horizon is more likely to result from Bronze Age cultural activity associated with the dense concentration of Bronze Age (and probable Bronze Age) archaeological structures identified within this landscape, but the stratigraphic relationships required to confirm this have not been identified. In contrast the characteristics of the anthropogenic horizon differ significantly from those of other known Bronze Age arable soils and most closely resemble the later plaggen horizon within Skaill Control and the post agricultural intensification soils identified at Barnhouse. Neither of these interpretations totally precludes the possibility of the other interpretation from being correct. All that can be robustly concluded is that the characteristics of this anthropogenic horizon suggests formation more recently than the Bronze Age but that it is unlikely to have formed post *c* 1850 AD. The landscape at Wasbister contains evidence for multiperiod usage including medieval field boundaries and a potential noust (Robertson 2005). It must be considered feasible that the anthropogenic horizon at Wasbister has resulted from differing or combined cultural practices undertaken within history and/or prehistory and determining the chronology of the formation of this anthropogenic horizon provides a clear opportunity for future research.

6.3.2 Materials and Processes of Formation

Pedogenesis at the Wasbister site has been greatly influenced by local environmental conditions including its low altitude and close proximity to the water table. The poorly-very poorly drained nature of the site has resulted in the dominant processes of gleying, producing peaty gleys and peat alluvium within the low lying land in close proximity to the pond (Figure 39) with shallow imperfectly drained podsols upon the better drained land upslope from the lowest lying ground (Macaulay Institute for Soil Research 1981). These pedogenic processes associated with hydromorphic conditions were observed by field observations as being dominant within profiles in the low lying southeast of the site where mottles, manganese and local concretions of ferric iron along with ferrous iron accumulations within the glacial drift C horizon were identified within profiles along with occasional flecks of peat (Duchaufour 1982). Occasional mottles and manganese features occurred within the anthropogenic horizons located upslope within the poorly drained podsols along with the identification of many typic iron nodules, iron depletion features within the fine matrix and iron depletion features upon siltstones in associated thin section samples. This clearly identifies that the deposition of this anthropogenic horizon has occurred under the natural processes associated with podsolisation and gleying and that these processes remained a dominant influence upon the anthropogenic horizon once deposited.

All profiles at this site were excavated to the glacial drift C horizon which was identified at a shallow depth between 0.2 m and 0.24 m in profiles containing no anthropogenic horizons. The

C horizon was identified at a deeper depth of between 0.31 and 0.45 m in profiles containing anthropogenic horizons and this increased depth of stratigraphy in these profiles is explained by addition of anthropogenic inclusions which have therefore deepened the profile. Within these profiles (C, E, F and H) the glacial drift C horizon was identified as immediately underlying the anthropogenic horizons. This suggests that the anthropogenic horizon identified at this site has been formed *in situ*, from the addition of anthropogenic inclusions including charcoal being incorporated into and deepening the existing soil profile. This is in contrast to the anthropogenic sediment at the Ness of Brodgar where the entire anthropogenic sediment overlying the structural archaeology has been removed from elsewhere in the landscape and deposited as the result of anthropogenic sedimentation processes.

The discrepancy between the depth of soil profiles containing, and not containing the anthropogenic horizon suggests that the anthropogenic horizon has formed from anthropogenic activities which involved the deposition of materials thereby deepening existing soil profiles. However, total phosphorus concentrations, which can be used to identify the intensity of organic material application to amended soil; and can therefore provide a proxy for a degree of soil amendment (Simpson 1997), are relatively low (mean 131.1 mgP/100g oven dried soil). The acidic pH associated with these profiles suggests that the substantial translocation of phosphorus within the profile is unlikely. Total phosphorus concentration from the anthropogenic horizon at Wasbister is significantly greater than total phosphorus concentration from the pre-settlement Finstown Control and from the Late Bronze Age/Iron Age amended arable soil identified within Skaill Control (Table 26). It is however significantly lower than total phosphorus concentrations associated with the plaggen horizon within Skaill Control and the anthropogenic sediment upon the Ness of Brodgar (Mann Whitney conducted at the 95% significant level, Table 26).

Table 26 Statistical comparison of analytical results

	Finstown Control	**Skaill Control LBA/IA**	**Skaill Control Plaggen**	**NoB Neolithic Sediment**
Function	None	Arable	Arable	Probable Arable
Wasbister soil property				
Total Phosphorus	WAS significantly greater than FT Control (Mann Whitney P=0.000)	WAS significantly greater than Skaill Control LBA/IA (Mann Whitney P=0.0194)	WAS significantly less than Skaill Control Plaggen (Mann Whitney P=0.000)	WAS significantly less than NoB (Mann Whitney P=0.000)
Mass Susceptibility	WAS significantly greater than FT Control (Mann Whitney P=0.0005)	WAS significantly greater than Skaill Control LBA/IA (Mann Whitney P=0.0108)	WAS significantly greater than Skaill Control Plaggen (Mann Whitney P=0.0031)	No Statistical evidence to suggest difference between NoB and WAS (Mann Whitney P=0.6043)

This analysis suggests that only a very small percentage of the anthropogenic horizon was composed of anthropogenic inclusions rich in phosphorus such as bone, charcoal and fuel ash. The minor burnt turf component identified within thin section suggests that turf has been added to these soils. Such an explanation would explain the observed significant increase in the depth of these profiles with associated relatively low total phosphorus concentrations but evidence for the significant deposition of turf as within the plaggen horizon of Skaill Control is lacking and such an interpretation remains insecure. Total phosphorus concentrations from the A horizons are greater than those associated with the underlying anthropogenic horizon. This suggests that the degree of amendment associated with the anthropogenic horizon is lower than that associated with recent pastoral land management as identified within the A horizon (Mr Bain pers comm.).

This pastoral land management may also be responsible for the occasional *sclerotia* spores identified within the anthropogenic horizon. The relatively low intensity of amendment through anthropogenic inclusions is also identified within PSD results where no noticeable difference exists between the PSD distribution of A horizons and the underlying anthropogenic horizon (Figure 49).

Despite this low intensity of amendment this anthropogenic horizon was clearly identified by field observations through its charcoal inclusions which are also identified within thin section samples. Charcoal was identified with an abundance of few (5-15%) within every thin section sample except within sample H1, where its abundance was only very few (<5%). The anthropogenic horizon contained a similar abundance of charcoal to that observed within the plaggen horizon of Skaill Control but appears to contain a significantly greater abundance of charcoal to the other control and field sites (Table 27). Within thin section, charcoal was the only identifiable anthropogenic inclusion except for a very minor component of black amorphous material interpreted as turf, with other burnt inclusions being noticeably absent. Despite the lack of burnt material within thin section mass susceptibilities from the anthropogenic horizon at Wasbister remain high and are much greater than those associated with present A horizons. Mass susceptibilities from the anthropogenic horizon at Wasbister are significantly greater than those associated with Finstown Control, horizons within Skaill Control (Table 26). There is no statistical evidence at the 95% significant level to suggest that the mass susceptibility of the anthropogenic horizon at Wasbister differs significantly from the magnetic susceptibility of the anthropogenic sediment identified upon the Ness of Brodgar. It is therefore postulated that the anthropogenic horizon identified at Wasbister does contain some degree of burnt material, but that this burnt material may be unidentifiable within the associated thin section samples.

Table 27 Comparison of key micromorphological features

Key thin section features	**Finstown Control**	**Skaill Control LBA/IA**	**Skaill Control Plaggen**	**NoB Neolithic Sediment**	**Wasbister**
Charcoal	None	Rare	Occasional	Rare	Occasional
Bone	None	Many unburnt	Occasional unburnt	Many cremated	None
Peat/turf fuel ash	None	Many	None	Many	None
Turf	None	Occasional burnt	Many unburnt	Many burnt	Occasional burnt
Fungal spores	None	Occasional	Occasional	Rare	Occasional
Mammiliate excrement	None	None	Rare	Occasional-many	Occasional
Textural pedofeatures	None	Many	Many	None	None

6.3.3 Post-depositional Function

The comparison of analytical results and key micromorphological features (Table 27) from the anthropogenic horizon at Wasbister with those from control sites and other field sites suggests that the soil properties of this anthropogenic horizon are most similar to the properties of the enhanced arable soils within the plaggen horizon of Skaill Control. Differences do exist between the anthropogenic horizon at Wasbister and these known arable soils which may be explained as being the result of slight differences in formation processes and/or slightly different environmental conditions such as the hydromorphic conditions identified at Wasbister. It is feasible that the features identified within the anthropogenic horizon at this site are consistent with those expected from repeated scrub heathland burning and regeneration episodes; although such an interpretation itself suggests an arable land management strategy such as slash and burn which is not consistent with the knowledge of Orcadian arable land management. Despite the differences observed between the known arable soils within Skaill Control the anthropogenic horizon at Wasbister does represent an accumulation of material including anthropogenic inclusions resulting from anthropogenic activity which has resulted in the thickening of these soil profiles. This is consistent with the arable land management strategies employed within Skaill Control with differences in the thickness of accumulation potentially easily explained by differing intensities of agricultural activities. It is therefore concluded that there is sufficient evidence to suggest that the SSBCR at Wasbister is the result of arable land management.

6.4 Conclusion

In relation to the original research questions, field observations have identified geographically dissociated anthropogenic horizons within the landscape at Wasbister. Despite the geographical discrete distribution of theses anthropogenic horizons, analyses suggest that it has resulted from the same formation processes. These horizons and the anthropogenic activites responsible for their formation and post-depositional function are therefore interpreted as representing a single SSBCR. Establishing an accurate period of formation of this SSBCR remains difficult and all that can be robustly concluded is that its formation occurred more recently than the Bronze Age but is unlikely to have occurred post-agricultural intensification (*c*1850 AD). The specific process of formation has involved the *in situ* amendment of an existing soil profile through the addition of charcoal and unburnt turf and there is sufficient evidence to suggest that subsequent to deposition that this SSBCR was utilised within arable agriculture.

Chapter 7 - Barnhouse and the Loch of Harray

The sites for excavation of soil profiles were decided on the basis of the magnetometry geophysical survey results (Gater and Shiel 2002) to investigate the possible presence of a SSBCR associated with Barnhouse Neolithic Settlement. Profiles were excavated in the field to the east of the Barnhouse Neolithic settlement due to Scheduled Monument status prescribed to the field south of the settlement. Initial soil profiles (BH A-C) were excavated around a group of geophysical anomalies which are typical of anomalies often associated with settlement and have tentatively been identified as being a continuation of the Barnhouse Neolithic Settlement (Gater and Shiel 2002, Figure 52). The absence of clear field evidence of a SSBCR containing anthropogenic inclusions led to subsequent profiles (BH D-F) being deliberately located upon geophysical anomalies identified as representing ridges and furrows associated with ploughing (Figure 52). Anthropogenic horizons were identified within these profiles which were further investigated through the excavation of two profiles located on ridge and furrow geophysical anomalies to the east of the Loch of Harray (LoH) (Orkney College Geophysics Unit 2005, Figure 59).

Figure 52 Barnhouse magnetmetry survey interpretations and profile locations (Adapted from Gater and Shiel 2002)

7.1 Field Observations

7.1.1 Barnhouse Profiles A and B (Figures 53 and 54)

Profile A was located in close proximity to the magnetic anomalies interpreted as possibly representing a continuation of Barnhouse Neolithic Settlement (Gater and Shiel 2002, Figure 52). Excavation of Profile A revealed a simple profile consisting of A, AC and C horizons and lacking a characteristic B horizon. The profile was excavated to a shallow depth with the underlying glacial drift C horizon identified and excavated at a depth of 0.25 m (Figure 53 and 54). Common-abundant, very small-medium angular stones were present within the A and AC horizon. Profile B was also located 80 m to the southeast of these magnetic anomalies interpreted as possibly representing a continuation of Barnhouse Neolithic Settlement (Gater and Shiel 2002, Figure 52). The excavation of this profile revealed a profile which was similar to that within profile A, consisting of an A, an AC and a C horizon. As within Profile A, the C horizon was excavated at a shallow depth of 0.25 m (Figure 53).

Anthropogenic inclusions of bone or charcoal were absent in both profiles which, along with their shallow depth suggests that the profiles have not been deliberately amended through the addition of anthropogenic inclusions. Bulk samples were taken from each soil horizon for analyses but the absence of any anthropogenic inclusions resulted in no samples being taken for associated thin section micromorphology. It seems probable that these profiles do not contain a SSBCR associated with Barnhouse Neolithic Settlement, although the absence of any such SSBCR within these profiles may result from Neolithic and/or later cultural activities and is discussed (Section 7.3). The identification of a piece of string bound into the profile of profile A at depth of 0.15 m (Figure 53 and 54) is interpreted as being the result of recent agricultural practice.

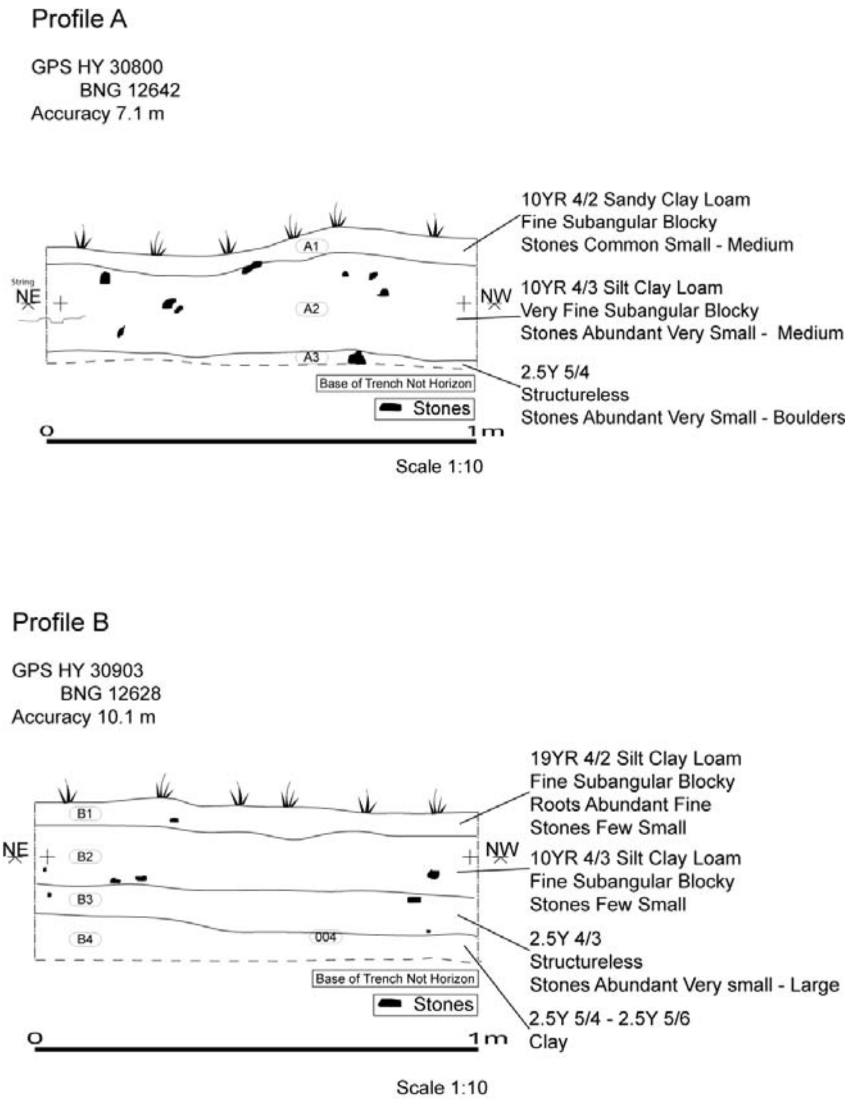


Figure 53 Barnhouse Profile A and Profile B

Figure 54 Barnhouse Profile A

7.1.2 Barnhouse Profile C (Figure 55)

Profile C was located *c*16 m to the east/northeast of the magnetic anomalies interpreted as possibly representing a continuation of Barnhouse Neolithic Settlement. This profile was more complicated than those within profiles A and B, consisting of an A horizon overlying a horizon which contained few, fine black inclusions (Figure 55). It was difficult to positively identify these inclusions as charcoal within the field therefore thin section samples were taken along with associated bulk samples from this profile to identify the nature of these inclusions. Beneath this potential anthropogenic horizon, a horizon was identified which was reddish grey (5YR 5/2) in colour with a silt clay loam texture. Field observations also identified abundant mottles (7.5YR 5/8) and abundant black manganese inclusion within this horizon. Beneath this horizon the glacial C horizon was excavated at a depth of 0.41 m, a slightly deeper depth than within Profile A and Profile B.

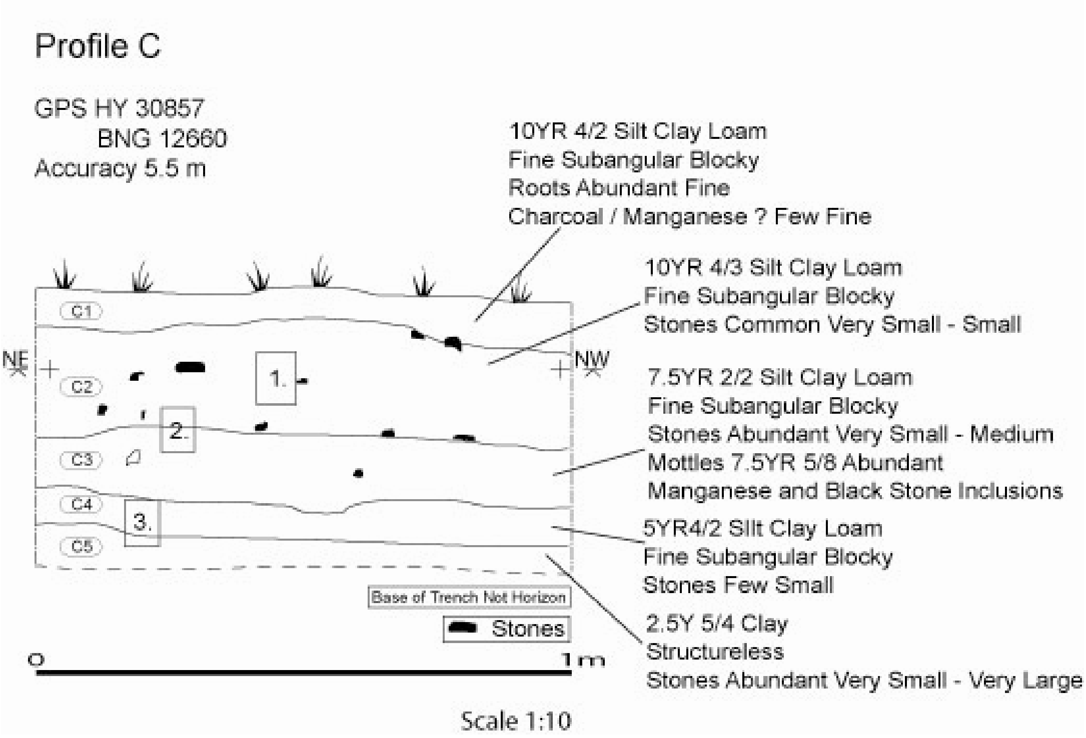


Figure 55 Barnhouse Profile C

7.1.3 Barnhouse Profiles D, E and F (Figures 56, 57 and 58)

In the absence of anthropogenic inclusions within profiles located in close proximity to Barnhouse Neolithic Settlement, subsequent profiles (D,E,F) were located on magnetic anomalies identified as representing ridges and furrows associated with ploughing (Gater and Shiel 2002). Each profile consisted of an A horizon overlying a horizon containing anthropogenic inclusions of charcoal, interpreted as an anthropogenic horizon. Charcoal was identified within this horizon as being fine and occurring with an abundance of few-common and occurred alongside few-common, small-large stones. The glacial drift C horizon was excavated at a depth of 0.65-0.75 m within profiles D, E and F, at a deeper depth than within profiles A and B where profiles contained no anthropogenic inclusions. Bulk and thin section micromorphology samples were obtained from profiles D and E for analyses.

