

The nature, distribution and significance of amended and
anthropogenic soils on old arable farms and the
elemental analysis of black carbonised particles

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Statement of originality

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

Signature of candidate:

Date:

Abstract

Eversince the development of farming humans have been implicitly linked with the landscape. Influences include the manipulation of natural environments by woodland clearance, field developments and animal husbandry. Development can also be determined by the identification and distribution of soils developed and modified by the addition of organic and inorganic components. Anthropogenic or amended soils have been identified in many forms across north west Europe that retain distinctive physical and chemical indications of historical agrarian and settlement history. This thesis researched the on-site distribution of anthropogenic and amended soils across different landuse areas and identified and quantified a range of black carbonised particles in order to investigate their role in the soils ability to retain high elemental concentrations of manuring and elements associated with domestic activity and industrial processes.

Three sites in contrasting environments were chosen for analysis; in Fair Isle, the Netherlands and Ireland on the basis of an excellent agrarian and settlement history and previous analysis of anthropogenic soils. The fieldwork results showed extremely deep plaggen soils in the Netherlands but considerably shallower horizons of amended arable soils on Fair Isle and in Ireland contrary to previous analysis. There was however, clear evidence of a reduction in anthropogenic and amended soils with increased distance from the farm centres as a result of less manuring.

The soil pH, organic matter, particle size, magnetic susceptibility and bulk elemental analysis results showed unexpected increases in the amended soils of Fair Isle and Ireland and reflected a similar manuring process. In the Netherlands the deep plaggen soils had very low results reflecting modern arable farming.

The micromorphology results illustrated distinctive characteristics associated with localised manuring techniques. On Fair Isle and in Ireland the main organic manuring material was peat and burnt peat, whereas in the Netherlands the plaggen soils were predominantly composed of meadowland and heathland turf. At all three sites there was a large number of black carbonised and black amorphous inclusions and point counting and image analysis results showed a decrease with depth and distance from settlement nuclei mirroring the fieldwork observations.

The elemental analysis conducted has proved to be an extremely useful tool for the identification of various forms of black carbon and for identifying the provenance of high elemental concentrations. The oxygen:carbon ratios confirmed the origins of organic components used in the development of the amended and anthropogenic soils and the elemental analysis showed that at each site over 80% of visually unidentifiable amorphous black carbon particles were heavily decomposed carbonised inclusions. Overall the elemental concentrations within the black carbonised particles was very low but this reflected the elemental results found in the bulk soils and the inclusions contained higher concentrations of P, Ca, K, Fe and Al and considerably lower concentrations of elements associated with domestic activity or industry Zn, Cu, Ba, Cr, As and Pb.

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1 SOIL AND ARCHAEOLOGY; A REVIEW OF PAST WORK AND THESIS DESIGN

1.1 INTRODUCTION

The study of human influence on soil development began in the mid 20th century by pedologists keen to develop the idea that anthropogenesis was a major factor in soil formation, and the classic conceptual models went some way to explaining how this occurred (Jenny, 1941; Simonson, 1959). However, anthropogenesis was always closely associated with natural soil forming processes and it was not until Bidwell and Hole (1965) and Yaalon and Yaron (1966) suggested that both direct human effects such as ploughing and manuring were as crucial to soil formation as indirect effects, deforestation and acidification, that interdisciplinary analysis and interaction of pedology and humanity, termed 'metapedogenesis' (Yaalon and Yaron, 1966). The development of metapedogenesis is, in part thanks to the discovery and analysis of anthropogenic soil in South America (Sombroek, 1966) and Europe (Pape, 1970; Conry, 1971; Davidson and Simpson, 1984) and detailed multidisciplinary analysis has shown distinct variations in these soils spatial, temporal and geochemical histories. A common factor found in many anthropogenic soils, however, is the presence of black inclusions which have been identified as charcoal, carbonised organics and black amorphous material. Like archaeological deposits and soils these black inclusions have been used to indicate the level of anthropogenic influence in settlements and within landscapes, however their key roles within anthropogenic soils are still relatively unknown.

It is imperative that black inclusions should be properly understood using a multidisciplinary approach to identify, quantify and interpret their use, and to aid the interpretation of the form and function of anthropogenic soils within individual farmsteads and across large regional contexts. To understand how and why anthropogenic and amended soils were developed in the past a clear understanding of natural pedogenesis is needed, and this takes up the first part of this introductory chapter (section 1.2). This leads into a discussion on the interactions between humans and soils and the development and understanding of anthropogenesis (section 1.3). The history of the discovery

and analysis of anthropogenic soils is covered in the next two sections with emphasis on rural (section 1.4) and urban soils (section 1.5). In section 1.4 the three main study areas in the last four decades are discussed; Netherlands (section 1.4.1), Ireland (section 1.4.2) and Scotland (section 1.4.3). The nature of black carbon particles is covered in sections 1.6 and 1.7 and focuses upon the initial discovery and analyses in natural sediments and soils as well as the creation of the carbon combustion continuum and the development of black carbon analysis in natural soils. Sections 1.8 and 1.9 detail the analysis of black carbonised particles in archaeology and through micromorphology and this leads into the analysis and discussion of the key themes of the thesis (section 1.10), the project aims (section 1.11) as well as a full methodology of the field and laboratory work (section 1.12).