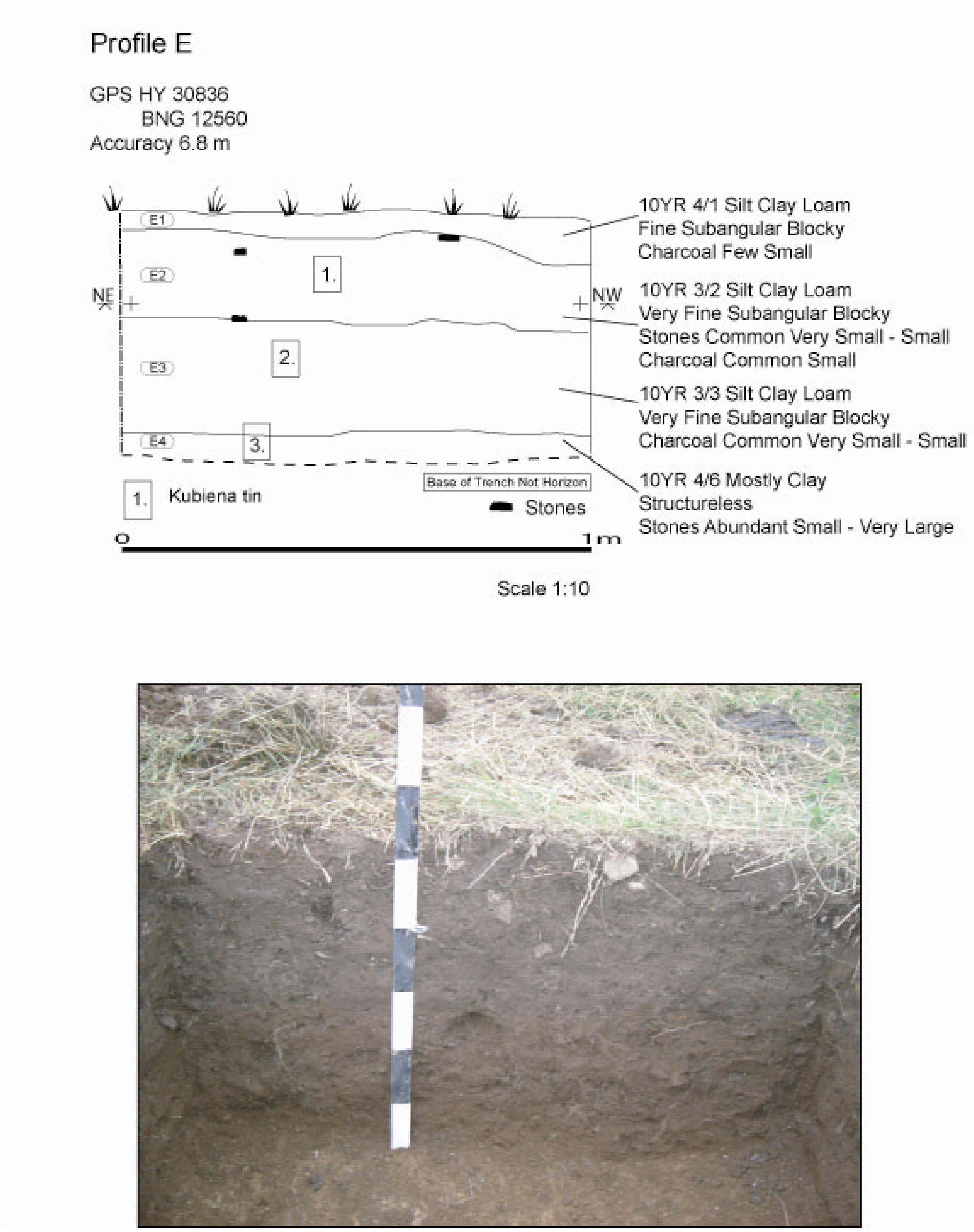


Figure 56 Barnhouse Profile E

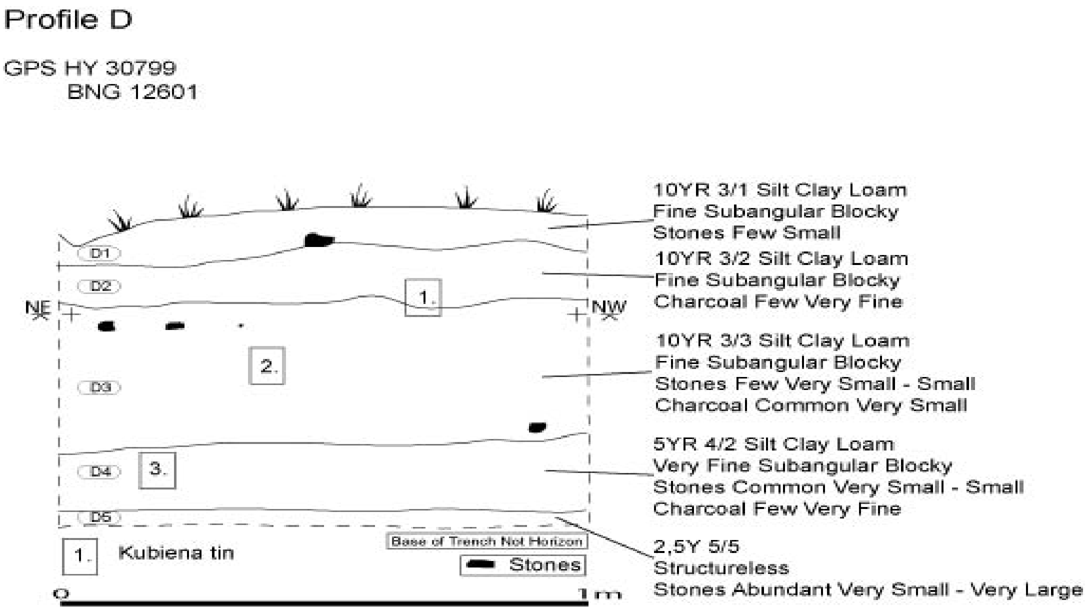


Figure 57 Barnhouse Profile D

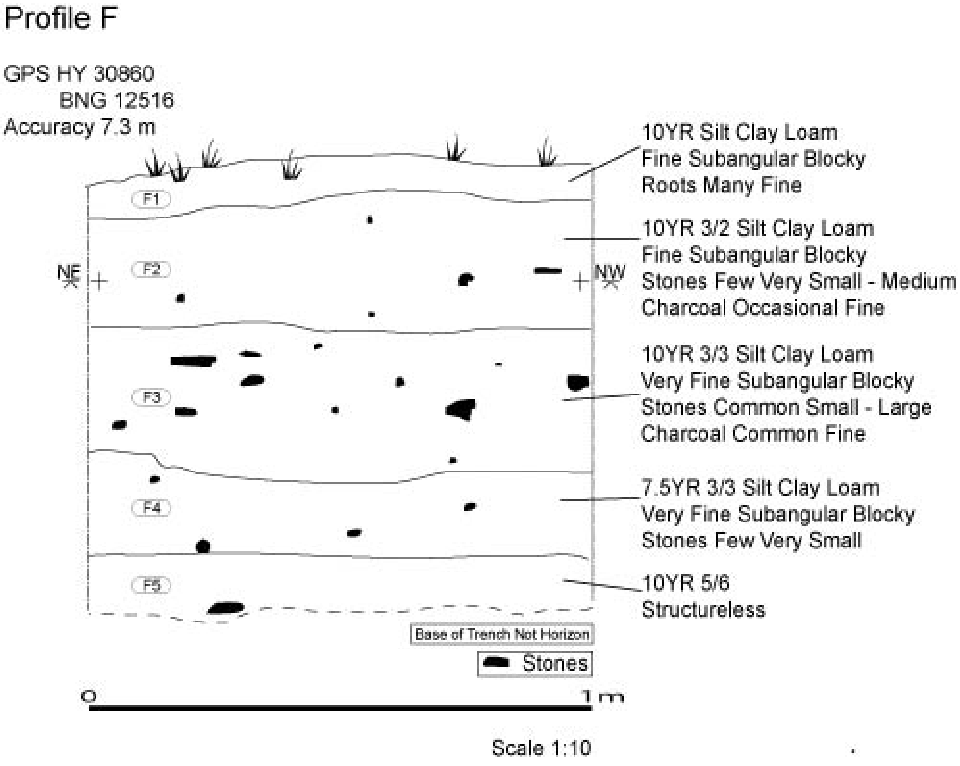


Figure 58 Barnhouse Profile F

7.1.4 Loch of Harray (LoH) Profile A and B (Figures 60 and 61)

To aid interpretation of the anthropogenic horizon identified within Barnhouse profiles D, E and F subsequent soil profiles were excavated to the east of the Loch of Harray. These profiles were deliberately located on a geographically extensive area of ridge and furrow identified through recent magnetometry survey (Orkney College Geophysics Unit 2005, Figure 59). Current land use prevented soil profiles from being located within the ridge and furrow anomalies identified through magnetometry survey within the present field boundaries. An opportunity did arise however to locate soil profiles between present day field boundaries and the eastern shore of the Loch of Harray. The geophysical survey has been constrained by present day field boundaries but indications are that the ridge and furrow features extend outwith present day field boundaries towards the eastern shore of the Loch of Harray. Two soil profiles were located upon this likely extension of these ridge and furrow features (Figure 59).

Both profiles contain an A horizon with many fine roots (Figure 60). The A horizon overlies a Bs horizon which is a dark brown (10YR 4/2) silt clay loam and contains few-common, very fine-fine charcoal inclusions along with few-many fine mottles (10YR 6/8, Figure 60). An iron pan was also observed within this horizon in profile B indicating its iron enriched nature. The underlying C horizon was identified as being glacial drift and was comparable to the C horizon identified within profiles at Barnhouse and at Wasbister.

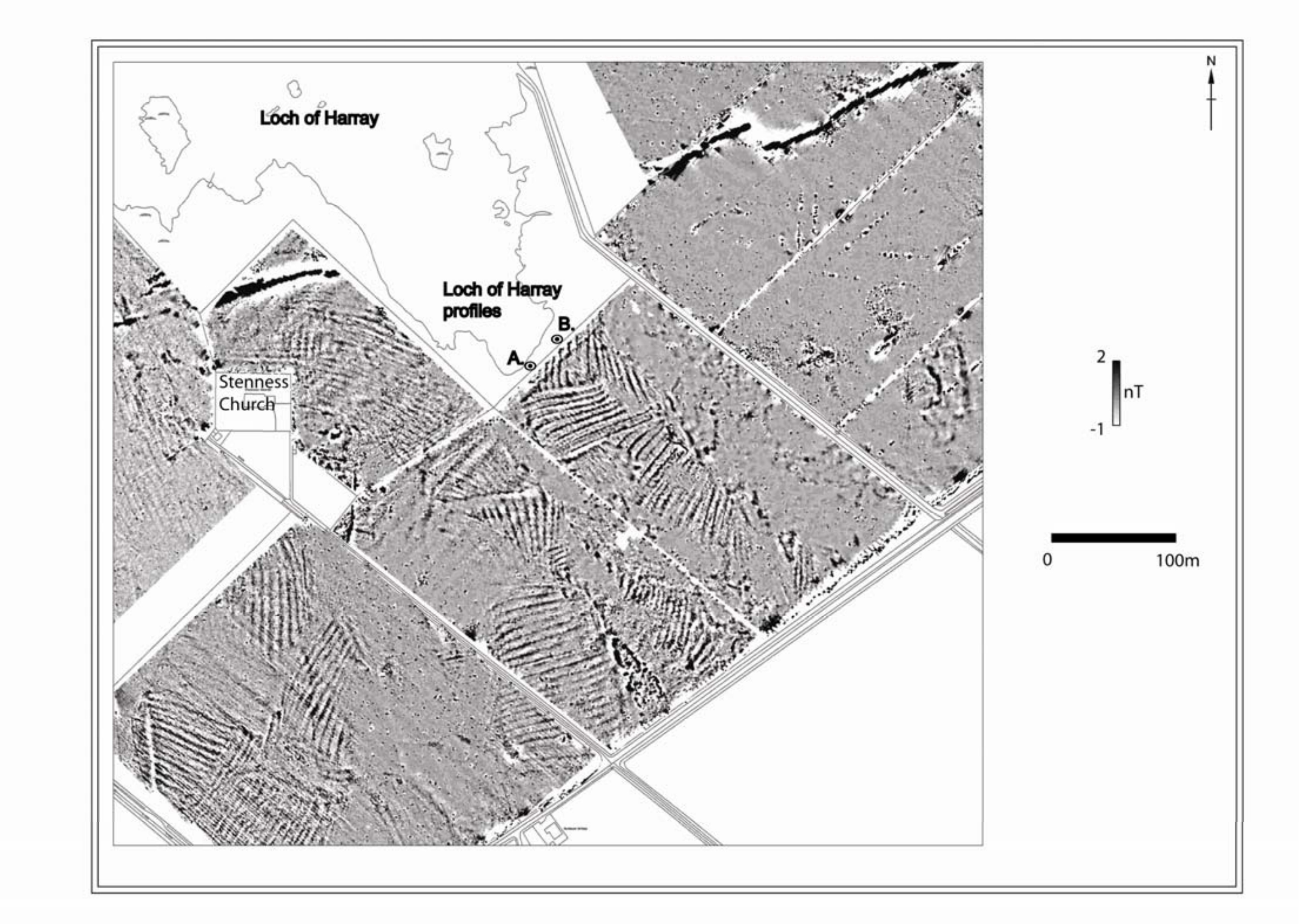


Figure 59 Loch of Harray magnetometry survey and profile locations (Orkney College Geophysics Unit 2005)

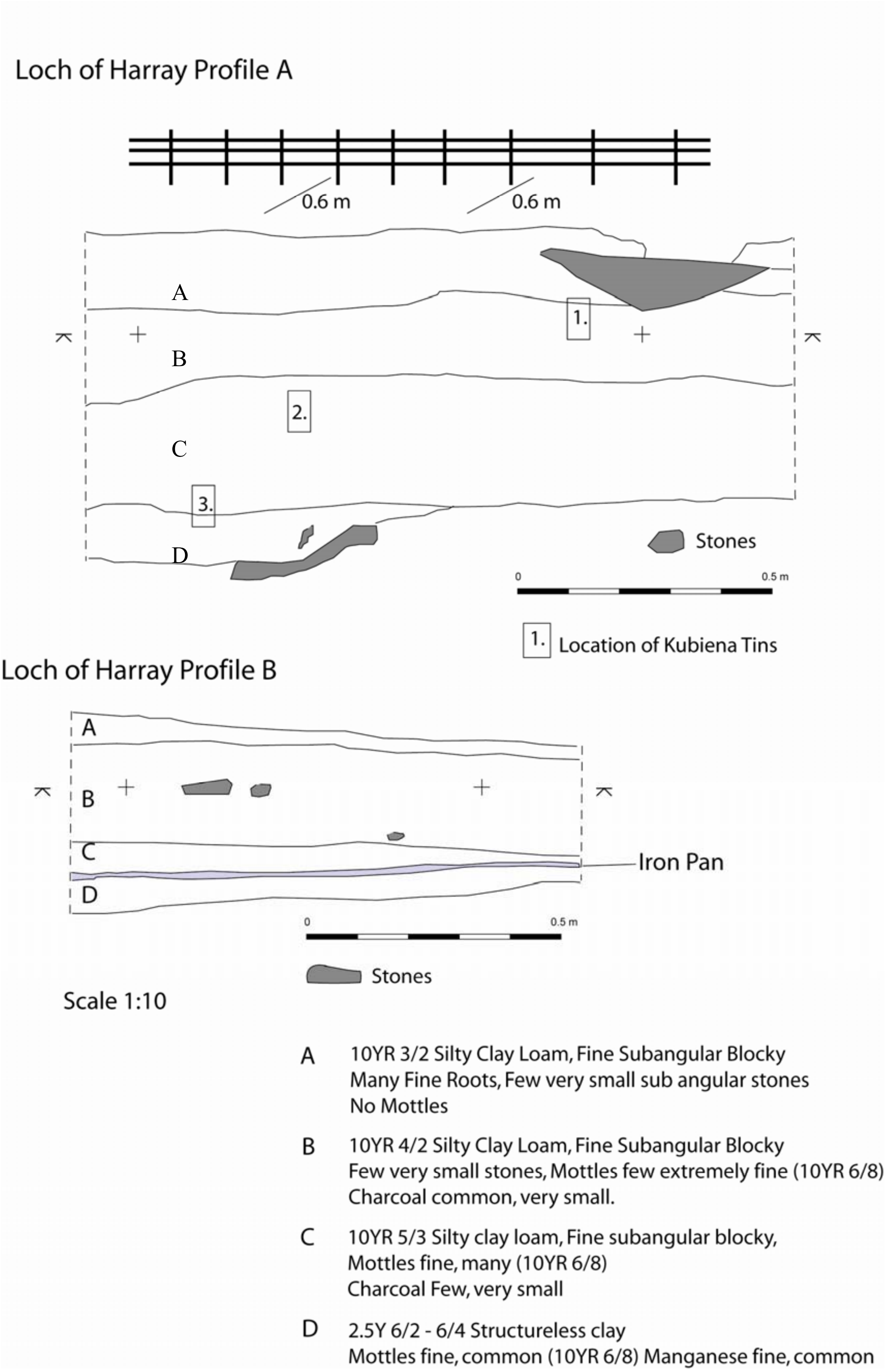


Figure 60 Loch of Harray Profiles A and B

7.1.5 Summation of Field Results

Anthropogenic inclusions were not identified in horizons at Barnhouse profiles A and B, where shallow profiles were identified with the glacial drift C horizon at 0.25 m. Field observations could not determine the presence of charcoal within horizons in Barnhouse Profile C and appropriate samples were taken to aid this interpretation. Anthropogenic inclusions of charcoal have been identified in horizons in Barnhouse profiles D, E and F and within the profiles excavated at the Loch of Harray (Loch of Harry profile A and B). Field observations identify similar characteristics between the anthropogenic horizons identified at Barnhouse (BH Profiles D-F) and at he Loch of Harray (LoH Profiles A and B), with soil horizons at both sites containing common, fine charcoal inclusions and being obviously similar in colour, structure and texture.

7.2 *Analytical Results*

Laboratory analyses were undertaken on samples from Barnhouse profiles A, B, C, D, E and from profiles A and B at the Loch of Harray. Table 28 and Table 29 provide a summary of the samples obtained.

Table 28 Barnhouse horizons sampled

	Horizon Bulk Sampled	**Horizon Kubiena Tin Sample**
A Horizon	Profile A, Profile C, Profile D, Profile E and F (all horizon 1)	
Anthropogenic Horizon	Profile D- horizons 2,3 and 4 Profile E-horizons 2 and 3 Profile F-horizons 2 and 3	Profile D (samples D2, D3, D4) Profile E (samples E1, E2 and E3)
C Horizon	Profile A, Profile C, Profile D, Profile E and Profile F	Profile E (sample E3)

Table 29 Loch of Harray horizons sampled

	Horizon Bulk Sampled	**Horizon Kubiena Tin Sample**
A Horizon	Profile A and Profile B (Horizon A)	Profile A (part of sample A1)
Anthropogenic Horizon	Profiles A and B (Horizons B and C)	Profile A (samples A1, A2 and A3)
C Horizon	Profiles A and B (Horizon D)	Profile A (part of sample A3)

7.2.1 pH

pH results from the soil horizons at Barnhouse and LoH are acidic but there is considerable variation with pH ranging from 4.0 to 6.8 (Table 30, full results available Appendix B, Soil Organic Matter and pH Results). Results indicate that pH of the anthropogenic horizon is slightly increased relative to surface A horizons and subsurface C horizons, although only minor differences exist between the mean pH of the A, anthropogenic and C horizons.

Table 30 Barnhouse and Loch of Harray summary pH results

Barnhouse				**Loch of Harray**		
Horizon	Minimum	Maximum	Mean	Minimum	Maximum	Mean
A	5	6.4	5.8	5	5.2	5.1
Anthropogenic	4.8	6.8	5.9	5.2	5.4	5.3
C	4.8	6.2	5.7	4.8	5	4.9

7.2.2 Soil Organic Matter Content

Loss on ignition (LOI) results indicate that soil organic matter from Barnhouse ranges from 10-12% associated with surface A horizons down to 3-5% associated with glacial drift C horizon (Table 31). Results from profiles at the Loch of Harray are comparable to these. LOI results indicate that within each profile organic matter decreases down profile from A horizons to glacial drift C horizon (full results available Appendix B, Soil Organic Matter and pH Results).

Table 31 Barnhouse and Loch of Harray summary soil organic matter content results

Barnhouse				**Loch of Harray**		
Horizon	Minimum %	Maximum %	Mean %	Minimum %	Maximum %	Mean %
A	11.5	11.5	11.6	8.7	9.4	9.05
Anthropogenic	6.3	9.9	8.5	6.7	8.0	7.25
C	3.1	5.6	4.3	3.7	4.3	4.0

7.2.3 Particle Size Distribution (PSD)

PSD results identify all soil horizons at these field sites as being dominated by a coarse silt component with a large medium fine and medium silt component, a minor clay component and a very minor sand component. The possible anthropogenic horizon identified within Profile C has a similar PSD but results identify this horizon as containing a greater percentage of fine and medium sand than either the overlying A horizon or the underlying glacial C (full results available Appendix C, Particle Size Distribution Results).

PSD from the anthropogenic horizons in Barnhouse profiles D, E and F and profiles from the Loch of Harray are very similar (Figure 61 and Figure 62). Results indicate that at both sites the mean PSD for anthopic horizons is almost identical to the mean PSD of the overlying A horizons. The mean C horizon PSD is also dominated by a coarse silt component but is found to contain less silt and a greater percentage of sand than the overlying horizons.

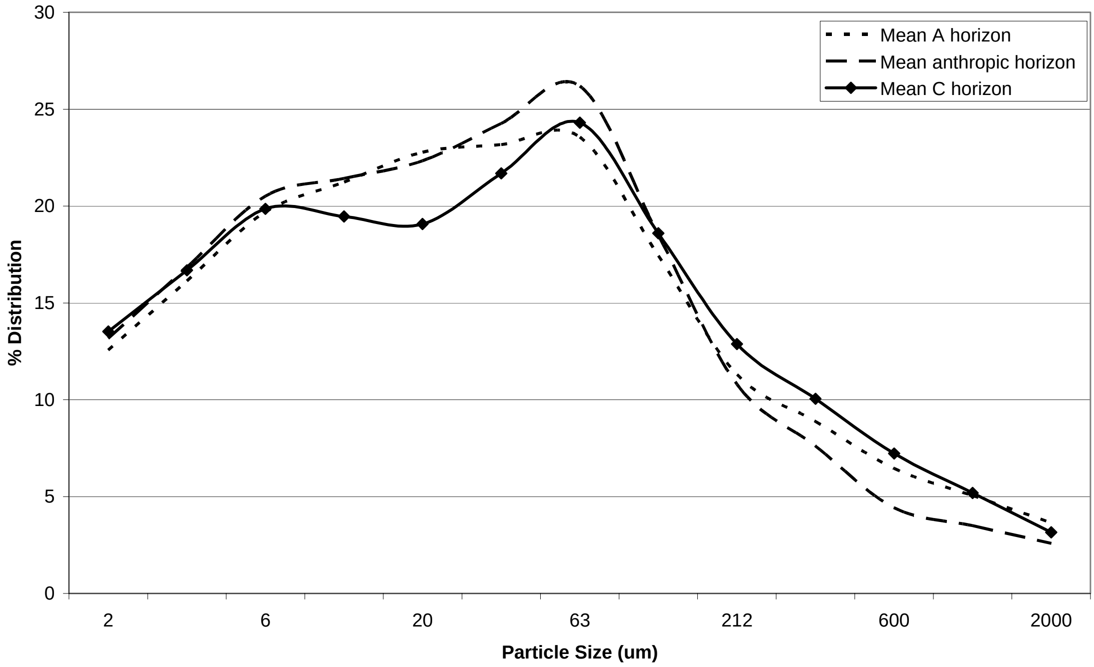


Figure 61 Barnhouse mean PSD

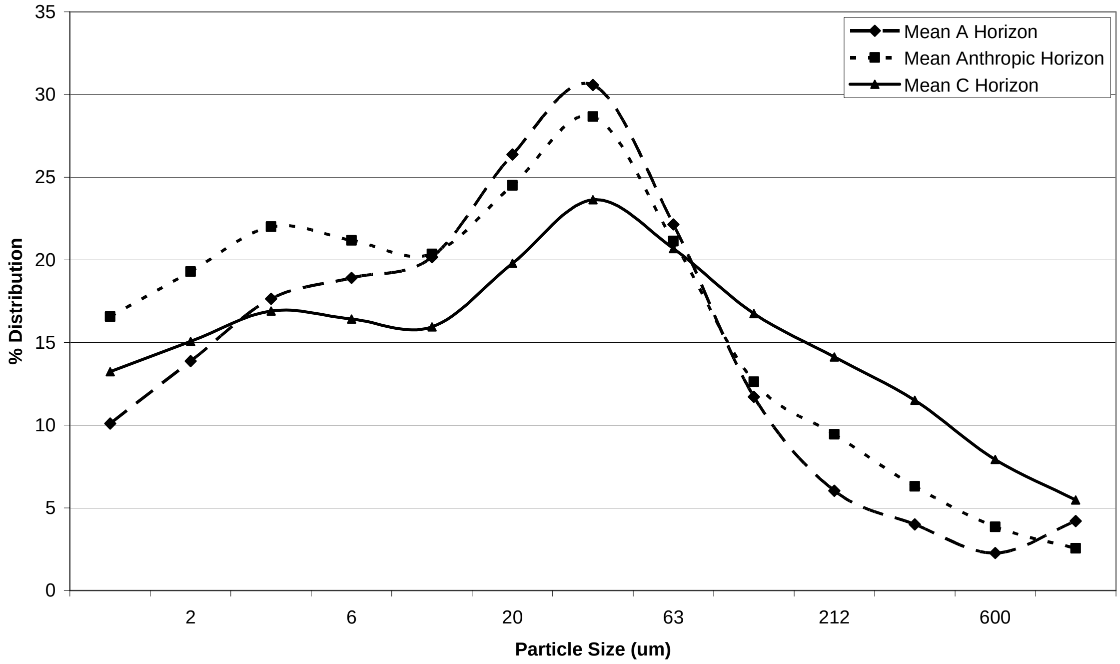


Figure 62 Loch of Harray mean PSD

7.2.4 Total Phosphorus

Total phosphorus concentrations associated with the A horizon for the Barnhouse profiles, and determined through NaOH fusion, range from 168 to 238 mgP/100g oven dried soil and have a mean total phosphorus concentration of 200 mgP/100g oven dried soil (Table 32). These concentrations are comparable to total phosphorus concentrations associated with anthropogenic horizons within Barnhouse profiles D, E and F which range from 190 to 251 mgP/100g oven dried soil with a mean of 220 mgP/100g oven dried soil (Table 32, for example see Profile E, Figure 63).

Table 32 Barnhouse and Loch of Harray Summary Total Phosphorus Results

Barnhouse				**Loch of Harray**		
Horizon	Minimum	Maximum	Mean	Minimum	Maximum	Mean
A	168.3	238.2	199.8	105.1	109.3	107.6
Anthropogenic	197.3	247.9	231.4	70.6	107.7	89.7
C	94.8	274.4	175.0	32.7	41.1	37.6

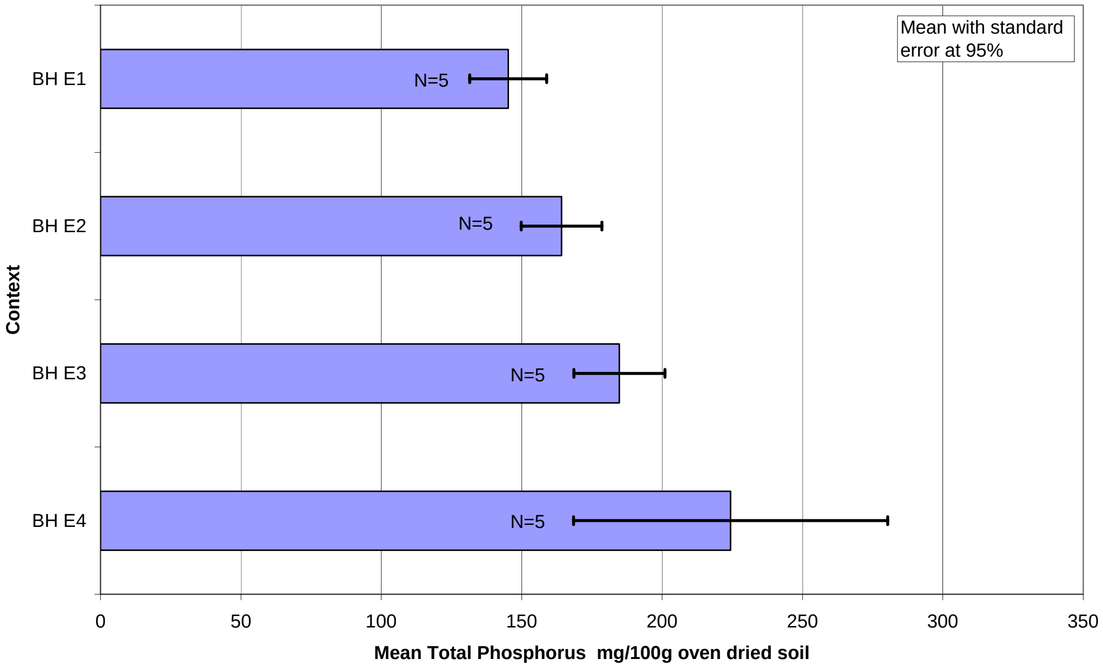


Figure 63 Total phosphorus Barnhouse Profile E

Mean total phosphorus concentration from the A horizons of profiles at the Loch of Harray (LoH) is 107 mgP/100g oven dried soil (Table 32). This is much lower than total phosphorus concentrations associated with the A horizons from Barnhouse. The mean total phosphorus from A horizons at LoH is also much greater than the phosphorus concentrations associated with the underlying anthropogenic horizons containing inclusions of charcoal (Table 32). Total phosphorus concentrations of the anthropogenic horizons at LoH ranges from 70 to 197 mgP/100g oven dried soil with a mean of 90 mgP/100g oven dried soil. (Full results available Appendix D Total Phosphorus Results).

Total phosphorus concentrations of the C horizons within the profiles at Barnhouse ranges from 94 to 274 mgP/100g oven dried soil (mean 172 mgP/100g oven dried soil) which is much greater than the total phosphorus concentrations of 33 and 41 mgP/100g oven dried soil associated with the glacial drift C horizon within LoH profile A and B (Table 32). The possible anthropogenic horizon within profile C has a total phosphorus concentration of 207 mgP/100g oven dried soil which is comparable to that of the A horizon within this profile of 201 mgP/100g oven dried soil (full results available Appendix D Total Phosphorus Results).

7.2.5 Mass Susceptibility (χ)

Mass susceptibility (χ) results from Barnhouse profiles D, E and F clearly identify that subsurface horizons containing anthropogenic inclusions have an enhanced mass susceptibility relative to both surface A and subsurface C horizons (Table 33). The mass susceptibility of the anthropogenic horizons within these profiles range from $1.86\text{x}10^{-6}\text{m}^3\text{kg}^{-1}$ to $6.48\ \text{x}10^{-6}\text{m}^3\text{kg}^{-1}$ with a mean of $4\ \text{x}10^{-6}\text{m}^3\text{kg}^{-1}$ (Table 33).

Table 33 Barnhouse and Loch of Harray Summary Mass Susceptibility Results (χ x10^{-6} m^{3}kg^{-1})

Barnhouse				**Loch of Harray**		
Horizon	Minimum	Maximum	Mean	Minimum	Maximum	Mean
A	0.59	2.29	2.0	0.56	1.01	1.57
Anthropogenic	1.86	6.48	4.0	0.38	1.66	0.78
C	0.1	2.64	1.04	0.1	0.21	0.31

Mass susceptibility results from horizons in profiles D, E and F at Barnhouse are greater than those from corresponding horizons in the LoH profiles. Mass susceptibility of the anthropogenic horizons within the LoH profiles ranges from 0.38 x10^{-6}m^{3}kg^{-1} to 1.66 x10^{-6}m^{3}kg^{-1} (mean 0.78 x10^{-6}m^{3}kg^{-1}).

7.2.6 Thin Section Micromorphology

7.2.6.1 Barnhouse Profile C (Table 34)

The coarse mineral component of thin section samples from this profile are comparable to those from profiles D and E and contain common-frequent (30%) quartz along with few-common (5-15%) siltstones exhibiting iron depleted stone rims, very few (<5%) amorphous black features and occasional-many typic iron nodules. Differences do exist between the thin section samples of Profile C and thin section samples from the anthropogenic horizon within Profile D and Profile E. Charcoal was not positively identified within Profile C and samples from the base of this profile also contained many discrete grey features, typically of a 2-3 mm in width which were composed of the fine soil matrix (as in LoH Profile A, Figure 64). These features were not iron depleted features but were grey in colour in comparison to the brown fine matrix of the soil and contained rare-occasional diatoms and phytoliths.

7.2.6.2 Barnhouse Profiles D and E (Table 34 and 35)

Thin section samples from the anthropogenic horizons identified within Barnhouse were obtained from profiles D and E. The coarse mineral component of each thin section is dominated by quartz which occurs within all samples with an abundance of common to frequent (25-30%). Siltstones are also present within all samples with an abundance of few to common (5-20%) except within Profile E slide 3 which contains dominant (50%) siltstones. Siltstones exhibit iron depleted stone rims within every thin section sample except for Profile D sample 1. The coarse mineral component of the thin section samples from these profiles is blocky in shape and has a subangular degree of roundness. These samples are moderately sorted and contain occasional-many typic iron nodules.

Charcoal inclusions occur within thin section samples from Profile D with an abundance of very few (<5%) and occur within thin section samples from Profile E with an abundance of very few and few (<5% and 10%, Figure 64). Amorphous black material was observed within each sample with a frequency of very few (<5%), the majority of which is unidentifiable with only several amorphous black features containing internal mineral inclusions under cross polars and being interpreted as turf (Figure 64). Black amorphous material within every thin section sample shows evidence of being iron enriched. Fungal spores are observed within both profiles with a rare frequency and biological activity is also indicated within each profile by the occurrence of mammilliate excrement with a frequency of rare-occasional. A trace occurrence of diatoms and phytoliths is present within grey features within the fine matrix of thin section samples from Profile D.

LoH Profile A (Table 35)

Thin section results from the anthropogenic horizon at LoH are very similar to those from Barnhouse profiles D and E. The coarse mineral component of these thin section samples are dominated by quartz with a common abundance (20%) and few siltstones (5-10%) which exhibit iron depleted stone rims. As within samples from Barnhouse, the coarse mineral component of the section samples from these samples is blocky in shape and has a subangular degree of roundness. These samples are moderately sorted and contain rare typic iron nodules.

Very few (<5%) charcoal inclusions were identified within these samples (<5%) and amorphous black material was observed within each sample with an abundance of very few (<5%). Slide 2 contains a large clinker type deposit which contains large vesicles and is clearly the product of being burnt (Figure 64). As within samples from Barnhouse, the source of the majority of the amorphous black material was unidentifiable but the amorphous black material itself was identified as organic matter which had been iron enriched. Only one piece of this material contained mineral inclusions under cross polars and is interpreted as turf. Fungal spores were observed with a rare frequency and biological activity is indicated by the rare-occasional occurrence of mamilliate excrement. The thin section sample taken towards the base of the LoH Profile A contains many discrete grey features within the fine matrix of the sample. These features are grey in colour, are well sorted and contain rare phytoliths and diatoms (Figure 64).

Table 34 Barnhouse Thin Section Micromorphology Results

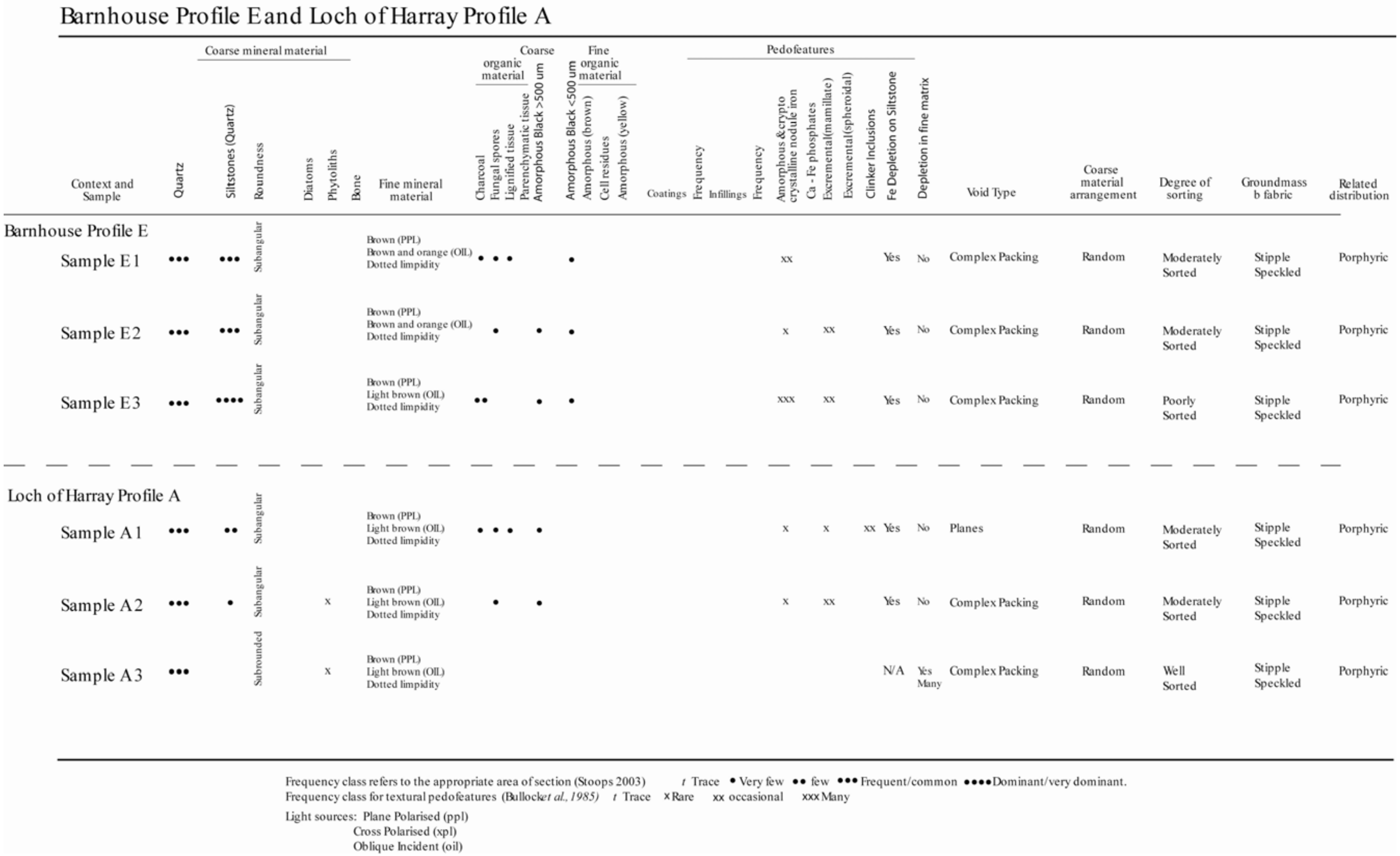
Barnhouse

		Coarse mineral material						Coarse organic material					Fine organic material				Pedofeatures														
Context and Sample	Quartz	Siltstones (Quartz)	Roundness	Diatoms	Phytoliths	Bone	Fine mineral material	Charcoal	Fungal spores	Lignified tissue	Parenchymatic tissue	Amorphous Black >500 um	Amorphous Black <500 um	Amorphous (brown)	Cell residues	Amorphous (yellow)	Coatings	Frequency	Infillings	Frequency	Amorphous & crypto crystalline nodule iron	Ca - Fe phosphates	Excremental (mamillate)	Excremental (spheroidal)	Fe Depletion on Siltstone	Depletion in fine matrix	Void Type	Coarse material arrangement	Degree of sorting	Groundmass b fabric	Related distribution
Sample C 1	•••	•••	Subangular				Brown (PPL) Light Brown (OIL) Dotted limpidity			•		•	•								xx		xx		Yes	No	Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample C 2	•••	••	Subangular				Brown + Grey (PPL) Light Brown (OIL) Dotted limpidity	•				•	•								xxx		x		Yes	Yes	Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample C 3	•••	••	Subangular	xx			Grey (PPL) Light Brown + Grey (OIL) Dotted limpidity	•				•									xxx		x		Yes	Yes	Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample D 1	•••	••	Subangular				Brown (PPL) Brown (OIL) Dotted limpidity	•	•	•	•	•	•								xx		x		No	Yes	Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample D 2	•••	••	Subangular				Brown (PPL) Brown (OIL) Dotted limpidity	•	•				•								xxx		xx		Yes	No	Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample D 3	•••	•••	Subangular				Brown (PPL) Brown (OIL) Dotted limpidity	•				•	•								xxx		x		Yes	Yes	Complex Packing	Random	Poorly Sorted	Stipple Speckled	Porphyric

Frequency class refers to the appropriate area of section (Stoops 2003) t Trace • Very few •• few ••• Frequent/common ••••Dominant/very dominant.
Frequency class for textural pedofeatures (Bullocket al., 1985) t Trace x Rare xx occasional xxx Many

Light sources: Plane Polarised (ppl)
Cross Polarised (xpl)
Oblique Incident (oil)

Table 35 Barnhouse Profile E and Loch of Harray Profile A, Thin Section Micromorphology Results



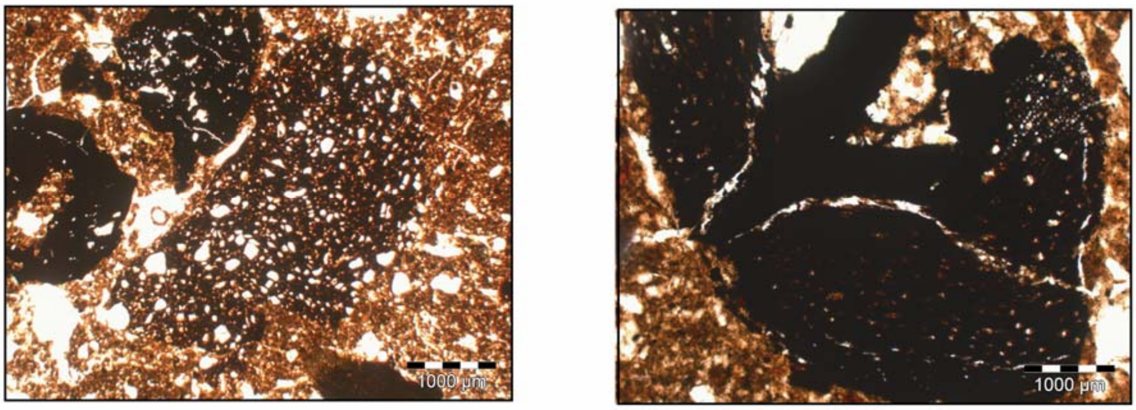
Barnhouse Profile E and Loch of Harray Profile A

		Coarse mineral material						Coarse organic material					Fine organic material				Pedofeatures															
Context and Sample	Quartz	Siltstones (Quartz)	Roundness	Diatoms	Phytoliths	Bone	Fine mineral material	Charcoal	Fungal spores	Lignified tissue	Parenchymatic tissue	Amorphous Black >500 um	Amorphous Black <500 um	Amorphous (brown)	Cell residues	Amorphous (yellow)	Coatings	Frequency	Infillings	Frequency	Amorphous &crypto crystalline nodule iron	Ca - Fe phosphates	Excremental(mamillate)	Excremental(spheroidal)	Clinker Inclusions	Fe Depletion on Siltstone	Depletion in fine matrix	Void Type	Coarse material arrangement	Degree of sorting	Groundmass b fabric	Related distribution
Barnhouse Profile E																																
Sample E1	•••	•••	Subangular				Brown (PPL) Brown and orange (OIL) Dotted limpidity	•	•	•			•								xx					Yes	No	Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample E2	•••	•••	Subangular				Brown (PPL) Brown and orange (OIL) Dotted limpidity		•			•	•								x		xx			Yes	No	Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample E3	•••	••••	Subangular				Brown (PPL) Light brown (OIL) Dotted limpidity	••				•	•								xxx		xx			Yes	No	Complex Packing	Random	Poorly Sorted	Stipple Speckled	Porphyric
Loch of Harray Profile A																																
Sample A1	•••	••	Subangular				Brown (PPL) Light brown (OIL) Dotted limpidity	•	•	•		•									x		x		xx	Yes	No	Planes	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample A2	•••	•	Subangular		x		Brown (PPL) Light brown (OIL) Dotted limpidity		•			•									x		xx			Yes	No	Complex Packing	Random	Moderately Sorted	Stipple Speckled	Porphyric
Sample A3	•••		Subrounded		x		Brown (PPL) Light brown (OIL) Dotted limpidity																			N/A	Yes Many	Complex Packing	Random	Well Sorted	Stipple Speckled	Porphyric

Frequency class refers to the appropriate area of section (Stoops 2003) *t* Trace • Very few •• few ••• Frequent/common ••••Dominant/very dominant.
Frequency class for textural pedofeatures (Bullock*et al., 1985)* *t* Trace ×Rare xx occasional xxx Many

Light sources: Plane Polarised (ppl)
Cross Polarised (xpl)
Oblique Incident (oil)

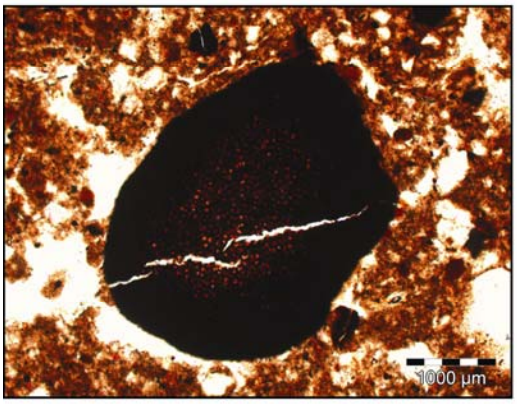
Barnhouse Profile E



Burnt Turf. Black amorphous feature containing mineral inclusions under cross polars.

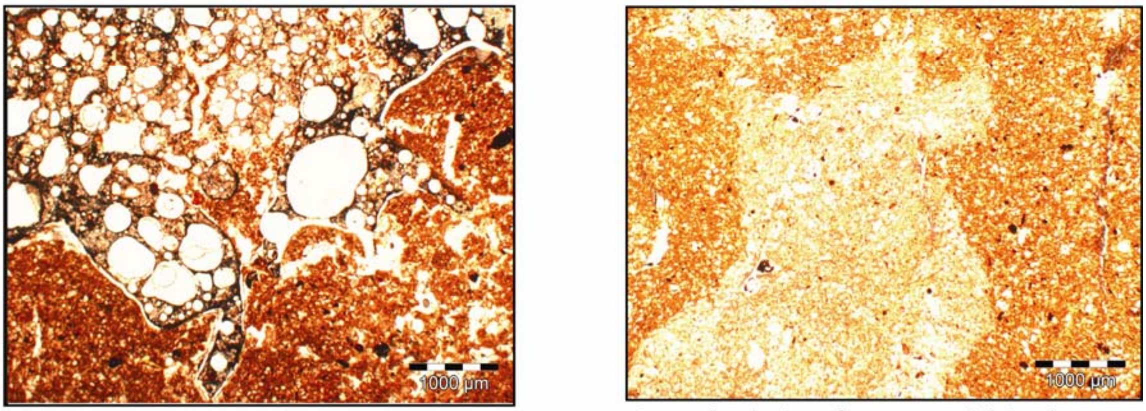
Charcoal evidence of internal cellular structure.

Barnhouse Profile D



Sclerotia fungal spores

Loch of Harray Profile A



Slag type feature formed from high intensity burning. Interpreted as clinker within this context.

Grey depletion features within the groundmass. Feautures represent lacustrine silt

Figure 64 Key micromorphological characteristics Barnhouse and the Loch of Harray (PPL)

7.3 Discussion, the Absence of a Cultural Record

The excavation of Barnhouse Neolithic Settlement identified the use of soil resources as intimately associated with Neolithic settlement activities involved in the formation and sustenance of the settlement (French 2005). The utilisation of soil resources, and the resulting SSBCR were observed within settlement construction but there is also evidence to suggest that the landscape immediately outwith Barnhouse Neolithic Settlement was utilised by the Neolithic community as pasture and maybe even for arable agriculture (French 2005, Richards 2005). It was therefore anticipated that the locating of Profiles A, B and C in close proximity to the excavated structural archaeology and its probable, as yet unexcavated continuation (Gater and Shiel 2003) would lead to the identification of anthropogenic horizons representing a SSBCR intimately associated with Barnhouse Neolithic Settlement. However, field observations suggest that there is an absence of any anthropogenic horizons within profiles A, B and C. Field observations are supported by total phosphorus results and mass susceptibility results indicating that values for subsurface AC horizons are lower than those associated with surface horizons, suggesting that there is no anthropogenic amendment within the AC horizon.

Total phosphorus results do identify a slight increase in total phosphorus concentrations in a subsurface horizon within Profile C, although no anthropogenic inclusions were identified in thin sections taken from this horizon, and mass susceptibility results for this horizon remain low. This slight increase in total phosphorus concentrations within subsurface horizons within Profile C is not therefore attributed to representing anthropogenic activity. The many grey features, containing rare diatoms identified within the fine matrix of the thin section sample from the base of Profile C are not interpreted as having an anthropogenic origin. These features are distinctively different within thin section to the grey fuel ash features identified within Skaill

Control and within the anthropogenic sediment at the Ness of Brodgar (Figure 38). These grey features do contain rare diatoms and are interpreted as being a lacustrine silt. The interpretation of a lacustrine silt is consistent with that of French (2005) who identifies this lacustrine silt incorporated with turf material in thin section samples obtained from the excavation of Barnhouse Neolithic Settlement. The interpretation of this lacustrine silt within these profiles and the well mixed nature of the fabric units is consistent with the suggestion that the close proximity to the Loch of Harray along with the potential frequent influence of high winds and high tides would have made this site susceptible to aggradation of lacustrine silt, from the shore of the loch of Harray, by aeolian deposition (French 2005). However, the identification of a discrete horizon of lacustrine silt within the base of Profile C, above the C horizon may also imply its deposition resulting from a raised loch level subsequent to glaciation.