1.2 NATURAL PEDOGENESIS

Human impacts on soil profiles cannot be fully understood without knowledge of the processes which occur in natural pedogenesis. Currently the understanding is that soils are complex ecosystems juxtaposed between the atmosphere, lithosphere and a highly mobile hydrosphere and biosphere, in which humans are included, from the very large scale to the incredibly small (Brady and Weil, 2002). This modern view of soils has developed from over 100 years of soil analysis from the concept of soil science by V.V. Dokuchaev and Hilgard in the late 19th century to the analysis with microphysical and chemical techniques including micromorphology and lipid analysis and the development of interdisciplinary interpretations of anthropogenic soils.

Eq 1
$$S = f(cl, o, r, p, t, \dots)$$

Hans Jenny's ground breaking analysis of soils showed that soil formation could be illustrated as a formula (Table 1, Equation 1). Jenny (1941) expressed five particular physical and chemical factors (f) for soil creation (S), climate (cl), organics (o), relief (r), parent material (p) and time (t). Each of the factors aids the formation of soils by a number of processes including the

physical and chemical soil properties. The physical property of soils is split into the quantities of inorganic sand, silt and clay particles deriving from geological and sedimentological sources with organic components of decaying plant and animal material.

Organic material in soil is derived from plant and animal residues. Plants growing on the surface provide stability to the underlying soils by binding with roots and extracting excess water through root intake. On the surface plants prevent soil erosion by reducing or stopping surface water flow, especially on slopes, and increasing water intake. When the plants die they decay in situ and increase the organic content providing food for a range of animal species, which in turn increases humic and fulvic acids.

Source	No	Equation	Abbreviations	Type
Jenny (1941)	1	$S = f(cl, o, r, p, t, \dots)$	S = Soil formation f = Factor cl = climate o = organics r = relief p = parent material t = time	Factor
Simonson (1959)	2	$S = f(a, r, t_1, t_2)$	S = Soil Formation f = Factor a = additions r = removals t_1 = transfers/translocations t_2 = transformations	Process
Runge's Energy Model (1973)	3	$S = f(o, w, t)$	S = Soil Formation f = Factor o = organics w = water available for leaching t = time	Factor/Process
Johnson's Soil Thickness Model (1985)	4	$T = D + U + R$	T = Thickness D = Deepening U = Upbuilding R = Removal	Process
Johnson & Watson-Stegner's Evolution Model (1987)	5	$S = f(P, R)$	S = Soil Formation f = Factor P = progressive pedogenesis R = retrogressive pedogenesis	Process

Table 1, Chronology of the development of the study of natural pedogenesis

Soils with high humus levels are more likely to have high numbers of faunal species. Such species range from very small microbial bacteria to large macro species and all assist with the breakdown and mixing of organic material by consumption and defecation. The action of faunal movement throughout a soil increases void space and substantially eases air and water movement. This transports mineral and organics in solution to lower soil horizons, keeping the soil pH at a semi neutral state.

Chemically, soils are regarded as reservoirs for key elemental loadings, especially carbon and nitrogen, necessary for the continued existence of plant and animal species. The carbon cycle considers the movement of carbon through photosynthesis by plants and the transfer from atmosphere into the soil, the process by respiration of CO₂ by plants and animals and addition of organic carbon from plants and animals to the soil profile. The nitrogen transfer within soils involves two main processes. First, mineralization involves the input of nitrogen from biological material into the soil and the change from organic to inorganic salts. Secondly, biological transfer or 'fixation' alters the nitrites to nitrates through a process of 'nitrogen fixation' especially by legumes e.g. clover, into a form which enables the absorption by plant roots.

Balancing the chemical and physical properties of soil is fundamental for maintaining the transfer of nutrients around soil systems. Soils with a low soil pH are likely to contain less biological activity and therefore less mixing and a slower breakdown of organic material, however too much biological mixing can also lead to de-calcification and a decrease in soil pH. Oxidation, especially of iron and manganese, can lead to the development of thick impenetrable pans hindering the movement of water and nutrients through the soil profile. Increased water movement can also lead to the leaching of organics and the development of eluviated horizons deficient in silicate clays, iron and aluminium oxides.

1.3 SOILS AND HUMAN INTERACTION

Jenny's equation (Table 1, Equation 1) remains fundamentally relevant to the understanding of soil formation, however, it has always been argued that

the role humans play in the development of soils is greatly underestimated (Davidson, 1982). The human role should have been included as an additional factor in the equation rather than simply as part of the larger organism group. Continued improvements in the understanding of human interaction with the landscape and soils has led to amendments in the original equation. However, Jenny (1941, p203) also stated that *“a number of anthropogenic forming processes stand no direct relationship with soil forming factors”*.

Bidwell and Hole (1965) considered the effects of human influence on soil formation, producing a table of beneficial and detrimental processes on each of the five factors in Jenny's equation. In addition, it has been suggested recently, that anthropogenic influence (a) should have been given new factor status (Effland and Pouyat, 1997) as illustrated in equation 2.

$$\text{Eq 2} \qquad S = f(a, c, l, o, r, p, t, \dots)$$

This concept is not a new one. Yaalon and Yaron (1966) have suggested that anthropogenic influence should constitute an entirely new factor and accordingly introduced the '6th' factor called 'metapedogenesis'. The introduction of this new factor suggested that soil and human impact upon soils should be analysed as a process-response which can occur at any stage and in any combination altering physical and chemical properties. A good example of the process of metapedogenesis is that which occurs through extensive deforestation, leading to increased surface run-off and erosion or the burning of fossil fuels affecting the acidity of rain. Schaetzl and Anderson (2005) argue against giving human influence a new factor status because of the time factor. They suggest that because anthropogenic alteration has occurred for only a comparatively short length of time compared to the other factors that the 'a' factor should not be given equal status, and instead humans should be seen as soil 'modifiers' rather than soil 'formers' (Schaetzl and Anderson, 2005).

The development in the understanding of soil development, from Dukuchiev's functional/factorial concept to a combination of factor-process-response, was developed by Simonson (1959). He suggested that soils evolved through natural processes and that soils *“may appear and disappear”*

(Simonson, 1959, p154). Simonson's model considered two steps in soil genesis: the accumulation of parent material and the differentiation of parent material into horizons. The model was illustrated as an equation (Eq 3) which defined soil development as factors of addition (a) and removal (r) through the processes of transfers and translocations (t_1) and transformations (t_2) within the horizons.

Eq 3
$$S=f(a,r,t_1,t_2)$$

The aim of Simonson's equation was to highlight the variability in the degree of processes occurring in soil forming processes across individual horizons rather than the different types of processes and this came under criticism that it was only one part of a larger soil formation system. Although the model was altered 19 years later (Simonson, 1978) it is still regarded as part of a larger model which needs to consider the initial state of soils, the processes those deposits have been subjected to and the duration of the subjection (Yaalon, 1975). Another issue with Simonson's model is that it relies upon scientists having a good understanding of soil processes unlike Jenny's equation; which was simpler and had the important factors of soil formation included. However, the model has been utilised very successfully in the analysis of quantifiable inputs and outputs within particular soil horizons especially in relation to anthropogenic action on soil (Schaetzl and Anderson, 2005).

Another factor-processional model of soil formation is Runge's Energy Model which focuses particularly upon the intensity of two priority factors: climate and relief (Runge, 1973). However, a more direct factorial equation (Eq 4) was developed by Johnson (1985) which took into consideration the direct addition of sediments to the soil surface which creates thick soil horizons and 'top-down' pedogenesis (coined by Almond and Tonkin, 1999). This was seen as a development of Simonson's model because it isolated soil horizons and examined the processes which affected their formation.

$$\text{Eq 4} \quad T = D+U+R$$

$$\text{Eq 4.1} \quad \text{Thicker Soils} = D+U>R$$

$$\text{Eq 4.2} \quad \text{Thinner Soils} = D+U<R$$

Johnson's soil thickness model worked on the premise that deepening was due to the downward migration of lower soil boundaries via leaching and weathering (Johnson, 1985). In the equation thickness (T) is in direct relationship to deepening (D) plus upbuilding (U) plus removal (R). Differences in this format would lead to either thickening (Eq 4.1) or thinning (Eq 4.2). Johnson described two methods of soil thickening: either *developmental*, which is a slow process allowing natural pedogenesis to continue as in loess and alluvial environments; or *retardant*, a fast process in which natural soil formation cannot keep up with upbuilding leading to buried soils. The dynamism of the processes of addition and removal from the soil surface led Johnson to develop a second model, with Watson-Stegner, detailing the evolution of soil processes as complex systems rather than static layers (Johnson and Watson-Stegner, 1987). This was a development created by the Russian pedologist C.C. Nikiforoff who suggested that soil development was continuous and that soil processes do not occur at a fixed rate and are rather highly variable across soil types and landscapes.

$$\text{Eq 5} \quad S = f(P,R)$$

Equation five shows Johnson and Watson-Stegner's model for soil development whereby soil development is formed by progressive (P) and retrogressive (R) pedogenesis. Progressive development includes the creation of horizons (Horizonation), the development of upbuilding and soil deepening and retrogressive processes including the removal of horizons (Hapoidisation), retardant upbuilding and soil thinning (Johnson and Watson-Stegner, 1987).

The subdivision of anthropogenesis has been studied recently, with an emphasis upon human timescales, in order to fully understand man's effect on soil development (Richter, 2007) (Fig 1). Richter's model, summarised as SM_x, SH_x, SC_x considers soil change and development across three timescales:

first, *multimillennial pedogenesis*, which emphasises Simonson's model of formation and is most closely linked to traditional pedological studies; secondly, *historic ecosystems* affected by human impacts and thirdly, soil formation and human impacts in a *contemporary ecosystem*.