The surprising absence of anthropogenic horizons representing a SSBCR associated with Barnhouse Neolthic Settlement may itself provide insight into the cultural activities of Neolithic and later communities and their activities within this landscape. The following discussion identifies possible interpretations for the absence of a Neolithic SSBCR within these profiles. Caution has been exercised within this discussion, as providing an interpretation for the absence of a SSBCR must rely in part on negative evidence. Furthermore, any absence of anthropogenic horizons does not nessesitate an absence of the influence of Neolithic cultural activites upon soils and a SSBCR may therefore exist which does not contain anthropogenic inclusions. Three multiple working hypotheses tested within the context of known activities within this landscape are firstly that the absence of the SSBCR is the result of the sampling strategy employed, secondly that its absence reflects an absence of utilisation of soil resources by the Neolithic community of Barnhouse and thirdly that its absence results from the activities of later communities.

7.3.1 Hypothesis 1- Absence Due to Sampling Strategy

Firstly it is entirely possible that any SSBCR associated with the Barnhouse Neolithic Settlement exists in the field to the south east of the settlement. This field is protected under Scheduled Monument status and excavation into it was not possible. It is possible therefore that the inability to identify a SSBCR containing anthropogenic inclusions intimately associated with Barnhouse Neolithic Settlement within these profiles was a result of the sampling strategy employed. However, limited excavation into this Scheduled field has been undertaken and has not recorded the identification of any anthropogenic horizons representing a SSBCR (Challands *et al* 2005a, Challands *et al* 2005b). This explanation therefore remains unlikely.

7.3.2 Hypothesis 2 – Absence Due to Lack of Resource Utilisation

Secondly it is possible that there is no SSBCR associated with the Barnhouse Neolithic Settlement, that the Neolithic people in the settlement were not utilising the resource of soil around the settlement in the settlement process. This however does not seem to be a plausible explanation in the light of the utilisation of soils and sediments within Neolithic cultural activities and more specifically of research which identifies a SSBCR associated with construction of Barnhouse Neolithic Settlement. This SSBCR was identified within thin section as being predominantly turf material mixed with lacustrine silt, probably utilised as walling or roofing material for the house structures (French 2005). The evidence of biological activity along with amorphous iron and phosphatic or coprolitic material within thin section has led to the suggestion that the turf material was removed from pre-existing pasture land which had received additions of lacustrine silt. The amorphous iron-phosphatic or coprolitic material is indicative of the animals grazing on the turf which French (2005) interprets as occurring prior to the incorporation of this turf material into the construction of the site.

This thesis identifies the significant value attributed to soil resources by communities within the Orcadian Neolithic and within this context it is considered questionable whether an Orcadian Neolithic community would decimate valuable pasture land for its incorporation into settlement construction. Irrespective of this it is apparent that a SSBCR exists which is intimately associated with Barnhouse Neolithic Settlement and it is presumed that the activities of the Neolithic community at this site must have influenced the soils surrounding the settlement.

7.3.3 Hypothesis 3 – Absence Due to Later Eradication

Thirdly it is possible that evidence of Neolithic cultural activity in soils associated with the Barnhouse Neolithic Settlement has been eradicated by later land use and more specifically by later, more intense agricultural practices. The landscape within this part of the WHS IBZ is clearly multi period in nature. The presence of Barnhouse Neolithic Settlement, Big Howe Iron Age Broch and ridge and furrow cultivation (Gater and Shiel 2002) in combination with recent agricultural history suggest that this land has been utilised continuously since at least the Neolithic. It is entirely possible that any Neolithic SSBCR has been eradicated by the use of the land by later people groups. There is possibly some evidence of profile truncation within Profile A where total phosphorus concentrations change significantly throughout the profile, although it is not possible to attribute this to any specific cultural practice. The eradication of a SSBCR becomes indeed most plausible when considering the plough damage associated with Barnhouse Neolithic Settlement (Richards 2005), the recent agriculturally intense practice of deep ploughing for potato cultivation (Gater and Shiel 2003) and the presence of string providing evidence of recent agricultural practices influencing the soil profile to just above the glacial drift C horizon within Profile A.

7.4 Discussion, the Presence of a Cultural Record

There is sufficient evidence from field observations to suggest that the anthropogenic horizons identified at Barnhouse Profiles D, E and F exhibit similar characteristics to those identified at the Loch of Harray Profiles A and B. The anthropogenic horizons within these profiles will therefore be discussed as a single anthropogenic horizon which forms the basis of this subsequent discussion.

7.4.1 Period of Formation

There is sufficient evidence from the association between the anthropogenic horizon (BH Profiles C,E,F and LoH Profiles A and B) and the ridge and furrow geophysical anomalies to suggest that the anthropogenic horizon has resulted from cultivation processes associated with the formation of the ridge and furrows. Ridge and furrow features are the result of past cultivation and land management strategies and have been identified as a valuable source of historical and scientific information as well as possessing an inherent aesthetic value within a landscape (Barber 2001, Foster and Smout 1994). Ridged cultivation surfaces have a very long history within Scotland and it is feasible that that these ridge and furrow features result from cultural activities associated with arable agriculture from the Bronze Age through to the present day (Barclay 1990, Barber 2001). The ridge and furrow features identified by the geophysical survey however are composed of narrow ridges which are straight and sharply defined. This is characteristic of 'Straight Rig and Grooving' typology (Barber 2001) which represents cultivation associated with agricultural improvements, dated from the mid nineteenth century on Orkney (Simpson 1997). Furthermore the ridge and furrow geophysical anomalies correlate broadly with areas of arable land identified by Thomas in 1849, supporting their likely formation resulting from Early Modern agricultural activities.

Despite the probable Early Modern agricultural intensification formation of the anthropogenic horizon at Barnhouse, it is entirely feasible that within this palimpsest landscape that this anthropogenic horizon initially formed as the result of Neolithic or other early cultural activities and that it has been subsequently utilised and modified by the cultural activities of later people groups. The profiles excavated upon ridge and furrow geophysical anomalies at the edge of the Loch of Harray were used to test this possibility. The distance (600m) between these profiles and Barnhouse Neolithic Settlement supports the interpretation that the anthropogenic horizon at the Loch of Harray is unlikely to be the result of any Neolithic cultural activity associated with Barnhouse Neolithic Settlement and is solely the product of agricultural practices associated with agricultural improvements from the mid nineteenth century. The anthropogenic horizon at Barnhouse is comparable in its nature to the anthropogenic horizon at the Loch of Harray which both lack domestic waste such as bone, fuel ash and pottery which are characteristic of Neolithic SSBCR (See Chapter 5). This suggests that the anthropogenic horizon identified at Barnhouse is also more likely to represent only cultural activities associated with agricultural practices from the Early Modern, and is unlikely to be the product of multiperiod cultural activities. This interpretation was unable to be supported through the determination of a radiocarbon chronology, as charcoal samples were retrieved from these profiles which were too small for single entity radiocarbon analysis.

7.4.2 Materials and Processes of Formation

Field observations and thin section results indicate that there is sufficient evidence to suggest that the anthropogenic horizons identified at Barnhouse and at the Loch of Harray have resulted from the same formation processes. Total phosphorus and mass susceptibility results from these two sites do differ but this does not preclude the formation as a result of the same formation process and only suggests differing intensity of amendment by the same formation process.

The anthropogenic horizon has formed within a site dominated by podsolisation, as evidenced by the iron pan in LoH, Profile B. Features resulting from podsolisation were also identified in associated thin sections including observations of many typic iron nodules, iron depletion features upon siltstones and the accumulation of iron within humic and amorphous black features. These features indicate that the deposition of this anthropogenic horizon occurred under the natural processes associated with podsolisation and that podsolisation continued to exert a dominant influence upon the anthropogenic horizon after deposition and during its function as an arable soil.

All profiles at this site were excavated to the glacial C horizon. The C horizon was generally encountered at a deeper depth within profiles containing the anthropogenic horizon, although there is no significant depth of accumulation of the anthropogenic horizon as for example as evident within Skaill Control. The glacial drift C horizon was identified as immediately underlying the anthropogenic horizon, suggesting that the anthropogenic horizon identified at these sites has been formed *in situ*, from the addition of anthropogenic inclusions into the existing soil profile. This suggests that this anthropogenic horizon is a soil amended through anthropogenic activity as opposed to an anthropogenic sediment as identified upon the Ness of Brodgar.

The only anthropogenic inclusion identified within anthropogenic horizon was charcoal which occurred with a very few abundance (<5%) within thin section. The charcoal recovered from bulk samples was dominated by *Ericales* species (40% by weight of total charcoal recovered, Ramsay *pers comm.*) suggesting the importance of turf both as a fuel resource, and also as a source of fertilisation within agricultural intensified arable management systems. This is consistent with the historical literature which also suggests that the turf incorporated into this anthropogenic horizon would have been taken from close proximity to the arable land (Fenton 1997). The abundance of only very few (<5%) charcoal inclusions is insufficient to account for the observed increase in depth associated with the anthropogenic horizon and it is suggested that this charcoal from turf would have been combined with other material within the anthropogenic horizon. Any organic materials of formation are now entirely decomposed and cannot be observed directly within thin section although the observation of very few (<5%) fungal spores may suggest the application of animal manures (Romans and Robertson 1985, Simpson 1997). The observation of very few (<5%) amorphous black features may support a turf contribution consistent with *Ericales* charcoal and the increase in depth, although the majority of this amorphous black remains unidentifiable with only a limited number of features positively identified as turf as containing mineral inclusions under cross polars (Figure 64). There is significantly less depth of an anthropogenic horizon at this site than is present within Skaill Control, although this does not preclude the application of turf.

It seems probable within context of historical literature than turf material has been incorporated in to this anthropogenic horizon. Turf was commonly used as manure around Brodgar within the mid nineteenth century during agricultural industrialisation and Thomas (1852) comments that *"Not only has turf or peat been cut for fuel but every layer of soil has been removed as fast as it has formed to serve as the manure for the infield"*. Thomas (1852) comments further that *"even The Ring of Brodgar has no sanctity with these barbarous depredations as the broken and scarified turf will witness"*. This suggests an intensive cultural practice of turf stripping for agricultural productivity within industrialising agricultural practices, which was likely to have occurred extensively throughout the WHS IBZ and influenced the soil profiles at Barnhouse and at the Loch of Harray. It is anticipated that any turf added to the arable soils at these sites would have been obtained from close proximity to the arable land and therefore would contain similar characteristics to the soils within the arable soil systems. This may account for any turf material being unidentifiable within the anthropogenic horizon and for the similarity between the PSD of the anthropogenic horizon and the present A horizons.

Historical literature suggests that that it would have been predominantly unburnt turf utilised as manure during this agricultural intensification (Fenton 1997) which thin section results suggest was combined with a minor charcoal component. Despite the minor charcoal component observed within thin section, mass susceptibility results are relatively high suggesting that the amount of burnt material within the anthropogenic horizon may be under represented within thin section observations. Mass susceptibilities from the anthropogenic horizon at Barnhouse are significantly greater than those from Skaill Control LBA/IA but there is no statistical evidence to suggest that the mass susceptibility from the anthropogenic horizon at Barnhouse differs from the mass susceptibility of Skaill Control Plaggen or the anthropogenic sediment upon the Ness of Brodgar (Table 36). Further characterisation of the anthropogenic horizon through thin section micromorphological analysis has identified the presence of charcoal and a noticeable complete absence of any peat/turf ash material and either cremated or uncremated bone. This suggests that the anthropogenic horizon at these sites is more comparable to the Skaill Control Plaggen soil than to the Neolithic anthropogenic sediment on the Ness of Brodgar. This may suggest that the plaggen type soil management system was more widespread throughout nineteenth century Orkney than has previously been identified (Simpson 1997) but that it was often not intensive enough to create a deepened topsoil of >70cm as identified and mapped by Macaulay (1981). The grey features previously interpreted a lacustrine silt are also present within the anthropogenic horizon and the mixing of these features within the fine matrix of the sample is interpreted as resulting from aeolian deposition of the lacustrine silt from the shore of the Loch of Harray and from subsequent cultivation including tillage (French 2005).

Table 36 Barnhouse statistical comparison

	Finstown Control	**Skaill Control LAB/IA**	**Skaill Control Plaggen**	**NoB Neolithic Sediment**	**Wasbister**
Function	None	Arable	Arable	Probable Arable	
Barnhouse soil property					
Total P **Mean 207** **Median 208**	BH significantly greater than FT Control (Mann Whitney P=0.000)	BH significantly greater than Skaill Control LBA/IA (Mann Whitney P=0.0002)	No statistical evidence to suggest BH differs to Skaill Control	No statistical evidence to suggest BH differs to NoB	BH significantly greater than WAS (Mann Whitney P=0.000)
Magnetic Susceptibility	BH significantly greater than FT Control (Mann Whitney P=0.0005)	No statistical evidence to suggest BH differs to Skaill Control EBA/IA	No statistical evidence to suggest BH differs to Skaill Control	No statistical evidence to suggest BH differs to NoB	BH significantly greater than WAS (Mann Whitney P=0.013)

Despite the complete absence of phosphorus rich anthropogenic inclusions of bone and ash within thin section, the total phosphorus concentration of the anthropogenic horizon identified at Barnhouse is high and is comparable to the total phosphorus concentrations of the anthropogenic horizons within Skaill Control and the anthropogenic sediment upon the Ness of Brodgar. This is somewhat surprising considering the only anthropogenic inclusions identified within the anthropogenic horizon at Barnhouse were charcoal and amorphous black features, which only occurred with an abundance of very few (<5%). It is considered unlikely that this minor charcoal content along with the addition of any turf and a minor input of lacustrine silt would be sufficient to account for the large total phosphorus concentration associated with the anthropogenic horizon, although the presence of these inclusions may be sufficient to raise the pH of the anthropogenic horizon relative to the surrounding soil profiles.

The large discrepancy between the high total phosphorus concentrations observed and the limited observation of anthropogenic inclusions observed within thin section can be explained by the addition of phosphorus rich material which is not identifiable within thin section. It is possible that as within the plaggen management system turf has been added to this anthropogenic horizon with a significant input of animal manure (Fenton 1997), the organic components of which are now totally decomposed and unrecognisable within thin section. However, the absence of any iron-phosphatic or coprolitic material as present within samples from Barnhouse Neolithic Settlement (French 2005) suggests this is unlikely to be the case.

It is considered to be much more likely that the high total phosphorus concentration associated with the anthropogenic horizon at Barnhouse is a result of the addition of inorganic phosphate within recent agricultural practices. Total phosphorus concentrations from the A horizon from profiles at Barnhouse is greater than total phosphorus concentrations associated with A horizons from other field sites, suggesting that within recent agricultural history this site has been subjected to a greater intensity of amendment than the Ness of Brodgar or Wasbister. This is validated by farmer interviews which indicate that the land at Barnhouse has been subjected to more intense agricultural practices along with a greater application of organic and inorganic fertiliser than the Ness of Brodgar or Wasbister (Mr Tulloch *pers comm*. Appendix F). Mr Tulloch was able to describe the agricultural practices for this site over the last 15 years including the application of inorganic fertiliser at depth and onto the land surface. Mr Tulloch further identified several land uses including crops of potatoes, barley and oil seed rape and more recently the pastoral use of the land for grazing. It is considered to be extremely likely that the addition of phosphorus in recent agricultural activities at this site has enhanced the subsurface anthropogenic horizon. Unlike Skaill Control and the other field sites the subsurface anthropogenic horizon at Barnhouse is not significantly phosphorus enhanced relative to the A horizon. The similarity between the total phosphorus concentrations of the A horizon and the underlying anthropogenic horizon supports the interpretation that the anthropogenic horizon has been phosphorus enhanced by recent agricultural practices.

The pH of the A horizons and the anthropogenic horizon ranges from 5.2 to 6.8. Phosphorus is most mobile within the soil profile at around pH 6.5 (Heron 2001) and it is therefore most probable that phosphorus has been leached down the profile from surface horizons and has enhanced the anthropogenic horizon. It is also possible that the anthropogenic horizon has been phosphorus enhanced by the addition of phosphate directly into it at depth. The cultivation of potatoes, which has occurred at this site within the last 15 years, involves the ploughing and addition of N P K fertiliser at a depth of 12 inches (0.3 m) (Mr Tulloch *pers comm*.). The ploughing and fertilising at this depth may explain the field observation of string at a depth of 0.15 m within Profile A and may also support the suggestion that cultural activities associated with Early Modern and recent agricultural activities have been responsible for the eradication of any earlier SSBCR.

Further evidence supporting the phosphorus enhancement of subsurface horizons as a result of recent agricultural practices is present within the glacial C horizon. Figure 63 indicates that within Barnhouse Profile E the glacial C horizon is considerably phosphorus enhanced relative to both the A horizon and the anthropogenic horizon. The mean total phosphorus concentration of the C horizon at Barnhouse is 172 mgP/100g oven dried soil whereas the mean total phosphorus concentration from the glacial moraine C horizon at Finstown Control is 54 mgP/100g oven dried soil. This suggests that the total phosphorus concentration of the glacial C horizon at Barnhouse is significantly enhanced (over three times) that of the glacial moraine at Finstown Control, suggesting that it has been phosphorus enhanced.

7.5 Post-depositional Function

The positive correlation between the ridge and furrow magnetometry anomolies and the profiles containing the anthropogenic horizons provide sufficient evidence to conclude that the anthropogenic horizon has resulted from cultivation which was also responsible for the formation of the ridges and furrows. It is therefore possible to conclude that this anthropogenic horizon was formed and utilised for the purpose of maintaining and enhancing the fertility of arable land. Furthermore, the similarities between the characteristics of the anthropogenic horizon at Barnhouse and the Plaggen horizon within Skaill Control which has a known post-depositional arable function support the conclusion of an arable post-depositional function for the anthropogenic horizon at Barnhouse.

7.6 Conclusion

This research has not identified a SSBCR associated with Barnhouse Neolithic settlement in the landscape surrounding the settlement, and reasons for its absence have been discussed. Anthropogenic horizons were identified only within profiles located upon narrow ridge and furrow features, suggesting that the anthropogenic horizons result from cultivation resulting from specfic cultural practices associated with agricultural intensification from the mid nineteenth century. This anthropogenic horizon therefore represents a SSBCR formed from specific cultural practices associated with Early Modern arable land management. These specific cultural practices involved the amendment of existing soil profiles through the addition of turf and a minor charcoal component and the subsequent cultivation of this anthropogenic horizon within Early Modern arable land management. This SSBCR has been significantly influenced by recent agricultural activities as evidenced by enhanced total phosphorus concentrations at depth and within the underlying C horizon and the observation of string at depth within the profiles.

Chapter 8 - The Bay of Skaill

The WHS Neolithic settlement of Skara Brae is located within the WHS IBZ on the west coast of mainland Orkney, in the Bay of Skaill. The settlement has been extremely well preserved due to the deposition of a significant volume of aeolian deposited calcareous sand, resulting in Skara Brae being described as the best, known surviving prehistoric settlement in Northern Europe (Clarke and Sharples 1985). The excellent preservation of the structural archaeological record has extended to the preservation of anthropogenic sediments intimately associated with the structural archaeological record. These anthropogenic sediments have been analysed and retain a cultural record elucidating resource selections and some specific cultural practices undertaken by Neolithic settlers at Skara Brae (Simpson *et al* 2006). At present there has been no explicit attempt to identify the presence of any SSBCR in the WHS IBZ surrounding Skara Brae, and any contribution such a record may make to the understanding of Skara Brae remains unknown. This chapter, therefore, extends the initial research questions to the IBZ surrounding Skara Brae.

An opportunity to investigate early soil horizons and possibly associated SSBCR in the IBZ became apparent during 2004 when field observations identified dark brown, thin and seemingly organic horizons towards the base of aeolian sand dune system but above the glacial material in the Bay of Skaill 100 m to the west of Skara Brae (NGR HY 231 188). Scheduled monument consent was granted by Historic Scotland to further investigate these dark, organic horizons and field work was conducted during April 2005.

8.1 Field Observations

The profile exposed by coastal erosion consisted mostly of calcareous sand, although there are darker horizons towards the base of the profile, which field observations suggest contain more organic matter (Figure 65). The base of the profile at a depth of 1.70 m was composed of glacial drift as identified at the base of Skaill Control profile and similar to the glacial moraine in Finstown Contol (Chapter 4). The glacial drift was again unsorted consisting of very small (2-6 mm) to very large (20-60 cm) angular stones set within a finer clay-rich matrix. Field observations suggest that the glacial drift horizon rises to the east and is immediately below the base of Skara Brae Neolithic settlement. Above this glacial drift horizon was a 0.1 m thick horizon of calcareous sand which is yellow in colour (10 YR 5/8). Two darker horizons (2.5Y/1) which appear to be organic were located above this yellow sand horizon at a depth within the profile of 1.6 m and were interspersed by more calcareous sand which is pale grey in colour (2.5Y/4) (Figure 65). Field observations of these darker horizons support the presence of humified organic material within the horizons however, upon closer field examination it was apparent that these horizons were dominated by calcareous sand. It is suggested that these weakly defined horizons which are only 0.04 m in thickness are not developed sufficiently to be classified as fossilised A horizons and are best classified as organo-mineral horizons (Duchaufour 1982). Anthropogenic inclusions were not identified in these organo-mineral horizons.

These organo-mineral horizons were located at a depth of 1.5 m depth within the exposed profile. Above these horizons calcareous sand extended up the profile to the surface, a thickness of 1.4 m (Figure 65) The sand varied in colour with patches of grey sand (2.5Y 7/3) within the majority of mustard yellow sand material (2.5Y 5/6). Within this calcareous sand at a depth of *c* 0.3 m from the land surface was a darker horizon *c* 0.03 m in thickness which was similar to those organo-mineral horizons located at depth within the profile, and was again dominated by calcareous sand (Figure 65). Root channels from the land surface containing black amorphous material were identified as penetrating to this depth, and even slightly below the depth of this organo-mineral horizon. Common medium (2-6 cm) and large (6-20 cm) stones were present within this calcareous sand horizon although they show no preferred orientation and distribution appears to be random (Hodgson 1997). The surface landforms were identified as machair coastal type with vegetation dominated by *Festuca rubra, Carex flacca, Agrostis tenuis and Plantago maritima* (Keatings and Dickson 1979). Field observations identified the uppermost vegetation as being slumped over the top of the profile. and no anthropogenic inclusions were identified within any horizon in this profile.

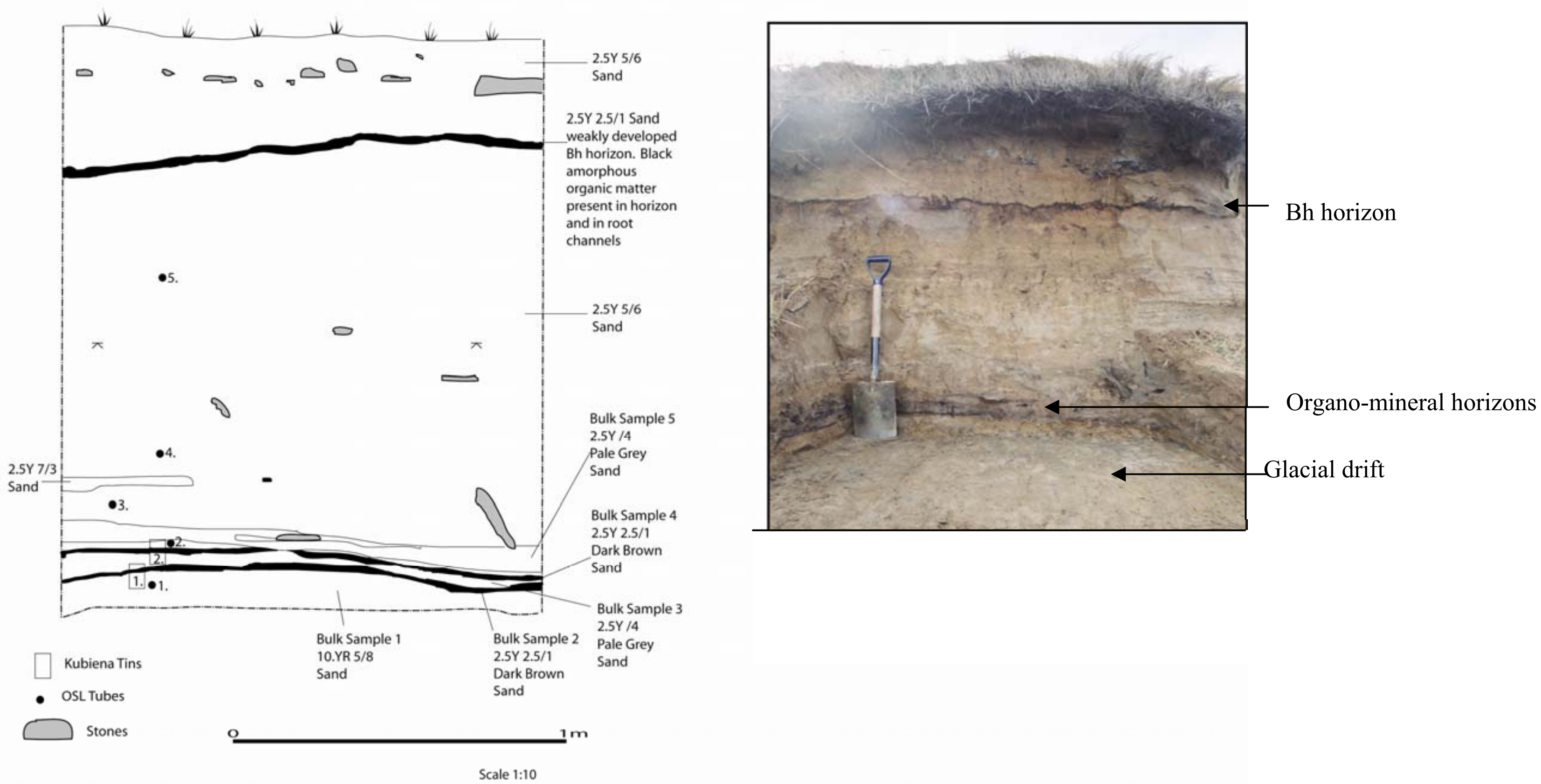


Figure 65 Bay of Skaill coastal section, including OSL sample locations

8.2 *Analytical Results*

Bulk samples were obtained from the two organo-mineral horizons at the base of this profile and from the interspersed sand horizons (Figure 65).

8.2.1 Soil Organic Matter and pH

The pH of all samples is alkaline and ranges from 9-8.6. This pH range reflects the dominance of calcareous sand within the profile. pH from the organo-mineral horizons is slightly lower than the pH for the interspersed sand horizons (Table 37). The soil organic matter content of all sampled horizons in this profile is low ranging from 1.2% to 1.8% (Table 37). No noticeable difference was observed between the soil organic matter content of the organo-mineral horizons and the sand horizons (Table 37).

Table 37 Bay of Skaill pH and loss on ignition results

Sample (Figure 12)	**pH**	**Mean Organic Matter Content (%)**
Bulk Sample 5	9.0	1.2
Bulk Sample 4 (organo-mineral horizon)	8.6	1.5
Bulk Sample 3	9.0	1.2
Bulk Sample 2 (organo-mineral horizon)	8.8	1.6
Bulk Sample 1	8.9	1.8

8.2.2 Thin Section Micromorphology

Two thin sections were analysed from samples taken across the dark organo-mineral horizons at the base of this dune system. These samples confirm the field based observations of the dominance of aeolian calcareous sand, represented by the dominant calcium carbonate and common quartz minerals in thin sections (Table 38, Figure 66). The coarse mineral component of each slide is well sorted with a size range of 250-500 µm interspersed with frequent complex packing voids and a crystallic groundmass B fabric. Siltstones are present within each thin section, although they are very few in abundance. Iron depletion features are present within rims of the siltstones in both thin sections (Table 38, Figure 66).

The dark organo-mineral horizon identified in the field is obvious in thin section and has resulted in the description of two microhorizons (A and B) for Skaill Bay thin section 1. The fine mineral material in microhorizon A is black in PPL and is dark brown and orange in OIL whereas the fine mineral material from microhorizon B is light brown in PPL and is bright orange in OIL. The dark material in microhorizon A is identified as being predominantly amorphous organic material with some enrichment of iron material indicated by its dark orange colour in OIL. Microhorizon B below this dark organic rich horizon is composed of material which is light brown in PPL and is easily distinguished from the darker organic rich microhorizon A. The fine mineral material in microhorizon B is bright orange under OIL and this microhorizon is clearly iron enriched.

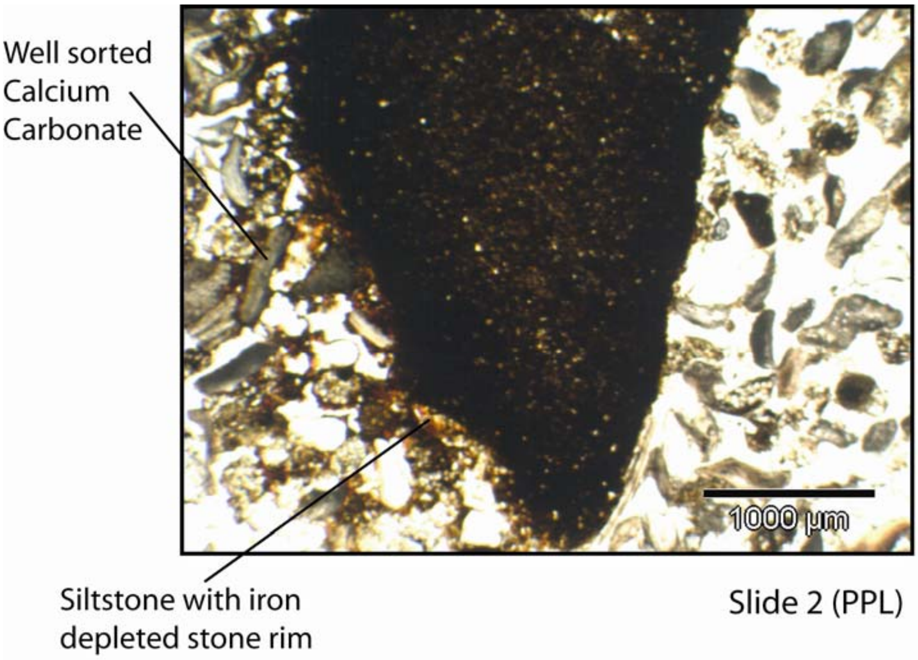
Table 38 Skaill Bay Thin section micromorphology results

Bay of Skaill

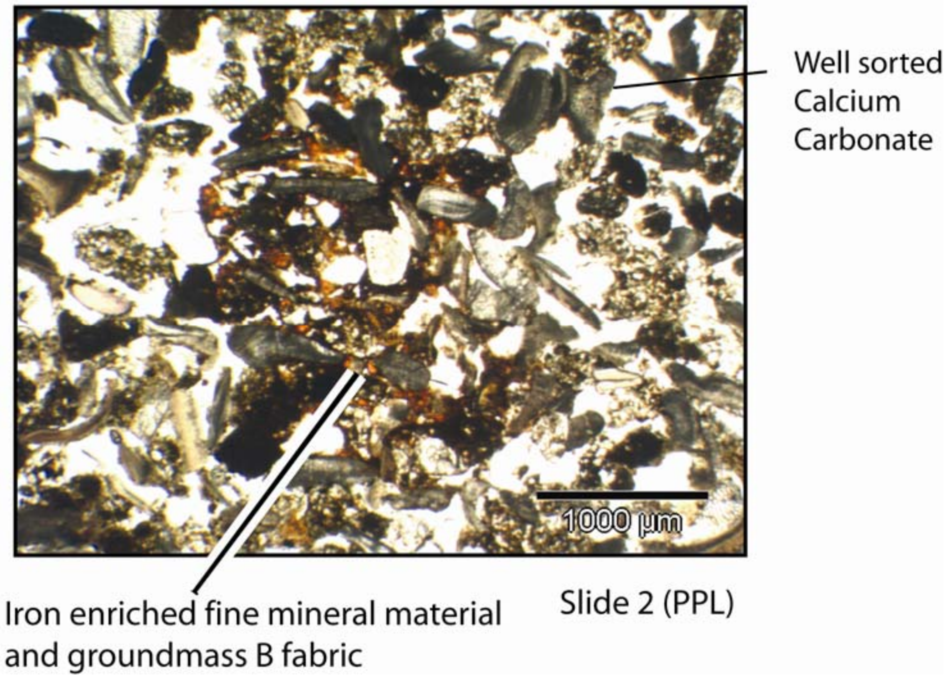
	Coarse mineral material						Fine organic material	Pedofeatures													
Context and Sample	Quartz	Calcium Carbonate	Siltstones (Quartz)	Roundness	Size Range	Fine mineral material	Amorphous Black <500 um	Coatings Frequency	Infillings Frequency	Amorphous & crypto crystalline nodule iron	Ca - Fe phosphates	Excremental (mamillate)	Excremental (spheroidal)	Fe Depletion on Siltstone	Depletion in fine matrix	Void Type	% Void Space	Coarse material arrangement	Degree of sorting	Groundmass b fabric	Related distribution
Skaill Bay 2	•••	••••	•	Blocky Subrounded	250-500 um	Dark Brown and Grey								Yes		Complex Packing	40%	Random	Well Sorted	Crystallic	Porphyric
Skaill Bay 1B	•••	••••	•	Blocky Subrounded	250-500 um	Black with some Grey	••							Yes		Complex Packing	40%	Random	Well Sorted	Crystallic	Porphyric
Skaill Bay 1A	•••	••••	•	Blocky Subrounded	250-500 um	Mostly Light Brown Some Grey								No		Complex Packing	40%	Random	Well Sorted	Crystallic	Porphyric

Frequency class refers to the appropriate area of section (Stoops 2003) t Trace • Very few few ••• Frequent/common •••• Dominant/very dominant.
Frequency class for textural pedofeatures (Bullock et al., 1985) t Trace × Rare xx occasional xxx Many

Light sources: Plane Polarised (ppl)
Cross Polarised (xpl)
Oblique Incident (oil)



Slide 2 (PPL)



Slide 2 (PPL)

Figure 66 Bay of Skaill thin section images (PPL)

8.3 Identification and Formation of a Paleo-Environmental Record

Field observations and analytical results have not identified anthropogenic inclusions characteristic of a SSBCR. This research has therefore not identified a SSBCR within the WHS IBZ surrounding Skara Brae. The weakly formed organo-mineral horizons contain no evidence of influence by any anthropogenic activity and their separation by calcareous aeolian deposited sand is interpreted as resulting from natural environmental processes. Horizons within this profile do however contain evidence of a paleo-environmental record which may contribute to an understanding of settlement activities at Skara Brae. As yet, the pertinent question concerning the organo-mineral horizons is whether these horizons represent fossilised soil horizons (or at least the initiation of soil formation) within an aeolian sand deposited dominated environment, or whether these horizons are the result of other pedogenic processes.

Field observations of organic matter within these horizons have been confirmed through thin section micromorphology, although the dark organic matter is amorphous and not identifiable as plant tissue and loss on ignition results suggest only a very minor soil organic matter content. Thin section micromorphology also confirms the dominance of calcareous, aeolian sand within these organo-mineral horizons containing organic matter and it is apparent that the darker organic matrix is present only within the void spaces surrounding this coarse mineral component. An interesting observation in thin section is the observation of free iron material within the fine soil matrix between and below the organic matter material, and the presence of iron depletion features on siltstones, similar to those observed in podsols with lower pH as at other sites within the WHS IBZ. This was slightly surprising in that the pH in samples from the Bay of Skaill ranged from 8.6-9.0 although it is possible that podsolisation can occur within profiles of a high pH (Duchaufour 1981).

The identification of podsolisation and the presence of iron-enriched material along with siltstones demonstrating iron depletion features within this profile implies either that the dark organo-mineral horizons at the base of this profile formed as a result of the translocation of organic matter and iron by podsolisation from the present land surface, or that the dark organo-mineral horizons are actually composed of organic matter associated with vegetation that formed from podsolisation *in situ* upon the calcareous sand, before being buried and fossilised by later sand-blow events.

The absence of root channels containing amorphous organic material leading from the surface to the depth of these horizons within the profile and the presence of two discrete organo-mineral horizons with iron enrichment immediately below them at the base of this profile suggests that these horizons are not the result of the translocation of organic matter from surface horizons but are actually the product of organic matter which has formed *in situ* from podsolisation. It is suggested that these organo-mineral horizons represent fossilised organic matter which formed on the land surface presumably during a period of weakening aeolian deposition and sand dune stabilisation, and that iron mobilisation evident within thin section below these horizons is the result of movement of iron out of the organic matter by podsolisation. Given the calcareous sand dominated environment this iron movement is unlikely to be from mineral dissolution.

There is however only a very limited amount of organic matter within these organo-mineral horizons (LOI range of 1.2-1.9%) and the continued dominance of calcium carbonate in thin section suggest that the deposition of calcareous sand remained the dominant depositional process during the formation of these organo-mineral horizons. Results in thin section suggest the occurrence of both some *in situ* organic matter formation, as evidenced by humic material, but also that some soil clasts have been blown into this horizon. These soil clasts are of a similar size to the calcareous sand particles deposited by aeolian deposition suggesting a continued influence of aeolian deposition within this landscape. It seems more likely that the majority of organic matter within these organo-mineralhorizons is the result of the deposition of terrestrial silt material by aeolian deposition, suggested for elsewhere within the Bay of Skaill (De La Vega Leinart *et al* 2000), although there is also evidence for the development of some *in situ* organic matter development. Both of these explanations suggest at least partial stabilisation and vegetation colonisation of the aeolian deposited calcareous sand dune systems within the Bay of Skaill, which may have had significant implications for any settlement activities coinciding with stabilisation.

In contrast to the organo-mineral horizons at the base of this profile, the organo-mineral horizon within this profile identified at a depth of 0.3 m from the land surface is interpreted as the result of the translocation of organic matter from the present land surface under the influence of podsolisation. There is clear field evidence of root channels containing amorphous black presumably organic matter penetrating to this depth and even joining this horizon suggesting that this horizon is a Bh horizon (Duchaufour 1982).

8.4 Chronology of the Paleo-Environmental Record

Outlining a detailed environmental history of the Bay of Skaill, with its implications for settlement activities at Skara Brae, remains a research objective highlighted by WHS research agenda (Downes 2005). A broad environmental history has been reconstructed for between *c* 6500 and 3000 BC through multi-faceted research undertaken by De La Vega Leinart *et al* (2000), summarised in Figure 67. De La Vega Leinart *et al* (2000) identified major aolian sand deposition episodes within the Bay of Skaill with sand deposition occurring before 5235-4855 cal BC and a major sand blow occurring soon after 4370-3695 cal BC. This is supported by evidence from excavations at Skara Brae, with sand layers identified immediately prior to the first phase of settlement, which began at the earliest between 3360 and 2920 cal BC (Childe 1931, Clarke 1976b and Ashmore 2005). Sand layers were also identified within the excavated archaeology suggesting that reoccurrent sand blow episodes affected activities during settlement occupation (Clarke 1976a). It is suggested that this exposed profile remains contextually relevant to Skara Brae and that the identification of the period of formation of the organo-mineral horizons and of the periods of aeolian deposition within this profile will potentially contribute to understanding the environmental context of the Skara Brae Neolithic settlement.

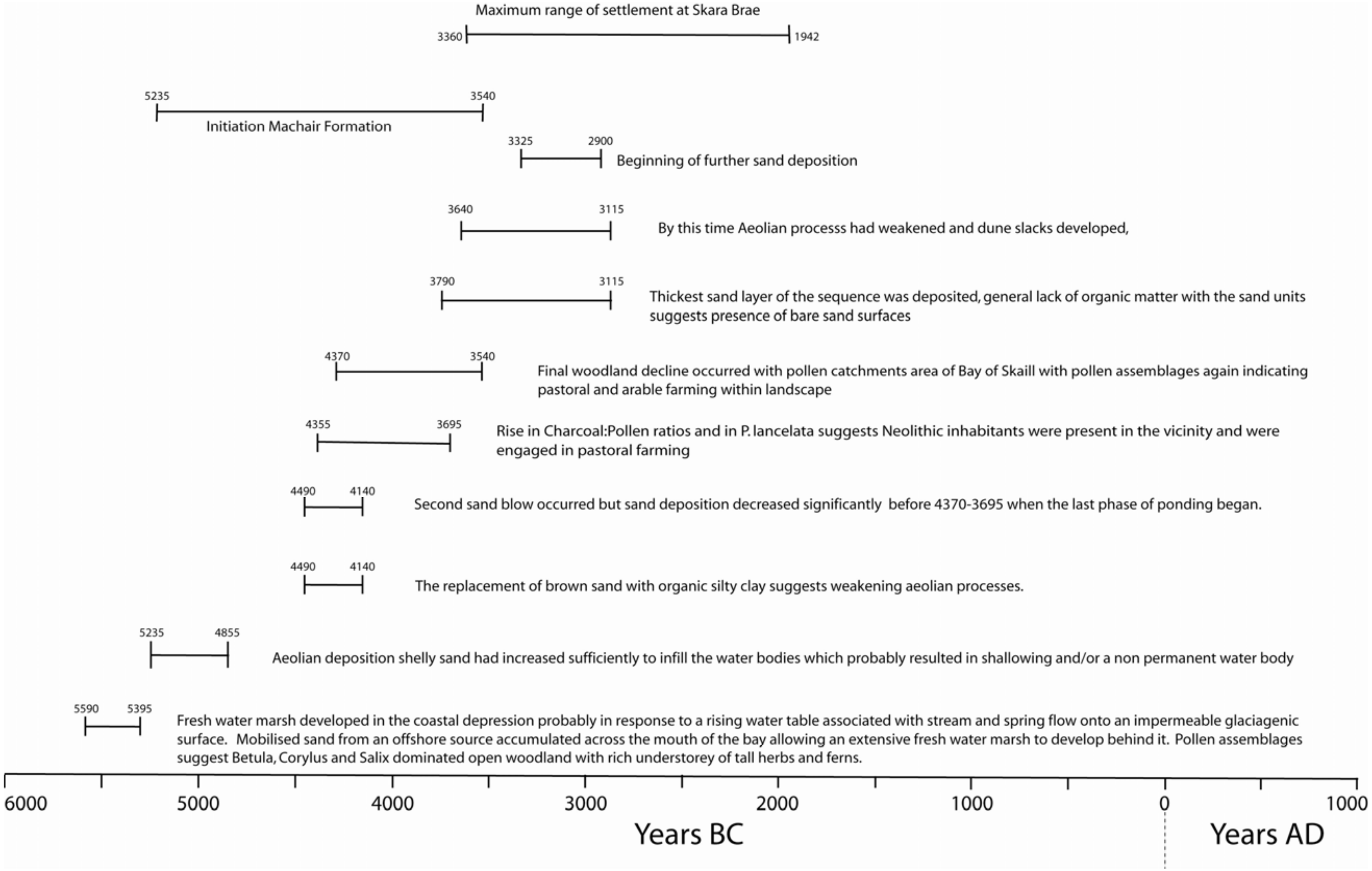


Figure 67 Bay of Skaill, existing paleo-environmental record

Based upon De La Vega Leinart *et al* (2000)

8.5 *Optically Stimulated Luminescence (OSL) Chronology*

Optical luminated luminescence dating (OSL) was chosen as the most appropriate analysis to date the formation of organo-mineral horizons and the subsequent commencement of aeolian sand deposition, as no organic materials suitable for radiocarbon analyses were present within the profile (See section 2.4). OSL dating samples were taken by inserting a series of 20 mm diameter tubes into the exposed stratigraphy. Table 39 provides a summary of dating sample descriptions.

Table 39 Sample descriptions

Context No.	Description of context
Sample 5	Well sorted calcareous sand associated with aeolian deposition Munsell colour 2.5Y 5/6
Sample 4	Well sorted calcareous sand associated with aeolian deposition Munsell colour 2.5Y 5/6
Sample 3	Well sorted calcareous sand associated with aeolian deposition Munsell colour 2.5Y 5/6
Sample 2	Well sorted calcareous sand associated with aeolian deposition Munsell colour 2.5Y 5/1
Sample 1	Well sorted calcareous sand associated with aeolian deposition Munsell colour 10YR 5/8

Optically stimulated luminescence was measured on the quartz mineral content of the dating samples. All of the dating samples were dry sieved to obtain the 90-125 μm and 125-250 μm fractions and the quartz was recovered using standard protocols including removing the carbonates with HCl, feldspars with 40% HF and heavy minerals by density separation using sodium polytungstate solution (Adderley *et al* 2004). Using the quartz obtained from the 125-250 μm fraction 20 discs per sample were dispensed onto stainless steel discs sprayed with Electrolube silicone grease. For the 90-125 μm fraction the number of discs dispensed depended on the amount of sediment that was available (between 4 and 20 discs). Optically stimulated luminescence was measured using a single aliquot regenerative dose protocol, as in Murray and Wintle (2000) and Adderley *et al* (2004).

All OSL dating sample preparation and analysis was performed at the Scottish Universities Environmental Research Centre (SUERC) by Anne Sommerville. The actual and saturated water content of the dating samples had to be calculated as water is able to attenuate some beta and gamma emissions (Grün 2001). It was not possible to assess how the water content has varied in this profile over time and therefore the water content used for the age calculation of each sample is based on a mean of the actual and saturated water contents. This measurement of mean water content is commonly applied to OSL research and is a reasonable measurement to use in the absence of the knowledge of known variance in the water content over time (Sanderson *per comm.*).

For dose rate reconstruction, *in situ* gamma dosimetry was undertaken using a 2"x2" NaI(Ti) detector combined with Ortec's Digidart and lap top computer operating Ortec's Scintivision software. Bulk samples were also taken from around OSL dating samples for dose rate reconstruction. The dose rate was therefore calculated from the *in situ* measurements, along with Thick Source Beta Counting (TSBC, see Sanderson 1988) and High Resolution Gamma Spectrometry (HRGS) measurements also taken on bulk samples at SUERC. Correction factors for the measured water content and modelled cosmic dose rates were also calculated. The measurement of TSBC and HRGS permitted the calculation of both internal and external dose rates. An assessment of the contribution of beta emissions to the dose rate (internal dose) is especially important in potentially low dose rate environments such as the quartz sand dunes present within the Bay of Skaill. In these environments any beta dose rate contribution to the sample may constitute a significant part of the total dose rate (Grün 2001).

8.6 Results

8.6.1 Dose Rate Measurements and Calculations

Table 40 presents dose rates from HRGS and thick source beta counting from bulk samples. There is a relatively large difference between the beta dose rates from the HRGS and the TSBC. The HRGS measurements were conducted with sealed samples which had been stored for radon accumulation, TSBC measurements were undertaken in open geometry and would therefore not be expected to retain full equilibrium radon levels. It is therefore possible that the differences between HRGS and TSBC are partly due to the radon retention conditions of the measurements. Taking account of these considerations the beta dose rate estimates from both methods were combined.