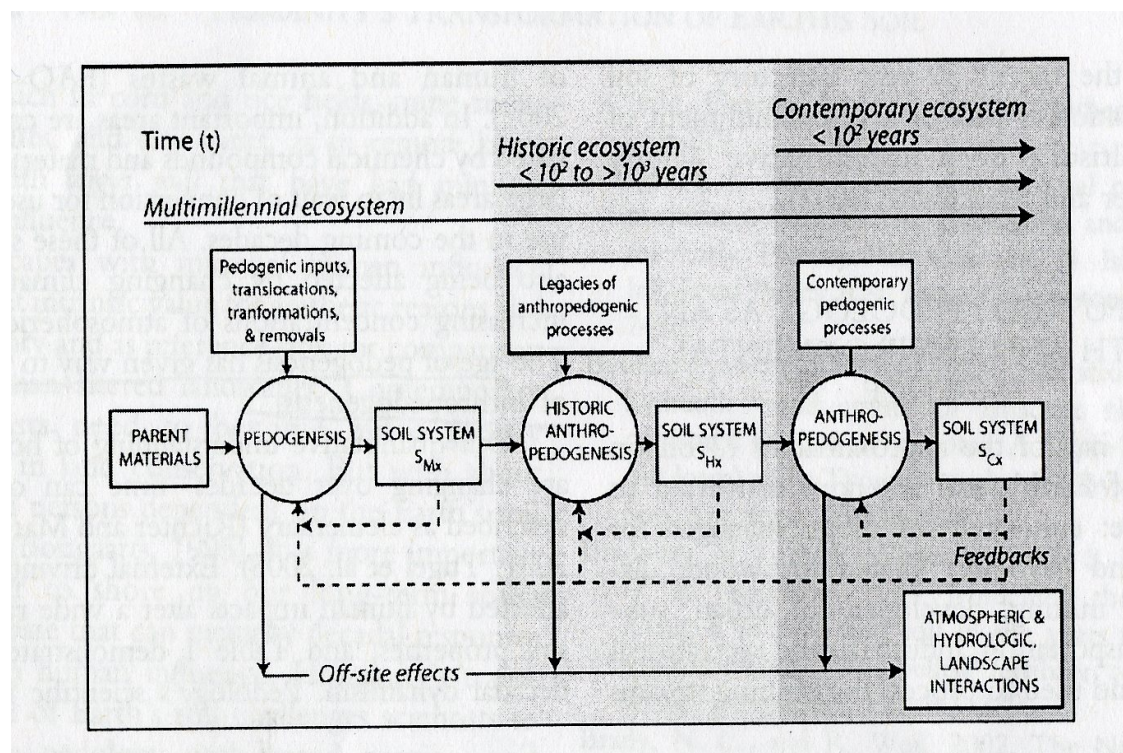


Figure 1, Contemporary soil change across three time scales (Richter, 2007)

Richter's model reiterates earlier ideas that soils are ecosystems which are constantly changing, depending upon landuse at a range of scales, from the individual field to entire landscapes. As an example the model shows how acidification varied in a changeable landscape. Longterm analysis of the natural parent material based soils at Calhoun soil-ecosystem showed an original acid soil. However, with the development of agriculture came the input of lime and fertilisers to increase yield and this led to an overall decrease in acidification and increased ability of the soil to exchange calcium (Richter, 2007). The modelling of anthropogenesis has been mirrored by the discovery and understanding of anthropogenic soils.

1.4 ANTHROPOGENIC SOILS

1.4.1 A DEFINITION

Identification, analysis and definition of rural anthropogenic soils began in mainland Europe and were initially found and described by Staring (1856) in the Netherlands. Over the next 100 years studies continued across north-west Europe and anthrosols were identified in Belgium (Niemeier and Taschenmacher, 1939; Edelman, 1950; Lindemans, 1952; Ameryckx 1960) and Germany (Niemeier and Taschenmacher, 1939; Fastabend and von Raupach, 1961; Muckenhausen, 1962). These highly distinctive dark coloured soils were called plaggen soils, from the German *Plagge* meaning 'sod' or 'to cut sods' (Siderius and de Bakker, 2003) from the distinctive method of their formation. J.C. Pape was the first to describe and map the plaggen soils in detail and he conducted his research in the Netherlands where the soils were extensive. Pape defined two distinctive plaggen soils. The first was the distinctive black, organic layer typically +500mm thick with inclusions of charcoal, earthenware and sand (Pape, 1970). He also described a less obvious lighter grey, brown coloured primary deposit which had an organic, loamy texture with charcoal and bleached sand fragments. This layer was called the brown plaggen soil and suggested that manuring had been conducted for many years (Pape, 1970; de Bakker, 1979).

Both types of plaggen soils are typically composed of a range of organic components including grass sods, heather, peat, sand and forest litter. The brown plaggen soil was typically composed of turf and grass cut from "woeste gronden" (waste ground or non-cultivated meadowland areas) (Siderius and de Bakker, 2003) and heather sods cut from the shallow acidic podzolic soils with a small quantity of burning conducted for fuel (Pape, 1970). The black plaggen soil is far more homogeneous and its formation is associated with a dramatic increase in the rate of manuring (Holliday, 2004). The distinctive colour of the soil has been associated with the addition of Sphagnum as seen in post medieval plaggen soils at Valthe, Drenthe (van Smeerdijk at al., 1995). The origin of humus and inorganic material in the black plaggen soils is strongly

linked to a heather source together with more domestic waste including charcoal, brick, coal and ceramic fragments (van de Westeringh, 1988). Traditionally, these, materials were collected and used as bedding for farm animals before being placed on sandy soils. A detailed historical analysis by van de Westeringh (1970) describes three methods of manure preparation for different animal types. Sheep dung was mixed with heather and forest litter, young cattle manure was mixed with earth sods and forest litter and dairy cattle waste was used in its natural state and mixed with turf, sand and clay from meadow land. This suggests an extremely well organised and long running tradition of manuring and plaggen production (van de Westeringh, 1988).

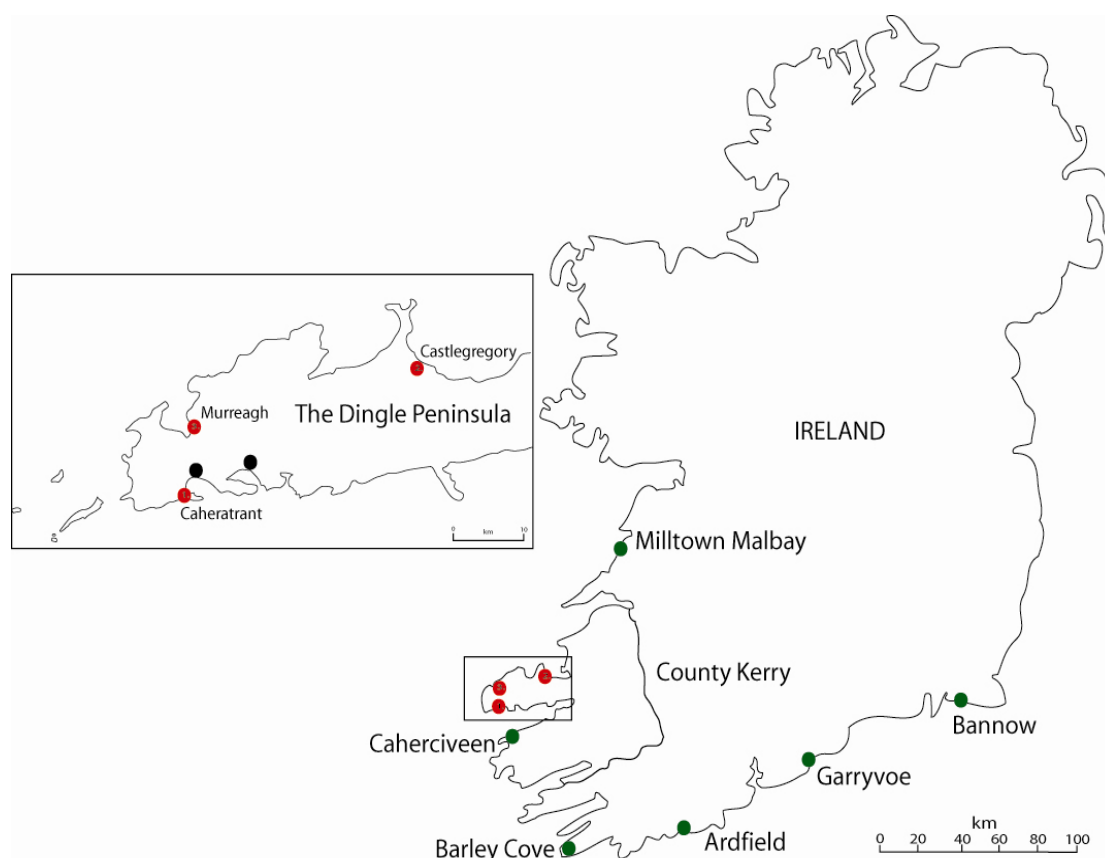


Figure 2, Sites where anthropogenic soils have been identified and analysed in Ireland (Adapted from Conry, 1971)

Anthropogenic soils have also been identified and studied at a number of sites across the south and south west of Ireland (Conry, 1971; 1972; 1974; Conry and Diamond, 1971; Conry and Mitchell, 1971) (Fig 2). In each case they have been described as 'Plaggen' soils because of their distinctive black

to dark grey and brown colour and high calcium carbonate sand material (Conry, 1971). This terminology must be challenged as historical documentation from the 18th century indicates a poor recycling of organic material from farm yards (Armit, 1998) alongside research which suggests that the majority of Irish anthropogenic soils are formed directly from the addition of sea sand (Conry, 1971). Work in Ireland has shown that anthropogenic soils occur on a wide number of natural soil types and acidic geologies derived mainly from sandstone and glacial till.

Of the sites outside the Dingle Peninsula where anthropogenic soils have been found, most work has been conducted at Ardfield on the south coast of County Cork. At this site an average of 1m of deepened soil was found at a number of contexts. Five anthropogenic soils were found with dark grey brown colours and calcareous sand and stones (Conry, 1971), but little attention was given to any specific organic or anthropogenic addition. The descriptive terminology suggests also that similar formation processes and materials are being used and the minimal soil geochemical analyses from Ireland only help to illustrate the distinct differences in formation with the Netherlands (Conry and MacNaeidhe, 1999). An increase in multidisciplinary analysis is vital, however, in order to further define anthropogenic soils from different geographical contexts.

On the northern islands of Scotland more detailed interdisciplinary analysis of anthropogenic soils have illustrated considerable differences in typology and therefore varying definitions. In Scotland anthropogenic soils were initially identified in the Inch basin, Aberdeenshire (Glentworth, 1944) and later research on the island of Hirta, St Kilda revealed anthropogenic soils within an isolated island environment (Hornung, 1974). Further analysis on the remote northern isles of Orkney and Shetland found anthropogenic evidence in the soil horizons mapped by the Survey for Scotland's of the Bilbster series (Soil Survey for Scotland, 1982). Detailed mapping of these soils highlighted the depth which in places exceeded 75cm and included a deep S or S/A horizon (Davidson and Simpson, 1984). From this analysis the Scottish anthropogenic soils were described as "*Deepened Topsoils*". Such soils have a distinctive brown to dark brown colour due to a predominantly grass sod

manure, similar to the brown plaggen soils of the Netherlands (Davidson and Simpson, 1984; Simpson, 1985a).

The analysis also showed, however, that there was a great deal of variation in anthropogenic soils across different parts of the landscape. Farm mounds on Orkney showed very different soils, typically very black soils intermixed with layers of ashes (Pringle, 1874) from building debris (Lamb, 1980) or farmyard manure and house refuse (Grant, 1843; Fenton, 1978).