Table 40 Dose rates determined by HRGS and TSBC measurements

Sample	**Dry infinite matrix dose rates by HRGS/mGya^{-1}**			**TSBC/mGya^{-1}**
	Dα (dry)	Dβ (dry)	Dγ (dry)	Dβ (dry)
Sample 5	5.19 ± 0.11	0.68 ± 0.03	0.37 ± 0.01	1.16 ± 0.06
Sample 4	3.35 ± 0.19	0.58 ± 0.04	0.29 ± 0.01	1.39 ± 0.07
Sample 3	3.96 ± 0.08	0.63 ± 0.03	0.32 ± 0.01	1.21 ± 0.08
Sample 2	6.49 ± 0.31	0.80 ± 0.04	0.45 ± 0.02	1.56 ± 0.08
Sample 1	6.20 ± 0.12	0.98 ± 0.04	0.50 ± 0.01	1.93 ± 0.07

Table 41 presents measured and assumed water content for all bulk samples. Water content corrections were applied to the mean beta dose rate calculated from HRGS and TSBC to calculate the effective beta dose rate (Zimmermann 1971). Water content corrections were also applied to the gamma dose rates measured by HRGS (Table 41). Effective gamma dose rates for samples 2 and 3 are based on a mean of HRGS and gamma field measurement as results from each analysis correlated well (Table 41). Effective gamma dose rate for samples 1 and 5 were taken from gamma field measurements, as these were significantly greater than corresponding laboratory results determined by HRGS and were therefore interpreted as more likely to be accurate. The higher field gamma dose rate is probably due to the surrounding sediment having a higher gamma dose rate contributing to the bulk sample. In the absence of any gamma field measurements for sample 4 the effective gamma dose was calculated from only HRGS results (Table 41). The total dose rate for each sample has been calculated from the effective beta and gamma dose rates and an addition of 0.185 mGya^{-1} allowing for the contribution to the dose rate from cosmic radiation (Prescott and Hutton 1994).

Table 41 Annual dose rates

Sample	**Water Content (%)**			**Effective β dose rate /mGya^{-1}**	**Field γ /mGya^{-1}**	**Dγ by HRGS /mGya^{-1}**	**Effective γ dose rate/mGya**	**Total dose rate /mGya^{-1}**
	FW	SW	Assumed					
5	3.3	37.1	20 ± 17	0.69 ± 0.12	0.04±0.04	0.30±0.05	0.35 ±0.04	**1.23 ± 0.13**
4	7.2	36.8	22 ± 14	0.74 ± 0.11		0.23±0.03	0.23 ±0.03	**1.16 ± 0.11**
3	12.3	30.6	21 ± 9	0.70 ± 0.07	0.25±0.06	0.26±0.02	0.26 ±0.03	**1.14 ± 0.08**
2	16.4	24.7	20.5 ± 5	0.89 ± 0.06	0.31±0.07	0.36±0.02	0.34 ±0.03	**1.41 ± 0.07**
1	13.3	39.9	26.5 ± 13	1.00 ± 0.12	0.07±0.03	0.39±0.04	0.68 ±0.03	**1.87 ± 0.13**

8.6.2 Single Aliquot Regenerative OSL results

Data from the single aliquot regenerative dose analyses were analysed using Excel spreadsheets and Jandel Sigmaplot software (Sommerville *pers comm.*). In ideal circumstances the individual disc measurements could be analysed in detail, however, the quartz from these samples did not respond well to the laboratory induced radiation. An attempt was made to calculate estimated doses for each disc but the lack of signal ensured that the analysis was not successful. As a result it was decided to calculate the estimated dose for each dating sample using the sum of the signal counts for each sample. For example, analysis was undertaken on each disc for each sample, for the natural signal and then the natural counts for the 20 discs were added together. In effect the natural signals from the 20 discs become the natural signal from a theoretical disc that contained all the quartz from the 20 discs. This analysis was repeated for the test doses and regenerative doses. Due to the poor sensitivity of all the samples it was decided to measure the prepared 90-125 μm quartz and to add the signals from these measurements to the coarse 125-250 μm measurements. Estimated doses and ages in Table 42 are based on all of the discs dispensed for each sample. Samples are in stratigraphic order.

Linear regression analysis was undertaken on the resultant dose response curves and for four out of the five samples this worked reasonably well (Appendix G). The lowest sample (Sample 1) had the poorest sensitivity of all the samples to irradiation, as evidenced by the natural signal which was too low to measure accurately and by the dose response curve of the laboratory induced irradiated samples. Successful linear regression was not possible for this sample (Appendix G). Linear regressions for Samples 2-5 were within 20-30% of a perfect linear fit and therefore with no other options available it was assumed that a linear relationship also existed between the normalised OSL signal and the irradiated dose (Gy) for Sample 1. A best fit line was applied to the dose response curve and the estimated dose was calculated using a natural signal of 0 (Appendix G). It is acknowledged that this only provides an estimate, and does not represent the true age of deposition of this sample. To allow an age to be determined from regression analysis more discs would need to be measured.

Table 42 Estimated dose, dose rate and age of samples

Sample	ED (Gy)	Dose Rate (mGya-1)	Age (before AD 2000)	Date (BC/AD)
Sample 5	2.03 ± 0.56	1.23 ± 0.13	1690 ± 190	310 ± 190 AD
Sample 4	3.61 ± 1.07	1.16 ± 0.11	3140 ± 370	1140 ± 370 BC
Sample 3	3.45 ± 1.00	1.14 ± 0.08	3020 ± 280	1020 ± 280 BC
Sample 2	4.17 ± 1.17	1.41 ± 0.07	296 ± 225	960 ± 225 BC
Sample 1	5.35 ± 1.54	1.87 ± 0.13	2865 ± 280	865 ± 280 BC

8.7 Discussion

The dates from the 5 samples fall into 2 groups. The lower 4 samples (1-4) all suggest deposition *c* 1000 BC, whilst the upper sample, sample 5, was deposited *c* 300 AD. This sample lies approximately 0.5 m above Sample 4 and its younger date reflects its position within the stratigraphy. Without further sampling it is not possible to determine if the sand between these two samples records 1400 years of deposition or if there has been erosion and recycling of the sand. It is possible that erosion and deposition of the same sediment could produce a section with no obvious erosional contact, but further luminescence profiling analysis would be required to determine this. It is however apparent that there have been processes of erosion and deposition within the Bay of Skaill which have been sufficiently powerful as to significantly alter the geomorphology of the bay including depositing sand blankets on an area up to 2 km inland of the Bay of Skaill covering the tops of the hills of Kier (57 m OD) and Sand Fiolds (42 m OD) (De La Vega Leinart *et al* 2000). It is therefore considered to be most probable that erosion and deposition has occurred between the dates of 1000 BC and 300 AD at this location and has influenced this profile.

The lower 4 samples all suggest deposition around 1000 BC. This suggests that partial dune stabilisation and the formation of these organo-mineral horizons occurred around 1000 BC which is surprising given their stratigraphic location within the profile almost immediately above the glacial drift C horizon. The glacial drift was deposited at the end of the last glaciation *c* 10,000 BC (Roe 1976) and it was expected that any OSL dates from immediately above this glacial drift would be more likely to reflect such an early date. This later date suggests that the glacial drift has been subsequently exposed and eroded before the later deposition of aeolian sand upon the exposed surface of the glacial drift. It is immediately apparent that an OSL age of around 1000 BC towards the base of this profile suggests deposition of aeolian sand at this point at a significantly later time than that associated with the occupation of Skara Brae Neolithic village which is estimated to have begun at the earliest 3360 and at latest at 2920 cal BC (Ashmore 2005). Results suggest that the inferred sand dune stabilisation and organic matter formation associated with these organo-mineral horizons occurred significantly later than the Neolithic, around the Late Bronze Age, early Iron Age. This supports a conclusion that these organo-mineral horizons do not represent a land surface contemporaneous with the occupation of Skara Brae.

The estimated doses of these samples are generally in stratigraphic order (Table 42) but the lowest two samples (Samples 1 and 2) have higher dose rates due to the proximity of these samples to both organo-mineral horizons and the underlying glacial drift. This ensures that despite the larger estimated doses the ages are in fact quite similar. The dates do suggest that there was a considerable amount of sand deposition around 1000 BC, but greater precision is required to identify any individual deflation or aeolian depositional events. The lack of precision on these OSL dates limits their usefulness to an environmental reconstruction and prevents a discussion of the impact of individual sand blow episodes upon archaeological sites within the Bay of Skaill between *c* 1000 BC and *c* 300 AD.

The lack of precision on these OSL dates is a product of the properties of the quartz mineral material at this site which demonstrates a very low sensitivity to irradiation. The properties and sensitivity of minerals to irradiation is dependant in part upon mineral genesis and the thermal history of the mineral material along with any associated depositional processes (Rink 2000). The original mineral genesis is unknown for this quartz but it is likely that it has been transported with calcareous sand by aeolian deposition from offshore sources (De La Vega Leinart *et al* 2000). These sources of sediment and mechanisms of transport dominate the beach and dune sand of the Northern Isles. The lack of sensitivity of quartz material to irradiation at this site is consistent with other results from Orkney obtained by Sommerville *et al* (2001). It is suggested that the precision of the results obtained in this research could only be increased by the analysis of a much greater number of samples.

8.8 Conclusion

Previous research from the north side of the Bay of Skaill suggests that the aeolian depositon of calcareous sand within the Bay of Skaill began *c* 5000 BC and has continued to the present day, along with Machair formation (De La Vega Leinart *et al* 2000, Figure 68). The results presented in this chapter do not extend back to *c* 5000 BC but they do identify the dominance of calcareous sand deposition from at least *c* 1000 BC, thereby supporting the later part of the existing paleo-environmental record for the Bay of Skaill (Figure 67 and Figure 68). The longevity of the dominance of aeolian deposition of calcareous sand in the Bay of Skail throughout history and pre-history suggests that the activities of any past people groups in the Bay of Skaill, including settlement activities must be interpreted under the backdrop of an environment dominated by significant calcareous sand deposition. Successful settlement sustenance within such a hostile environment must have been problematic and it is not immediately apparent why a Neolithic community would choose to establish the settlement of Skara Brae in this location, as opposed to a more environmentally stable, inland location as at Barnhouse or the Ness of Brodgar.

The structural archaeological record at Skara Brae suggests a continual building and re-building of the settlement, with at least two main phases of construction, which began at the earliest between *c* 3360 and 2920 cal BC (Shepherd 2000 and Ashmore 2005). Sand layers have been identified immediately below the phase 1 settlement which suggests that sand-blow was affecting the site prior to phase 1 construction (Childe 1931 and Clarke 1976b). This implies that the construction of phase 1 of Skara Brae occurred at a site already affected by the deposition of aeolian sand. It is however also feasible that initial settlement within the Bay of Skaill pre-dates current phase 1 construction and therefore that initial settlement was established in a more stable environment, before the commencement of major sand blow episodes *c* 3000

BC (De La Vega Leinart *et al* 2000, Figure 68). Socially-constructed association for example with people, place and identity may therefore have resulted in the continued locating and persistence of settlement at Skara Brae, in a hostile environment, dominated by calcareous sand deposition. The continuation, or indeed initiation of settlement at Skara Brae presumably found that benefits to settlement in this location outweighed any negative effects associated with calcareous sand deposition. Benefits may have been socially-constructed but may also have included geographic factors such as the proximity to marine resources. No matter what these benefits were, they must have been sufficient for the settlers at Skara Brae to invest considerable effort into constructing a settlement in an environment dominated by aeolian sand deposition.

The confirmation that phase 1 and phase 2 construction of Skara Brae occurred in an environment already dominated by calcareous sand deposition may have a significant contribution to the discussion of site abandonment at Skara Brae. It is evident that chronic deposition occurred before and during occupation (Childe 1931 and Clarke 1976b) but this does not preclude the possibility of catastrophic depositional events affecting settlement at Skara Brae. The lack of precision on OSL dates within Bay of Skaill makes the accurate dating of individual sand blow episodes difficult and it is therefore difficult to distinguish chronic deposition from any catastrophic depositional events and to evaluate any individual depositional events upon settlement activity at Skara Brae.

It is considered likely that when settling in this hostile environment already dominated by aeolian deposition that the settlers at Skara Brae would already have existing, or would devise and develop new strategies in order to maintain settlement activity. This is becoming apparent in the strategies used in the construction of Skara Brae (Simpson *et al* 2006). It is anticipated that these strategies would also extend to land management strategies around the settlement, including those required for the presumed cultivation of arable crops in this hostile environment (Clarke and Sharples 1985). There is evidence for the development of deliberate land management strategies to sustain prehistoric settlement in areas dominated by calcareous sand deposition from elsewhere within the Northern Isles of Scotland. In particular the evidence of deliberate manuring strategies to maintain arable land fertility at Tofts Ness (Sanday, Simpson and Dockrill 1998) within the Late Neolithic and Early Bronze Age supports the suggestion that deliberate land management strategies were developed by Neolithic settlers at Skara Brae to sustain settlement within the Bay of Skaill. The absence of identification of land management strategies in off site SSBCR around Skara Brae is therefore problematic, particulary when considering that the hostile environment would nessecitate the development of such strategies for the observed long term site sustenance. It may be that no such SSBCR ever existed but it seems more probable that any SSBCR around Skara Brae has been removed by deflation events before the commencement of the significant deposition of aeolian sand upon the glacial drift *c* 1000 BC.

Results from the palaeo-environmental record create an image of the Late Neolithic settlement of Skara Brae isolated and seemingly stratigraphically above significantly younger calcareous sand deposits which were potentially deposited 2000 years after the commencement of settlement construction (Figure 68). This implies that deflation events and depositional events have occurred at least since the abandonment of Skara Brae and it is perplexing to consider why Skara Brae should remain preserved within an environment clearly influenced by major deflation events. The construction of Skara Brae with double walling packed with cultural sediments (Simpson *et al* 2006) is a testimony to the hostile environment in which Skara Brae was constructed, with thick insulated walls designed to protect settlers from the environment. Indeed, construction as a response to environmental conditions may be sufficient to explain the observed differences between subterranean construction at Skara Brae and sites constructed as free standing structures encased with turf as at Barnhouse (Jones and Richards 2005). Certainly Skara Brae was built to withstand a hostile environment and was therefore inadvertently built to last. It is entirely possible that the use of soil resources and domestic waste resources in construction not only aided settlement sustenance but that this SSBCR identified has also contributed to the preservation of the entire settlement within this hostile environment.

It does appear that *c* 1000 BC there was sufficient partial stabilisation within the Bay of Skaill, probably as a result of weakening aeolian deposition of calcareous sand, for weakly developed organo-mineral horizons to begin to form. Wider field observations within the Bay of Skaill suggest that any stabilisation was not just localised at this profile but that episodes of this nature occurred within the entire Bay of Skaill. It is possible to link some of these organo-mineral horizons stratigraphically with the organo-mineral horizons within this profile estimated at forming *c* 1000 BC, but the scale and size of the Bay of Skaill and the likelihood of multiple localised stabilisation and organic matter formation prevents secure stratigraphic interpretation across the bay. It is unlikely that these partial stabilistaion episodes were sufficient to make a significant difference to any settlement activities within this environment dominated by calcareous sand deposition.

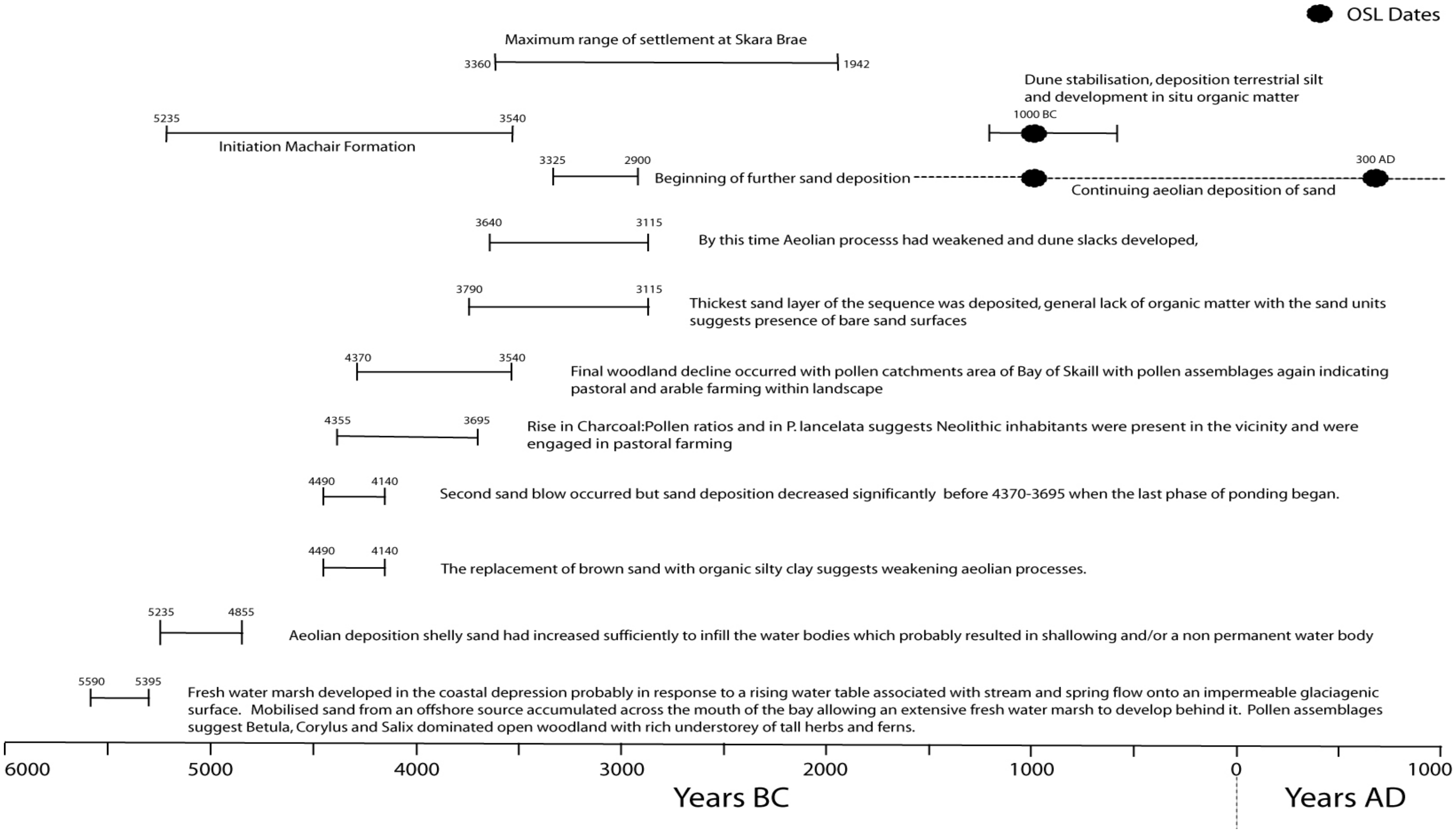


Figure 68 Environmental change within the Bay of Skaill

Based upon De La Vega Leinart et al (2000)

Chapter 9 - SSBCR and The Heart of Neolithic Orkney World Heritage Site

9.1 Introduction

Systematic geoarchaeological research across the Brodgar WHS IBZ has identified soils based cultural records (SSBCR) whose formation and post-depositional functions have been attributed to cultural groups from the Late Neolithic through to the present day. No such SSBCR has been identified within the World Heritage Site (WHS) inner buffer zone (IBZ) at Skaill Bay, however a palaeo-environmental record has been identified, the interpretation of which has furthered the understanding of the environmental context of Skara Brae.

Initial research questions (page 27) have been addressed at individual field sites in The Heart of Neolithic Orkney WHS IBZ. This thesis has been structured according to field sites, the preceding chapters can therefore be interpreted as discrete bodies of research; each identifying and interpreting the SSBCR at different sites within the WHS IBZ. It is not the intention that this concluding chapter should merely reiterate previous interpretations and conclusions concerning SSBCR at individual field sites within the IBZ. This chapter evaluates the overall conclusions of this research to the overriding research theme: How soils and sediments should be considered and assessed as contributing to the overall cultural value preserved in and around WHS.

9.2 The Heart of Neolithic Orkney

The major contribution of this research to the understanding of the Orcadian Neolithic, and the cultural record preserved within the WHS, is the identification and interpretation of the SSBCR deposited as a result of Late Neolithic settlement activity (*c*3000 BC – *c*2800) at the Ness of Brodgar (Chapter 5). The identification and interpretation of this Late Neolithic settlement and SSBCR amidst the WHS monuments is of pivotal importance to the discussion of the Orcadian Neolithic cultural identity. It supports the conclusions of research from Barnhouse Neolithic Settlement (Richards 2005) by providing compelling evidence for an intimate association between settlement and activities involved with the contemporary WHS monument construction and utilisation. The identification of settlement at the Ness of Brodgar, in close proximity and with contemporary occupation to Barnhouse Neolithic Settlement, also suggests that community interactions occurred between settlements within this landscape dominated by the WHS monuments. It has not been possible to measure the strength, importance or value of these Late Neolithic community interactions to an interpretation of the wider Neolithic society but it must at least be considered that it was these interactions which formed the core of Neolithic activities within the landscape now designated as the WHS IBZ. Certainly it can be concluded that it is most probable that some of the inhabitants from the Ness of Brodgar were involved along with inhabitants of Barnhouse Neolithic Settlement in building and frequenting the Stones of Stenness henge monument and the passage grave of Maeshowe. It seems likely that the subsequent generations from both of these settlement sites lived under the influences and association of these monuments.

The proximity and contemporary occupation of settlements at the Ness of Brodgar and Barnhouse, along with the construction of Maeshowe and the Stones of Stenness, suggest intimate interaction between community groups and further contributes to an interpretation of Orcadian Neolithic cultural identity. These interactions presumably extended beyond interactions involved in monument construction and utilisation and it is anticipated that comparison of the excavation results from these settlement sites will contribute further to the understanding of Orcadian Neolithic communities and the wider society. Differences do exist between the architecture and spatial organisation of these two settlements (Card 2004, Card and Cluett 2005, Richards 2005). This suggests either that these contemporary settlements performed different functions within the landscape, or, that the diffences in architecture and spatial organisation reflect different expressions of discete, contemporary community groups who still interacted in the construction of the WHS monuments. At present, excavations at the Ness of Brodgar along with post excavation analyses remain ongoing and the full implications of this site to the understanding of WHS and the wider Late Neolithic must await this further research. However, the identification of these settlements along with the implied community interactions is sufficient to suggest that any interpretation of a segregated society within the Orcadian Neolithic as advanced by Childe (1931), or of ritual landcapes and societal evolution from a segmented society to a chiefdom with associated ritual monuments (Renfrew 1979) is no longer tenable in application to the WHS and IBZ.

The completed geoarchaeological analysis presented within this thesis suggests the probability of Late Neolithic community interactions within the landscape surrounding the WHS monuments, now designated as the IBZ. The significant volume of anthropogenic sediment at the Ness of Brodgar is the result of the deposition of a large quantity of turf material which was stripped from a wet substrate, burnt within domestic settlement activity, mixed with various aspects of household waste before then being deposited in a geographically discrete area. The pre-depositional function of this burnt turf in domestic activities, for heating and lighting is not in doubt and is consistent with results from Barnhouse Neolithic Settlement where turf heathland was also utilised as the dominant fuel resource. An adequate fuel supply is of course a prerequisite for sustainable settlement and the large volume of this anthropogenic sediment at the Ness of Brodgar raises further questions concerning community interactions and the utilisation of the fuel resource within this Late Neolithic landscape. For example, from where was this fuel obtained within the landscape? Did the likely association between communities involved in WHS monument construction extend to a communal resource utilisation and management or did these communities operate independent control over geographically separated resources?

Despite the proximity of settlement at Barnhouse and the Ness of Brodgar, and the presumed community interactions involved in WHS monument construction, it is possible that these settlement sites remained geographically separated by the confluence of the Lochs of Stenness and Harray. A geographic separation may have acted to socially segregate these discrete Late Neolithic settlement sites within this landscape and it does seem probable that the community at each settlement was responsible for their own domestic resource selection and management. This is perhaps evidenced by the deliberate incorporation of the local lacustrine silt resource into the construction of Barnhouse Neolithic Settlement (French 2005) and its absence from construction upon the Ness of Brodgar (although excavation is ongoing) and further by the evidence of arable agriculture at both sites (French 2005, Chapter 5). This conclusion suggests that discrete, separate expressions of cultural identity were expressed through settlement activities at these two settlement sites, but that some aspects of cultural identity were shared.