Results from detailed geoarchaeological and multi-disciplined analysis of Scottish anthropogenic soils illustrate that using the term 'Plaggen' to describe soil sequences in Ireland anthropogenic soils is incorrect and needs to be challenged. When compared to a range of sites from the Netherlands and the Scottish Islands the Irish anthropogenic soils illustrate little physical deepening despite occasional depths in excess of 850mm (Conry, 1971). A lack of detailed site-based fieldwork has not allowed any clear interpretations of spatial distribution. The work which has been conducted, however, does illustrate that human amendment with organic and inorganic material has occurred predominantly in cultivated areas and therefore should be named 'amended arable soils'.

The difference between anthropogenic and amended arable soils should therefore be defined thus and used throughout the thesis:

ANTHROPOGENIC SOILS:

Soils which exist because of the absolute necessity to 'create' an organic 'A' horizon within landscapes which contain shallow, poor quality soils which are unable to support annual cultivation. Intensive manuring with organic and inorganic material leads to a distinctive 'raised' A horizons, typically black/dark brown colour and in excess of 500mm deep. e.g. Traditional 'Plaggen' soils of the Netherlands and Germany, Terra preta and mulata soils of the Brazilian Amazon and deepened topsoils of Orkney and Shetland, Scotland.

AMENDED ARABLE SOILS:

Natural 'A' horizons which have been manured with organic and inorganic inclusions to amend/improve an existing arable soil. These horizons

demonstrate a dark brown to brown colour but no distinctive deepening compared to natural soils. The horizons also contain evidence of organic and inorganic inclusions typically peat, turf and calcareous sand alongside archaeological material. e.g. Ireland and SW England.

1.4.2 MULTIDISCIPLINARY ANALYSIS OF SCOTTISH ANTHROPOGENIC SOILS

The analysis of deepened topsoils in Scotland and especially the Northern Isles has been very closely associated with multidisciplinary scientific analysis, archaeological excavations and landscape surveys and because of this the analysis of Scottish anthropogenic soils is at the forefront of spatial, temporal and geochemical analysis using techniques such as micromorphology, (Bryant and Davidson, 1996; Davidson and Carter, 1997; Simpson, 1997, 1998; Guttman, et al., 2003; Mackenzie, 2006) particle size, (Bryant and Davidson, 1996; Simpson, 1997) magnetic susceptibility, (Dockrill and Simpson, 1994) stable carbon isotope analysis, (Simpson, 1985b; Simpson, 1997; Simpson, et al., 1999) image analysis, (Adderley, et al., 2002, 2006) total phosphorus analysis (Guttman, 2001) and multi-element analysis (Wilson, et al., 2005, 2006, 2008).

Simpson (1985b) utilised stable carbon isotopes to characterise the farm mound soils at West Marwick, Orkney. He showed that, as well as being quite different in appearance to the deepened topsoils, their composition was a mixture of turf, manure, ashes and a small marine input: seaweed and shells. From this evidence Simpson concluded that different manuring strategies were being used within each farmstead, on various parts of the farm and on contrasting farms across the Orkney Islands of Sanday and North Ronaldsay (Simpson 1985b). Particle size and micromorphological analysis have been utilised to show that the deepened topsoils of Marwick on the Mainland of Orkney are composed of grassy turves from the upland landscape surrounding the farmsteads (Simpson, 1997). Total phosphorus, stable carbon isotope and thin section analysis results also suggest that the soils contained high organic content deriving from turf, seaweed and animal manure. Lipid biomarker

analysis was conducted with the aim of determining the source of the manures present in the Orcadian soils (Simpson, et al., 1999). Deep topsoils were also discovered at Quoygrew on Westray, Orkney and these horizons were found alongside fish middens and farm mounds (Simpson, et al., 2005). The field and micromorphological evidence suggested that the soils were formed with organic rich turves mixed with animal manure in a very similar manuring process as that used at Marwick (Simpson, et al 2005). However, the initial choice of site may have been as a result of the pre-existing organic rich midden and farm mound material present.

At Tofts Ness, Sanday prehistoric deepened topsoils were analysed to determine prehistoric land management and answer questions about their formation and distribution (Simpson, et al., 1998). The identified anthropogenic horizons range from 300mm to 900mm deep and appear to have been formed from podzolised, grassy turf and burnt turf and ash (Simpson, et al., 1998). This soil formation process mirrors other areas around Orkney and also areas of prehistoric plaggen soils in the Netherlands (Pape, 1970).

The deepened topsoils of Shetland have been analysed to a lesser extent than those on Orkney, however, in several areas the soils are directly associated with settlement sites which have undergone detailed archaeological excavations. Anthropogenic soils commonly occur in small areas as seen at South Nesting (Dockrill and Simpson, 1994), Hill of Taing (Dockrill, et al., 1998) and Underhoull (Mackenzie, 2006) but the soils at Old Scatness and on Papa Stour are much more widespread. The site of Old Scatness is a multiperiod settlement site occupied from the Early Bronze Age to the Early Modern period (Dockrill, 1998). It is unique because it has deepened topsoils associated with the period of most concentrated settlement activity on the site, between the Late Bronze Age and Early Iron Age transition, and this has enabled a distinctive chronosequence and spatial distribution of the soils and settlement to be determined (Simpson, et al., 1998b). Analysis of the soils has been conducted to determine micromorphology, particle size, total phosphorus (Simpson, et al., 1998b; Guttman, et al., 2006), magnetic susceptibility (Batt and Dockrill, 1998; Dewar, et al., 2002) and optically stimulated luminescence (Burbidge, et al., 2001). The results of these analyses have illustrated a

distinctive similarity in date and formation with the Orcadian soil formation seen at Tofts Ness however the major difference between the two areas regards the use of peat.

The second major area of deepened topsoil analysis in Shetland is on the isolated island of Papa Stour (Bryant and Davidson, 1996; Davidson and Carter, 1998). Detailed historical evidence indicates that during the Viking and Norse periods the island was a key trading and transport link between Scandinavia and Iceland. Detailed field and laboratory work indicate that the deepened topsoils have been formed in a similar continental style to that of the Netherlands (Pape, 1970) and at Marwick (Simpson, 1997). Bryant and Davidson (1996) showed that there are considerably deeper anthropogenic soils in the kaleyard than in the peripheral arable farmland and outfield areas. This difference in depth was attributed to a decrease in organic input from the centre of the farm outwards. The organic material was formed by removing turf from the upland areas, storing it in byres in order to absorb animal urine and faeces and then mixing it with seaweed and hearth waste (Davidson and Carter, 1998). Alongside rural areas urban sites also illustrate distinctive evidence of the development of anthropogenic soils.

1.5 URBAN SOILS

The use of urban materials as manuring components for rural soils has been conducted for centuries, whether intentionally or not (Porteous, undated in Bridges, 1991) and that urban material has been drawn from a range of anthropogenic sources but most notably from middens, sewers, rubbish heaps and from building material. In western Europe the nature and composition of 'dark earth' has been analysed in great detail with micromorphology. The results showed that the soil consists of the remnants of urban materials, wood, brick, stone, daub, wattle and also a considerable charcoal and burnt fraction component which has accreted over many years from the decay of buildings and build up of sediments through processes including burning, bioturbation, compaction and weathering (Goldberg and Macphail, 2006).

The horizon has been identified in major urban centres in the UK at London, York, Winchester (Macphail, 1983; Yule, 1990) and in France at Paris (Cammass, et al., 1996; Guyard, 2003), as well as in Germany, Italy and Belgium (Goldberg and Macphail, 2006). Dark earth was initially thought to have been created by the post Roman decline in urbanism, however detailed laboratory analysis showed that the development was in fact due to either a change in urban land use (Macphail et al., 2003) or in other cases due to a swift change to a rural agricultural area, for example in Buraburg, Nordhessen, Germany (Henning and Macphail, 2004). London's Guildhall shows stratigraphic evidence of intensive Roman activity which after abandonment became a farmstead and then returned to urban use during the medieval period (Bateman, 1997).

The use of micromorphology in the study of 'dark earth' has enabled a systematic study of the formation processes on a site based level. Richard Macphail has succeeded in determining that the horizon is a highly complex series of sedimentation phases beginning during the post Roman period, Saxon, medieval and continuing up to post World War II Berlin (Goldberg and Macphail, 2006). Goldberg and Macphail illustrate that at different sites 'dark earth' formation has reached certain phases. At Deansway, Worcestershire the evidence shows a change from urban landuse, with brown earth from midden deposits, to small scale occupation and pastoral use with a mature brown earth development occurring over 600 years (Macphail, 1994). A more complex sequence has been analysed at the Courage Brewery, Southwark in London, where three phases were interpreted. The sequence shows a shallow (10 – 50mm) pararendzina layer packed with compacted anthropogenic occupation materials including lime mortar, plaster and brickearth floor layers of early Roman date. This initial horizon is overlain by a phase 2 dark earth soil consisting of calcareous brown earths with rich ash midden material associated with low level occupation and wasteland, indicating a move away from urbanism in the late Roman period (Macphail, et al., 2003). This is followed by total abandonment for over 600 years until A.D.1050 and the development of a dark brown calcareous earth interpreted as abandoned waste ground (Macphail, et al., 2003).

Most recently urban soils have also been analysed in and around the development of large medieval centres and their uses as highly fertile manuring material for personal 'garden soils' (Hortisols) as shown at St Andrews (Carter, 2001), Aberdeen (Murray, 1982), Perth (Bowler et al., 1995) and in agricultural land. At Nairn, Scotland, a process of "urban composting" appears to have been occurring where anthropogenic waste, including organic turf and animal dung was combined with charcoal, ash and sand, to soak up fluids and stored in large heaps before being deliberately relocated onto farmland creating a "deepened topsoil" (Davidson et al., 2006). This soil is not totally dissimilar to the classic 'dark earth' soils; they both have distinctly dark black colourations and contain a large quantity of urban anthropogenic inclusions. However, the 'dark earth's' have been associated with *in situ* deposition and archaeological features clearly distinguished by micromorphology. Analysis has also taken place on Scottish Burghs at Pittenweem, Fife and Lauder, Borders across the burgh core, and radiating outwards towards the settlement hinterland and agricultural land, to determine the levels of human addition to the soil profile (Golding and Davidson, 2005). In each case evidence of manuring was more extensive in the core of the settlements creating a deeper topsoil horizon compared to arable areas.