The interpretation of a post-depositional arable function from the anthropogenic sediment at the Ness of Brodgar remains ambiguous. It is worth re-emphasising here that the contribution of the anthropogenic sediment to the overall cultural value preserved within the WHS and associated IBZ is not necessarily dependant upon the identification of a post-depositional function. The identification of this large volume of anthropogenic sediment resulting from Late Neolithic activity itself contributes significantly to the understanding of Late Neolithic activities and therefore furthers the interpretation of the WHS. Indeed the ambiguity which remains associated with its post-depositional function may be a greater cause for the future conservation of this anthropogenic sediment within the Historic Scotland WHS and IBZ management plan (Historic Scotland 2001). This anthropogenic sediment provides present evidence of Late Neolithic cultural activities but it may also provide future, unique evidence of Late Neolithic cultural activities which are only likely to be ascertained after large scale excavation can properly reveal the complex relationship between the structural archaeology and the anthropogenic sediment and confirm its post-depositional function.

9.3 Further Conservation of this Cultural Record

The further preservation of the Late Neolithic cultural record as a common heritage for all mankind is at the core of the designation of The Heart of Neolithic Orkney as a WHS and the designation of its inner buffer zones (UNESCO World Heritage Centre 2006, Foster and Linge 2002). A major concern within the IBZ, is the extent to which present day agricultural land use and management are influencing the retention of these SSBCR (Historic Scotland 2001). The identification of SSBCR at sites within the IBZ which have been subjected to different recent land management allows some broad conclusions to be reached concerning the further management of the SSBCR within the IBZ.

9.3.1 Cultivation

As with the structural archaeological record, ploughing probably poses the greatest threat to the retention of SSBCR within the IBZ (Richards 2005). The influence of ploughing at a depth of *c* 12 inches (*c* 0.30 m, Mr Tullach *pers comm.*) was observed in profiles at Barnhouse where modern string was observed directly above C horizon (Figure 54), and where an interpretation of the possible eradication of any SSBCR by modern, recent agricultural activities is consistent with the interpretation of recent plough damage to structural archaeology (Richards 2005). Ploughing is also likely to have affected the Late Neolithic SSBCR at the Ness of Brodgar, where the anthropogenic sediment was identified at 0.2 m below the present land surface but where recent ploughing has occurred at a depth of 5-6 inches (*c*0.13-0.15 m, Mr Slater *pers comm.*). The confirmation of settlement at this site resulted from the ploughing up of structural archaeology (Ballin Smith and Petersen 2003) and plough damage has obviously affected structural archaeology as evidenced by plough marks upon buried structural archaeology (Card 2005). The intimate association between the structural archaeology and the SSBCR at this site (Chapter 5) suggests that recent ploughing will have adversely affected the retention of the SSBCR.

Ploughing can adversely affect the retention of any SSBCR and should be considered as a major threat to their further conservation. The impact of ploughing upon SSBCR is of course dependant upon both their depth and the depth of ploughing. Evidence from the IBZ suggests that both structural archaeology and SSBCR are located immediately beneath present A horizons in close proximity to the present land surface. This research clearly identifies that any tillage to a depth of greater than 5 inches (*c*0.13 m) within the IBZ is likely to have an adverse affect upon the retention of SSBCR.

9.3.2 Fertilising and Manuring

Interviews with current land owners indicate that recent fertilising strategies vary within the IBZ and include both inorganic fertilisers and manures (Appendix F). Application rates vary geographically between sites and also vary temporally at each site in response to changing land management strategies. Total phosphorus concentration within the A horizons of profiles at each site is likely to be the result of recent agricultural practices and the comparison of total phosphorus results from A horizons with the total phosphorus results of the underlying SSBCR does provide some indication of the affects of recent manuring and fertilising upon the SSBCR. Interpretation however is difficult. Total phosphorus concentration is a key indicator of anthropogenic influence in SSBCR and it is therefore difficult to distinguish between phosphorus enhancement associated with the formation of a SSBCR and phosphorus enhancement resulting from the translocation of phosphorus from more recent agricultural practices.

Interviews with landowners suggest that recent pastoral land use at Wasbister has involved the surface application of fertiliser and that cultivation associated with recent barley crops on the Ness of Brodgar involving the application of fertiliser at a depth of 2 inches (*c*0.05 m, Mr Bain *pers comm.,* Mr Slater *pers comm.*). A horizons from profiles at the Ness of Brodgar and from Wasbister contain a lower concentration of total phosphorus than the underlying SSBCR suggesting that the phosphorus applied at or near to the land surface within these recent land uses has not been translocated down the profile to enhance the SSBCR. This suggests that it is unlikely that the surface application of manures and fertilisers at current application rates are likely to adversely influence existing SSBCR within the IBZ.

At Barnhouse there is clear evidence of phosphorus enhancement down the profile. Recent agricultural practices at Barnhouse of cultivation for potatoes has involved ploughing at a depth of 12 inches (*c*0.3 m, Mr Tullach *pers comm.*) and the incorporation of inorganic fertiliser to the plough depth. It is concluded that the phosphorus enhancement evident within subsurface horizons at Barnhouse has resulted from the application of inorganic fertiliser and ploughing to depth. These cultivation practices clearly adversely affect the SSBCR.

9.3.3 Pastoral

The recent pastoral land use at Wasbister along with associated land management strategies involving the yearly surface application of inorganic fertiliser does not appear to have influenced the underlying SSBCR. It is suggested that pastoral land use is the most appropriate land use for the furthering conservation of SSBCR within The Heart of Neolithic Orkney WHS IBZ.

9.4 A Contribution to World Heritage

The designation of World Heritage Sites under United Nations legislation remains the principal international and formally recognised strategy allowing the conservation of international sites of cultural value, such as the Heart of Neolithic Orkney WHS. Research within this thesis has furthered the understanding of The Heart of Neolithic Orkney WHS but also has significant implications for identifying and interpreting cultural records associated with other WHS, and indeed other designated archaeological sites. This research clearly demonstrates that off site cultural records (including SSBCR) exist around WHS and that the identification and interpretation of these cultural records is important to furthering the understanding of the WHS. It also demonstrates that the cultural record associated with WHS extends into the landscape surrounding the WHS, and that this cultural record may consist of more than just a structural record, including for example SSBCR.

This research as part of the multifaceted WHS research agenda has demonstrated that the designation of IBZ can provide a useful focus for contextualising a WHS within associated cultural records. It is concluded that IBZ be designated around WHS not only to protect and conserve the WHS but also to provide a focus and an impetus for research into broader geographic and temporal cultural records which contribute to the understanding of the WHS. The identification of more recent SSBCR within The Heart of Neolithic Orkney WHS IBZ suggests that a fuller understanding of WHS can be obtained by considering changes in temporal cultural activities within the landscape. The Heart of Neolithic Orkney WHS IBZ can be considered a palimpsest of cultural records (including SSBCR) resulting from the activities of cultural groups from the Late Neolithic through to the present day. A fuller understanding of WHS must therefore consider both how cultural records associated with WHS are a result of differential preservation in the landscape, and may have been eradicated or changed by the actions of later cultural groups. It must also consider how the activities of later people groups may have been influenced and even determined by the cultural activities associated with WHS.

These conclusions are clearly demonstrated from this research in The Heart of Neolithic Orkney WHS IBZ and the significance of the results presented suggests that specific consideration be given to identifying and interpreting SSBCR within other designated WHS and associated IBZ. To obtain a fuller understanding of existing WHS, and to correctly designate WHS in the future, the landscape context of WHS must be considered. Sites designated as WHS are not the result of isolated, discrete cultural activities, but are the result of cultural activities occurring within a landscape. A fuller understanding of any WHS designated for its cultural value is likely to be obtained only when it is interpreted within a landscape context with an appreciation that the cultural record preserved within the site extends outwith superimposed, modern WHS boundaries.

Difficulties exist in incorporating the ideas and conclusions of this research to influencing the designation and management of WHS by UNESCO. The management of individual WHS remains the responsibility of individual countries and it is therefore difficult to disseminate the conclusions of this thesis efficiently into the planning frameworks of WHS owned and managed by other countries. It is however hoped that the conclusions of this research will be incorporated into policy concerned with the management of WHS and other designated sites within the UK. It is anticipated that the incorporation of these ideas and conclusions into existing WHS management and future WHS designation BY UNESCO will have greater efficacy through publication in peer reviewed journals.

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Appendices

Appendix A, WHS Selection Criteria **http://whc.unesco.org/en/criteria/**

To be included on the World Heritage List, sites must be of outstanding universal value and meet at least one out of ten selection criteria. These criteria are explained in the Operational Guidelines for the Implementation of the World Heritage Convention which, besides the text of the Convention, is the main working tool on World Heritage. The criteria are regularly revised by the Committee to reflect the evolution of the World Heritage concept itself.

Until the end of 2004, World Heritage sites were selected on the basis of six cultural and four natural criteria. With the adoption of the revised Operational Guidelines for the Implementation of the World Heritage Convention, only one set of ten criteria exists.

Selection criteria:

to represent a masterpiece of human creative genius;
to exhibit an important interchange of human values, over a span of time or within a cultural area of the world, on developments in architecture or technology, monumental arts, town-planning or landscape design;
to bear a unique or at least exceptional testimony to a cultural tradition or to a civilization which is living or which has disappeared;
to be an outstanding example of a type of building, architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history;
to be an outstanding example of a traditional human settlement, land-use, or sea-use which is representative of a culture (or cultures), or human interaction with the environment especially when it has become vulnerable under the impact of irreversible change;
to be directly or tangibly associated with events or living traditions, with ideas, or with beliefs, with artistic and literary works of outstanding universal significance. (The Committee considers that this criterion should preferably be used in conjunction with other criteria);
to contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance;
to be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features;

to be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals;
to contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation.

The protection, management, authenticity and integrity of properties are also important considerations. Since 1992 significant interactions between people and the natural environment have been recognized as cultural landscapes.

9.5 *Appendix B, Soil Organic Matter and pH Results*

Sample	**SOM % by LOI**	**Replicate**	**Replicate**		**pH**	**Rep 1**	**Rep 2**
Ness of Brodgar							
NOB A 088	13.33				5.8		
NOB A 091	7.68				6		
NOB E 047	3.93	4.26	3.86		6.3	6.3	6.2
NOB E 046	3.84	3.51	3.79		6.3	6.3	6.3
NOB E 045	3.99	3.86	3.84		6.1	6.1	6.2
NOB E 023	4.94	4.98	4.93		6.2	6.2	6.3
NOB E 004	5.81	5.96	5.80		6.4	6.4	6.3
NOB E 003	7.31	7.51	7.06		6.4	6.4	6.4
NOB E 002	10.43	10.4	7.51		6.3	6.3	6.2
NOB E 001	13.35	13.2	13.43		6.4	6.4	6.4
5M E E	5.81				6.1	6.1	6.1
5 M W E	8.05				6.4	6.3	6.4
NOB G 015	3.16				6.1		
NOB G 013	7.33				6.2		
NOB G 012	5.92				6.2		
NOB G 011	2.07				6.6		
NOB G 010	11.65				5.9		
NOB F 044	4.78	4.58	5.26		6.0		
NOB F 030	2.63	3.62	3.48		5.8		
NOB F 026	4.36	4.56	4.79		6.2		
NOB F 016	7.10	7.65	7.85		5.8		
NOB F 007	9.07	9.35	9.63		6.2		
NOB F 006	11.80	11.69	11.52		5.7		
NOB F 005	13.51	13.23	12.92		6.1		
NOB C 086	4.36				6.3		
NOB C 075	4.00				6.1		
NOB C 073	7.25				5.8		
NOB C 072	9.46				5.8		
NOB C 071	11.21				5.8		

Sample	SOM % by LOI	Replicate	Replicate		pH	Rep 1	Rep 2
Finstown Control							
FT 1	1.22	1.1	1.25		5.8	5.8	5.8
FT 2	1.41	1.43	1.41		5.4	5.4	5.4
FT 4	1.33	1.36	1.53		4.7	4.6	4.6
FT 5	3.25	3.52	2.98		4.4	4.4	4.5
FT 6	9.08	9.23	8.51		4.2	4.2	4.2
FT 7	12.69	11.38	11.56		4.3	4.3	4.3
Wasbister							
WAS C1	9.78				5.0		
C2	8.07				5.2		
C3	6.07				5.3		
C4	3.94				5.3		
C5	3.08				5.4		
C6	3.70				5.3		
WAS H1	10.31						
H2	17.16						
H3	4.15						
H4	3.40						
WAS E1	15.48	14.3	14.96		4.4	4.4	4.3
E2	15.92	16.65	16.02		4.5	4.5	4.4
E3	4.52	4.69	4.82		4.4	4.4	4.4
E4	3.83	3.9	3.84		4.2	4.1	4.2
WAS F1	10.68	10.32	11.06		4.9		
F2	9.66	10.75	9.83		5.2		
F3	5.57	5.26	5.92		5.3		
F4	3.42	3.25	3.56		5.2		
Barnhouse							
BH A1	8.71	7.69	8.92		6.1		
A2	7.08	7.23	6.83		6.4		
A3	2.74	2.09	2.64		6.8		
BH C1	9.42				5.2		
C2	7.71				5.2		
C3	5.37				5.1		
C4	4.80				5.1		
C5	3.73				5.1		

Sample	SOM % by LOI	Replicate	Replicate		pH	Rep 1	Rep 2
BH D1	11.51				5.2	5.2	5.1
D2	9.85				5.4	5.4	5.4
D3	8.76				5.3	5.3	5.4
D4	6.23				4.8	4.8	4.6
D5	3.13				4.8	4.7	4.7
BH F1	11.56				6.4		
F2	9.27				6.8		
F3	8.02				6.6		
F4	6.37				6.4		
F5	4.34				6.1		
BH E1	11.51				6.2		
E2	9.66				6.3		
E3	9.60				5.5		
E4	5.57				6.2		
E5							
Skaill Control							
Ap Horizon	5.18	6.23	6.59		7.4	7.4	7.3
Horizon 2a	3.52	4.6	3.9		7.8	7.8	7.8
Horizon 2b	3.32	3.46	3.76		7.4	7.4	7.5
Horizon 3	5.41	6.90	6.58		6.6	6.7	6.6
Horizon 4	14.97	16.3	14.67		7.4	7.4	7.4
Horizon 5	2.75	3.87	4.89		7.2	7.2	7.2
Horizon 6	2.41	2.36	3.26		7.8	7.8	7.7
C Horizon	3.94	5.48	4.67		7.4	7.3	7.3
Skaill Bay							
Skail Bay 5	1.23	1.26	1.19		7.8		
Skail Bay 4	1.53	1.46	1.54		8		
Skail Bay 3	1.16	1.10	1.19		7.8		
Skail Bay 2	1.56	1.60	1.54		7.7		
Skail Bay 1	1.93	1.98	1.63		8.9		

9.6 *Appendix C, Particle Size Distribution Results*

Particle Size Classes µm							
	< 2	**2-6**	**6-20**	**20-63**	**63-212**	**212-600**	**600-2000**
Finstown							
Sample 7	8.84	13.20	26.20	38.26	11.30	0.50	0.50
Sample 6	11.92	21.68	32.03	29.02	5.35	0.50	0.50
Sample 5	7.24	11.70	19.07	23.61	13.72	10.34	14.32
Sample 4	3.86	5.28	7.94	15.22	11.08	13.11	43.51
Sample 3	3.41	5.01	5.91	10.70	11.40	17.21	46.36
Sample 2	4.73	6.63	7.85	10.95	9.09	12.85	47.90
Sample 1	4.78	7.00	8.82	9.90	10.57	17.53	41.40
Skaill Control							
2a	2.93	6.19	11.74	15.83	20.19	37.18	5.94
2b	2.46	4.70	6.60	9.95	10.69	56.40	9.20
3	6.62	11.84	19.49	26.09	25.67	10.23	0.06
4	5.47	8.40	12.66	25.73	22.69	16.87	8.18
C Horizon	4.78	7.00	8.82	9.90	10.57	17.53	41.40
Ness of Brodgar							
A 088	11.32	18.35	21.00	18.45	15.77	12.67	2.44
A 091	15.09	20.63	17.64	16.82	14.85	9.18	5.79
E 001	13.26	17.16	21.78	27.34	12.25	6.73	1.48
E 002	14.16	19.99	21.14	29.80	14.72	0.19	0.00
E 003	7.52	12.33	15.64	29.01	26.43	5.54	3.53
E 004	9.75	14.77	15.26	21.26	22.55	7.77	8.64
E 023	10.13	15.55	18.36	29.85	24.96	0.10	1.25
E 045	10.42	16.50	18.32	21.79	23.96	5.09	3.92
E 046	10.56	17.36	18.65	30.29	21.01	2.13	0.00
E 047	14.41	23.51	23.38	27.81	10.89	0.00	0.00
F 006	13.34	13.34	21.39	26.37	14.34	7.95	3.27
F 007	13.05	17.91	18.34	23.54	14.40	5.23	7.53
F 016	9.47	14.52	15.80	22.27	13.70	10.49	13.75
F 026	12.52	15.02	17.11	23.50	17.96	8.42	5.47
F 030	14.46	19.04	23.03	19.68	14.04	6.27	3.48
F 044	14.46	19.04	23.03	19.68	14.04	6.27	3.48
G 010	11.03	21.06	23.70	23.82	11.22	5.04	4.13
G 011	20.62	32.14	33.01	14.18	0.05	0.00	0.00
G 012	15.69	22.39	20.69	30.42	10.81	0.00	0.00
G 015	12.32	13.54	15.39	26.88	26.64	5.23	0.00

	< 2	**2-6**	**6-20**	**20-63**	**63-212**	**212-600**	**600-2000**
Wasbister							
C1	10.57	18.11	20.63	33.04	12.18	0.81	4.66
C2	12.27	19.81	22.33	34.74	13.88	2.51	6.36
C3	1.34	1.34	1.34	1.34	1.34	1.34	1.34
C4	1.27	1.27	1.27	1.27	1.27	1.27	1.27
C5	0.26	0.26	0.26	0.26	0.26	0.26	0.26
C6	10.70	14.30	12.60	28.60	21.10	12.60	2.00
E1	11.30	18.24	20.36	32.50	13.26	1.50	3.60
E2	17.11	19.63	32.04	11.18	-0.19	0.50	0.35
E4	16.46	28.41	26.60	26.95	3.60	0.00	0.00
F1	10.12	16.54	23.40	36.50	10.30	2.60	5.30
F2	0.76	0.76	0.76	0.76	0.76	0.76	0.76
F3	2.67	2.67	2.67	2.67	2.67	2.67	2.67
F4	9.71	13.49	13.43	27.51	22.52	11.54	1.80
H1	11.23	19.30	21.30	27.56	11.36	0.92	4.36
H2	2.69	2.69	2.69	2.69	2.69	2.69	2.69
H3	1.58	1.58	1.58	1.58	1.58	1.58	1.58
H4	14.32	18.07	17.86	17.23	12.94	12.05	7.53
Barnhouse							
C1	10.57	18.11	20.63	33.04	12.18	0.81	4.66
C2	10.57	18.11	20.63	33.04	12.18	0.81	4.66
C3	7.72	11.91	17.10	30.25	16.26	9.54	7.22
C4	16.46	27.88	25.32	26.95	3.39	0.00	0.00
D1	13.33	21.60	23.63	27.36	11.61	2.47	0.00
D2	17.45	28.53	19.59	20.96	10.99	2.48	0.00
D3	19.41	26.70	25.08	25.71	3.10	0.00	0.00
D4	16.01	25.36	29.61	23.91	5.11	0.00	0.00
D5	13.58	19.97	19.69	25.53	12.65	5.31	3.27
E1	11.80	17.79	21.93	19.76	11.00	10.43	7.29
E2	11.48	17.30	20.87	27.12	14.78	7.43	1.02
E3	11.23	16.02	21.19	28.46	12.35	6.43	4.32
E4	14.32	18.07	17.86	17.23	12.94	12.05	7.53
F1	12.97	19.08	24.15	35.71	8.09	0.00	0.00
F2	10.52	18.99	25.32	27.93	9.34	4.68	3.22
F3	14.10	21.68	21.65	18.34	13.03	8.37	2.83
F4	9.71	13.49	13.43	27.51	22.52	11.54	1.80
Loch of Harray							
A1	8.81	16.35	18.87	31.28	10.42	1.01	2.90
A2	21.94	29.23	27.61	28.24	5.63	2.53	2.53
A3	13.38	16.98	15.28	31.28	21.80	12.20	4.68
A4	14.05	17.80	17.59	16.96	12.67	11.78	7.26
B1	11.41	18.95	21.47	33.88	13.02	1.65	5.50
B2	19.27	26.56	24.94	25.57	2.96	0.00	0.00
B3	11.69	15.29	13.59	29.59	20.11	10.51	2.99
B4	12.42	16.02	14.32	30.32	20.84	11.24	3.72

9.7 *Appendix D Total Phosphorus Results*

	(mg/100g oven dried soil)	**Replicate1**	**Rep 2**	**Rep 3**	**Rep 4**	**Rep 5**	**Rep 6**
Finstown Control							
FT 1	90.72						
FT 2	54.16	51.35	55.52	58.56	56.64		
FT 3	51.20						
FT 4	43.45						
FT 5	45.93	45.26	49.75	49.27	48.15		
FT 6	59.10	52.63	54.23	56.16	61.28		
FT 7	68.65	60.00	52.63	47.03	53.43		
Ness of Brodgar							
A 091	327.02						
A 088	152.20						
C 086	162.25						
C 075	183.00						
C 073	285.85	322.76	273.91	360.02	408.87		
C 072	294.08	205.56	214.79	216.43	225.33		
C 071	196.01						
E047	104.27	95.28	99.65	94.40	98.63		
E046	124.04	114.67	111.90	117.29	121.67		
E045	112.84	109.27	91.19	99.65	107.52		
E 023	149.15	146.39	141.43	147.22	227.54		
E 004	197.73	165.44	202.70	201.87	214.29		
E 003	275.14	248.24	269.77	280.53	292.12		
E 002	238.91	175.76	187.86	181.15	189.46		
E 001	151.05						
5m. East E	192.79						
5m West E	229.85						
F 044	163.73						
F 030	131.94						
F 026	149.24						
F 016	247.14						
F 007	205.97						
F 006	182.91						
F 005	158.30						
G 015	85.33						
G 013	191.15						
G 012	167.52						
G 011	174.93						
G 010	118.77						
K1	314.06						
K2	328.64						
K3	424.13	348.90	311.95	331.52			
K4	399.35	399.35	440.17	400.81			
K5	487.56	411.21	424.25	423.53	447.44		
K6	474.44	440.17					

	(mg/100g oven dried soil)	**Replicates**					
Wasbister							
WAS E4	96.69						
E3	141.33						
E2	107.89						
WAS E1	137.21						
WAS F4	125.85	108.53	107.74	123.25	121.84		
F3	147.59	120.90	132.96	120.90	131.08		
F2	176.57	127.64	119.81	133.90	133.12		
WAS F1	191.07	155.83	149.56	152.69	144.08		
WAS H4	134.41						
H3	148.90						
H2	180.03						
WAS H1	190.24						
WAS C6	121.81						
C5	105.65						
C4	111.83						
C3	90.45						
C2	103.75						
WAS C1	116.11						
Skaill Control							
7	61.70						
6.00	95.65						
5.00	96.53						
4.00	109.82	96.20	90.27	98.18	98.84		
3.00	155.28						
2B	174.02	181.52	176.97	194.39	177.07	186.29	184.15
2A	227.75	202.27	197.16	207.21	196.83		
1	131.37						
Barnhouse							
BH A.3	180.03						
A2	72.48						
A1	183.00						
B2	158.46						
C5	140.18						
C4	252.33						
C3	166.00						
C2	206.71						
C1	200.85						
D5	94.80						
D4	211.24						
D3	197.27						
D2	190.58						
D1	238.17						
	(mg/100g oven dried soil)	**Replicates**					

Barnhouse							
E4	274.42	389.61	241.37	254.40	234.04		
E3	257.00	218.57	216.94	234.04	251.96		
E2	231.29	221.01	197.39	191.69	208.79		
E1	168.31	183.48	201.89	161.16	177.78		
F5	185.49						
F4	243.46						
F3	247.90						
F2	201.96						
F1	208.45						
Pool	424.20	391.64	419.17	373.60	413.38		
Skara Brae							
4.1	457.45	471.53	417.71	473.18	428.85		
4.2	709.16	655.34	716.62	651.20	*660.62*		
4.3	*653.58*	*654.36*	*583.89*	*621.47*	*600.33*		
4.4	619.74	656.17	629.68	651.20	*600.33*		
4.5	378.79	384.59	377.96	339.88	*344.29*		
Loch of Harray							
Profile A	107.75	107.00	108.32	105.13	107.16		
Horizon A	82.23						
Horizon B	70.57						
Horizon C	41.41						
Horizon D							
Profile B							
Horizon A	109.94						
Horizon B	107.75						
Horizon C	98.27						
Horizon D	32.66						

Appendix E Mass Susceptibility Results

Sample ID	**$\chi 10^{-6}m^3kg^{-1}$**	**Replicate 1**	**Rep 2**	**Rep 3**
Skaill Control 1	1.90	1.86	1.92	
Skaill Control 2a	2.42	2.36	2.56	
Skaill Control 2b	3.02	3.01	3.09	
Skaill Control 3	0.76	0.86	0.91	
Skaill Control 4	2.49	2.30	2.69	
Skaill Control 5	3.81	3.75	3.60	
Skaill Control 6	1.29	1.01	0.98	
Skaill Control 7	0.00	0.12	0.04	
Finstown 1	0.11	0.11	0.10	
Finstown 2	0.13	0.12	0.13	
Finstown 3	0.12	0.12	0.13	
Finstown 4	0.11	0.12	0.11	
Finstown 5	0.14	0.13	0.12	
Finstown 6	0.02	0.02	0.01	
Finstown 7	0.04	0.03	0.04	
Pool	9.30	9.20	9.35	
Pool (Rep)	9.14	9.56	9.31	
Ness of Brodgar				
NOB A 088	2.20			
NOB A 091	3.32			
NOB C 071	4.14			
NOB C 072	6.64			
NOB C 073	8.61			
NOB C 075	8.76			
NOB C 086	10.11			
NOB E 001	3.04	3.15	3.24	3.11
NOB E002	7.24	7.37	7.21	7.26
NOB E 003	12.63	12.27	12.21	12.33
NOB 004	1.97	3.29	2.07	2.54
NOB 023	0.68	0.11	1.49	1.72
NOB 045	0.13	0.25	0.99	0.73
NOB 046	11.23	11.16	11.56	11.23
NOB 047	11.07	11.16	11.16	11.45
NOB K 1	5.73	5.63	5.40	
NOB K 2	8.00	7.59	7.96	
NOB K 3	8.97	8.57	9.31	
NOB K 4	10.50	11.64	10.78	
NOB K 5	2.83	3.52	2.96	
NOB K 6	4.10	4.30	4.29	

Sample ID	**$\chi 10^{-6} m^3 kg^{-1}$**	**Replicate 1**	**Rep 2**	**Rep 3**
NOB F 005	2.58			
NOB F 006	4.19			
NOB F 007	6.22			
NOB F016	7.05			
NOB F 026	6.37			
NOB F030	1.66			
NOB F 044	0.62			
NOB G 10	1.38			
NOB G11	1.26			
NOB G12	0.60			
NOB G15	0.10			
Barnhouse				
BH E:1	2.29			
BH E:2	2.64			
BH E:3	3.95			
BH E:4	2.64			
BH05 C:1	0.59			
BH05 C:2	0.61			
BH05 C:3	0.43			
BH05 C:4	0.25			
BH05 C:5	0.10			
BH F:1	2.56	2.69	3.12	
BH F:2	3.02	3.56	3.17	
BH F:3	5.08	6.01	6.48	
BH F:4	8.29	7.69	8.54	
BH F:5	2.15	2.13	2.01	
BH 1:1	0.81			
BH 1:2	1.05			
BH 1:3	0.14			
BH 4:1	1.94			
BH 4:2	2.10			
BH 4:3	2.51			
BH 4:4	1.86			
BH 4:5	0.18			
BH 2:2	0.31			

Sample ID	**$\chi 10^{-6} m^3 kg^{-1}$**	**Replicates**		
Loch of Harray				
LOH A:A	1.01			
LOH A:B	1.66			
LOH A:C	0.61			
LOH A:D	0.21			
LOH B:A	0.56			
LOH B:B	0.47			
LOH B:C	0.38			
LOH B:D	0.10			
Wasbister				
WAS C1	7.92			
WAS C2	9.01			
WAS C3	10.38			
WAS C4	5.97			
WAS C5	1.39			
WAS C6	0.38			
WAS E1	1.82			
WAS E2	2.07			
WAS E3	10.51			
WAS E4	1.60			
WAS F1	4.92			
WAS F2	5.12			
WAS F3	5.62			
WAS F4	0.54			
WAS H1	4.42			
WAS H2	5.20			
WAS H3	8.53			
WAS H4	0.58			

Appendix F, Semi-structured Farmer Interviews

9.7.1 Mr Bain (Wasbister)

Interview conducted June 2005

Mr Bain bought the land at Wasbister 1n 1999. Between 1999 and 2005 he applied 50 units of straight nitrogen yearly. Since 2005 he has applied 27 units of Nitrogen, 5 units of phosphate and 5 units of potash yearly with fertiliser being applied only to the land surface. No slurry or dung ahs been applied by Mr Bain.

Mr Bain has only used the land for grazing cattle, with the cattle grazed between May and the end of October. He is aware of limited barley cultivation at this site which was occurring in the 1970's and 1980's but which was only likely to have begun at the earliest in the 1960's. Only half of the field was cultivated, as evidenced by the rig and furrows on magnetometry results. Mr Bain suggests that Barley cultivation was not intensive with the crop only used to support the farmers cattle over winter and not sold as a cash crop.

9.7.2 Mr Tulloch (Barnhouse)

Interview conducted June 2005

Mr Tulloch has owned the land at Barnhouse since 1990. In the first years he owned it he grew potatoes which involved ploughing to a depth of 12 inches. Six hundredweight of (ratio, 12 nitrogen:20 phosphorus:20potassium) was applied yearly to the plough depth. Fertiliser was therefore applied to a depth of 12 inches within the profile.

After the potato crops Mr Tulloch grew barley and oil seed rape which both involved ploughing to a depth of 2-3 inches and the application of a large amount of animal dung to the land surface. Ploughing for these crops occurred yearly along with the yearly surface application of animal dung and feriliser (three hundredweight of N:P:K, ratio 17:17:17).

The land has been under pasture for the last 7 years with one hundredweight of fertiliser (N:P:K, ratio 20:13:13) applied yearly

9.7.3 Mr Slater (Ness of Brodgar)

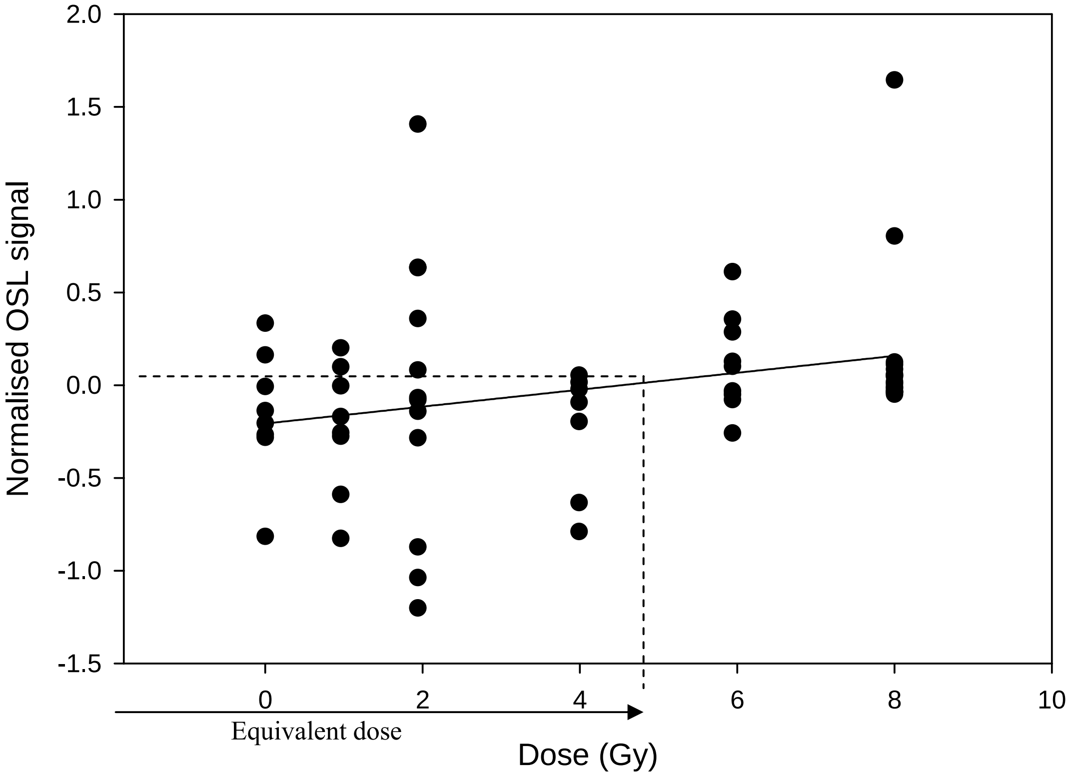
Interview conducted June 2005

Mr Slater has leased the land upon the Ness of Brodgar since 2000. He grew barley for 2 years and then used the land for silage production. Barley was cultivated by ploughing to a depth of 5 or 6 inches. The barley was then sown at septh of 2 inches along with the fertiliser (nitrogen, potash and potassium in a ratio of 20:10:10).

Mr Slater can only remember this land being cultivated for oats and corn which both require only relatively shallow ploughing. He has no memory of crops such as turnips or potatoes being grown here which would have required ploughing to a greater depth.

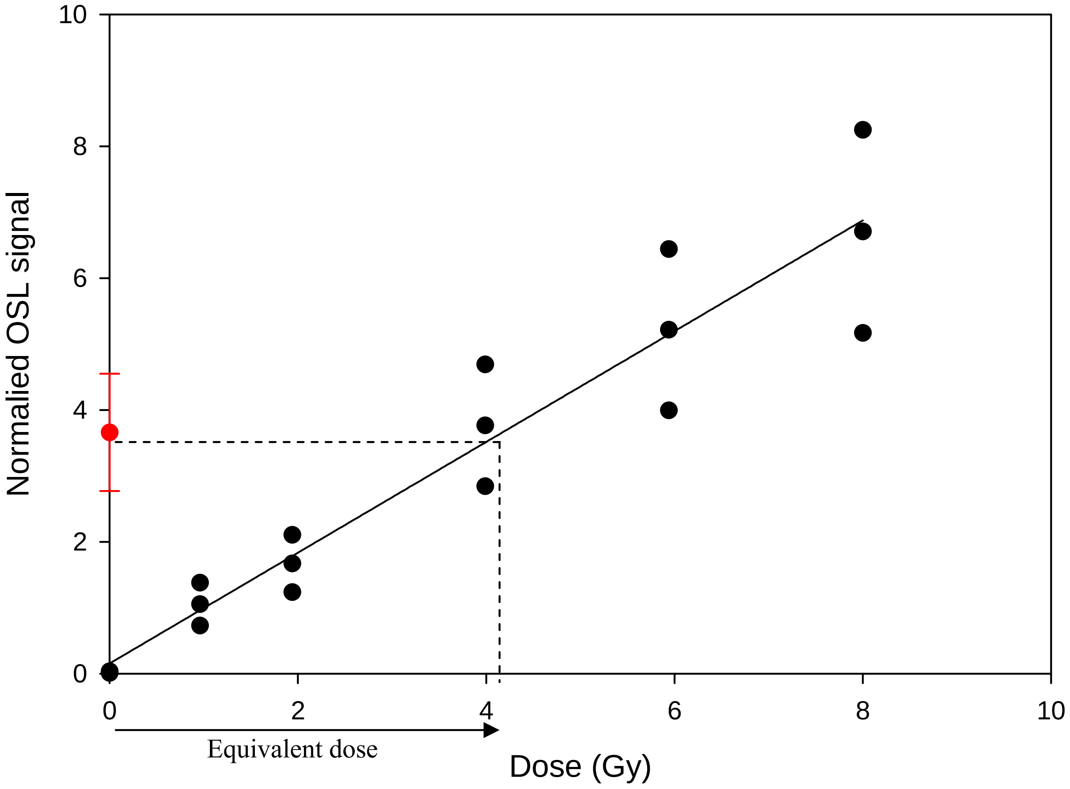
Appendix G, OSL Dose Response Linear Regressions

Sample 1



The poor sensitivity of this sample to irradiation resulted in a wide scattering of data points and an inaccurate measurement of a very low natural signal. It was not possible to successfully complete linear regression analysis on this data. Linear regression of the dose response has been successfully completed for the other samples and an assumption was therefore made that the relationship between the normalised OSl signal and Dose (Gy) for Sample 1 would also be a linear relationship. A best fit line was therefore added to the data which allowed an equivalent dose to be calculated using a natural signal of 0.

Sample 2



Yo = 0.1538 ± 0.3025

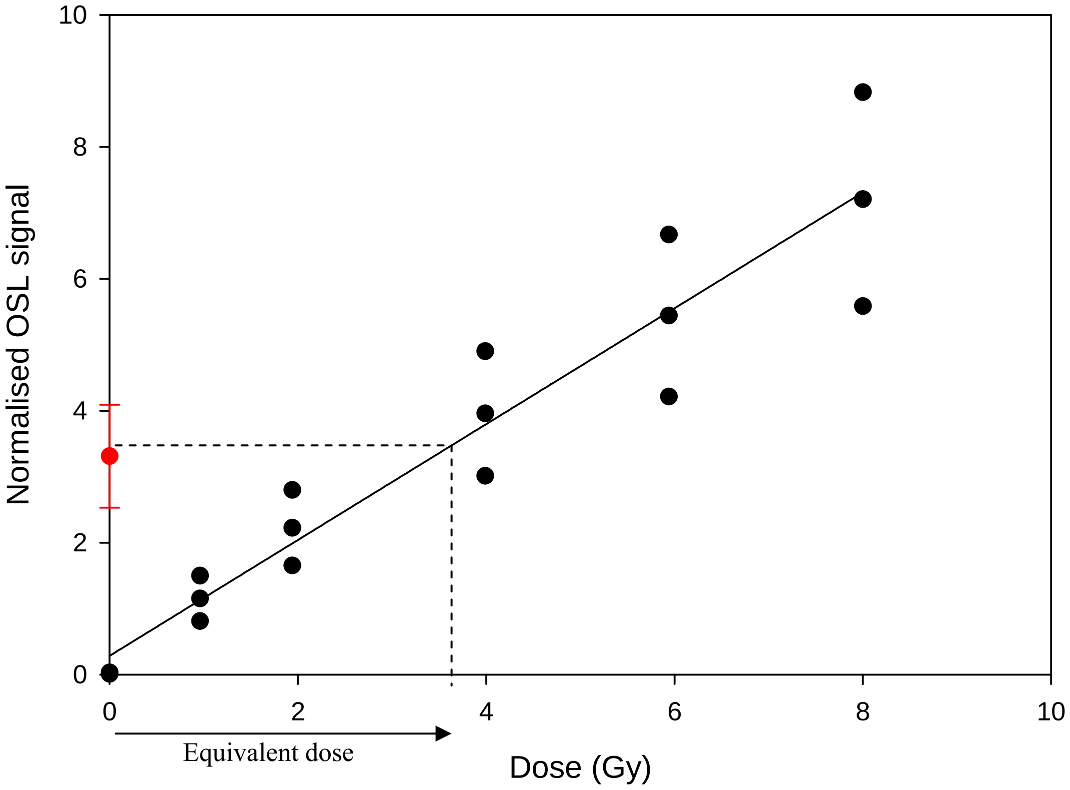
a = 0.8401± 0.0677

Natural signal = 3.66 ± 0.89

Equivalent Dose = 4.17 ± 1.17

The natural signal (in red on the Y axis) was measured as 2.98 ± 0.67. The equivalent dose was calculated as 4.17 ± 1.17 Gy by intercepting the natural signal with the linear regression.

Sample 3



Yo = 0.2837 ± 0.3169

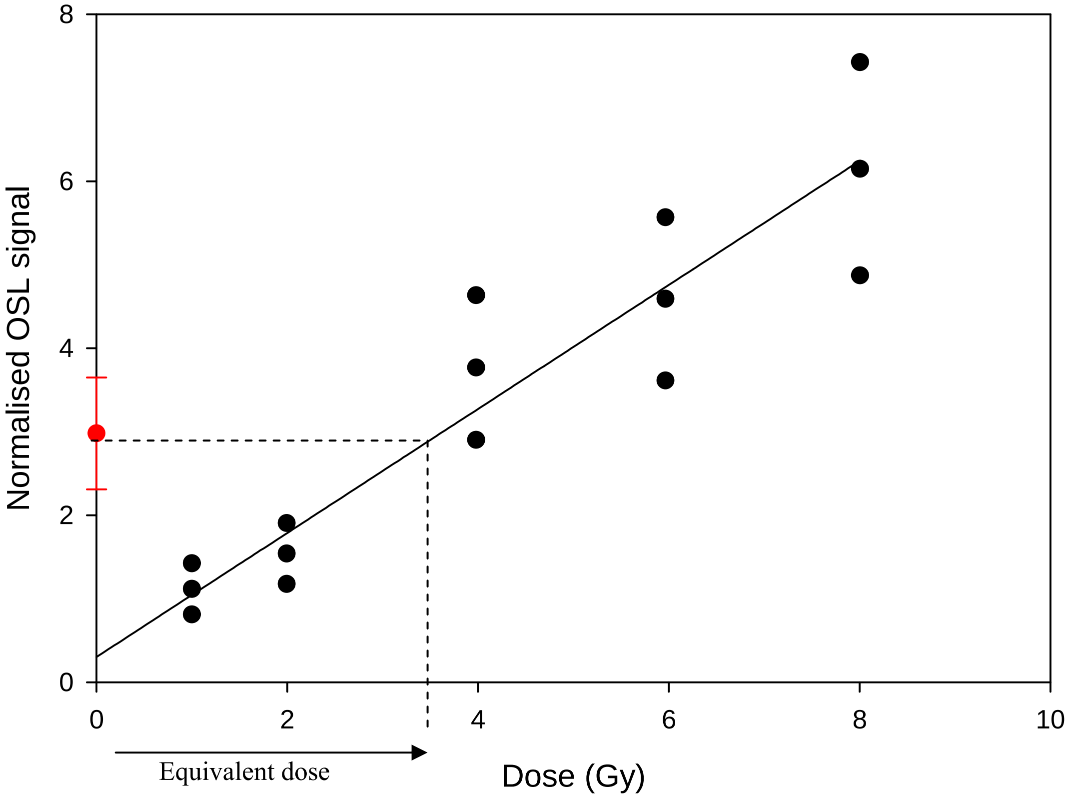
a = 0.8781 ± 0.0709

Natural signal = 3.31 ± 0.78

Equivalent Dose = 3.45 ± 1.0

The natural signal (in red on the Y axis) was measured as 3.31 ± 0.78. The equivalent dose was calculated as 3.45 ± 1.0 Gy by intercepting the natural signal with the linear regression.

Sample 4



Yo = 0.3005 ± 0.3415

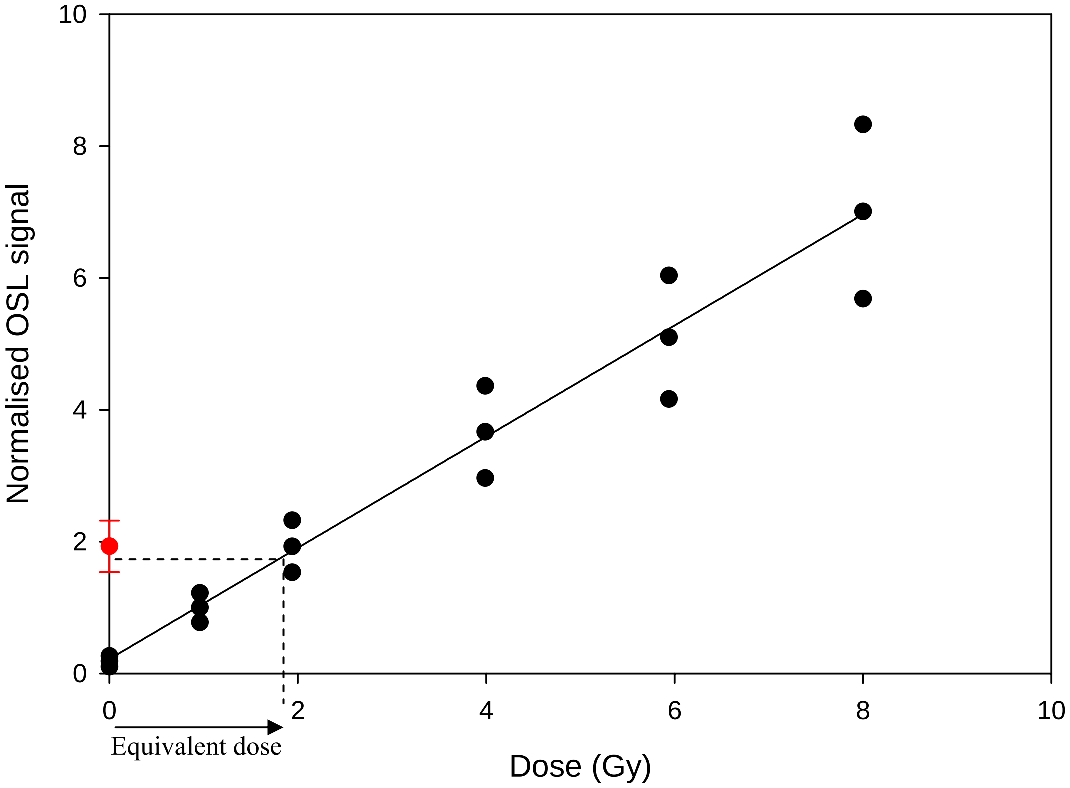
a = 0.7428 ± 0.0718

Natural signal = 2.98 ± 0.67

Equivalent Dose = 3.61 ± 1.07

The natural signal (in red on the Y axis) was measured as 2.98 ± 0.67. The equivalent dose was calculated as 3.61 ± 1.07 Gy by intercepting the natural signal with the linear regression.

Sample 5



Yo = 0.2181 ± 0.243

a = 0.8433 ± 0.0544

Natural signal = 1.93 ± 0.39

Equivalent Dose = 2.03 ± 0.56 Gy

The natural signal (in red on the Y axis) was measured as 1.93 ± 0.39. The equivalent dose was calculated as 2.03 ± 0.56 Gy by intercepting the natural signal with the linear regression.