1.6 BLACK CARBON PARTICLES

Common to all anthropogenically influenced soils is the presence of black organic and inorganic inclusions which are associated with the addition of a variety of materials to the soil. In natural soils and sediments these inclusions are known as amorphous carbonaceous material or black carbon (BC). The study of BC has been conducted for over 20 years, and the term was initially used by Novakov (1984) who described it as "*combustion-produced black particulate carbon having a graphitic microstructure*" (Novakov, 1984, p124). Goldberg (1985) in his book entitled "*Black Carbon in the Environment*", showed for the first time that the chemical composition of BC consisted of <60% carbon and other elements including: hydrogen, oxygen, nitrogen and sulphur. He also conducted an in depth analysis into the

incomplete combustion formation process. Bullock (1985) placed BC in a larger landscape context by suggesting that, “*Black Carbon is one of the ubiquitous materials circulating around the surface of the earth. It is found in air, soils, sediments, crustal rocks, meteorites, waters and ices. Its universality is related to its refractory nature with respect to reactions with its surroundings and to its origin in burning processes, which are widespread*” (Bullock 1985, p69). The importance of BC as a global retainer of natural carbon was understood by the early 1980s (Seiler and Crutzen, 1980), however Bullock (1985) highlighted the fact that BC has an extremely long survival time and would therefore affect the Earth’s carbon pool.

Early work on BC was conducted on natural soils, including charred plant materials in volcanic deposits as a possible source of humic material (Kumada, 1983). However, abundant charcoal fragments had been identified and mapped in Terra Preta anthrosols of the Brazilian Amazon as early as the 1960s (Sombroek, 1966) and this divide clearly showed that a multidisciplinary approach was required for archaeologists and pedologists to understand the BC role in anthrosols.

BC FORM	Slightly Charred Biomass	Char	Charcoal	Soot	Ground Black Carbon
PRODUCTS					
Formation Temperature	LOW-----HIGH				
Size	-----mm +-----mm TO SUB MICRONSUBMICRON				
Plant Structures	ABUNDANT	SIGNIFICANT PRESENCE		FEW	NONE
Reactivity	HIGH-----LOW				
Initial Reservoir	-----SOILS-----SOILS AND ATMOSPHERE-----				
Palaeotracer Range	SHORT (m)	SHORT (m TO Km)		LONG (1000's Km)	

Figure 3, The black carbon combustion continuum model (Adapted from Hedges, et al., 2000)

A further obstacle in early pedological and archaeological analysis was the assumption that charcoal was the singular form of BC. Charcoal makes up

a great deal of BC inclusions as shown by the extensive studies of fire-affected soils, especially in wooded areas (Wright and Bailey, 1982). Further BC has been shown to originate at temperatures between 250 - 500°C due to incomplete combustion (Baldock and Smernik, 2002). However, at lower temperatures slightly charred biomass, and char is formed (Mackay and Roberts, 1982) and, at higher temperatures, soot (Akhter et al., 1985) and ground black carbon (Smith, 2002).

In 2000, BC was classified in the Combustion Continuum Model (CCM) which outlines all forms of black carbon from slightly charred biomass to soot and groundblack carbon (Hedges et al., 2000). The CCM (Fig 3) clearly shows how an increase in temperature forms each of the individual components, the inclusions size, remaining organic structure, reactivity, storage reservoir and the paleotracer range. The development of a clear model of the different variations of BC has proved to be indispensable to the analysis and formation of anthropogenic and amended arable soils but there are still some remaining problems.

Massiello (2004) states that the understanding of the various components of BC is essential for accurate interpretation of black carbon data, however there are also discrepancies which, although focused on natural BC inclusions in natural soils, are also clearly relevant to anthropogenic soils. The problems occur in the limited range of techniques available for analysis and a lack of good reference material to aid analysis and interpretation (Masiello, 2004). The three main problems are:

1. A lack of common definition of black carbon.
2. Potential under-reporting (i.e. failure to detect material understood to be fire derived).
3. Potential over detection (i.e. material not derived from combustion).

(Massiello, 2004)

In 2000 a long term research project was set up by the United States Geochemical Society (USGS) with the aim of creating a large database of BC reference materials to enable the positive identification of different forms in a

variety of environmental contexts. Samples from across the combustion continuum were collected together with aerosols, sediment and soil as well as a set of materials which were shown to be potentially created during analysis.

Two different soil types were taken: both with high levels of char. First, in a Pellustert, a common soil of the Vertisol order, characterised by a high clay content high nutrient capability and highly fertile. Such soils are common to Australia, India, East Africa and the USA. The second sample was from a 10,000 year old German Chernozem, a distinctive black soil with a high level of organic matter. Both the Pellustert and the Chernozem contained large BC particles, which were analysed using UV-oxidation NMR methodology to ascertain that the inclusions made up between 30 to 50% of the total organic carbon in the soil (Schmidt et al., 1999; Skjemstad et al., 1999).

There are a number of problems with the USGS's reference collection. Firstly, there is a very narrow collection of samples and none from Scotland, Ireland, and the Netherlands. Secondly, the 10,000 year old chernozem does not fully represent a period of large scale farming or manuring in Europe (Conry and Mitchell, 1971; Spek, 1992). Previous fieldwork has shown that these soils contain very large numbers of black carbonised particles (Pape, 1970; Conry, 1971; Davidson and Simpson, 1984) which has the potential to reveal information on past land use and agricultural methods. However, the analysis of BC in natural and anthropogenic soils has been conducted for many years.

1.7 BLACK CARBON ANALYSIS IN SOILS STUDIES

Past work on anthropogenic soils from around the world has shown that they contain an abundance of BC particles. Initially the identification of Terra Preta (Fimic Anthrosols) soils in the Amazonian basin highlighted the regular occurrence of BC particles (Sombroek, 1966). Investigations continued into the soil organic matter, nutrient holding capacity (e.g. N, P, Ca and K), soil pH values and moisture holding capacity (Smith, 1980; Zech, et al., 1990). Recent work has shown that BC makes up over 35% of the organic component and is responsible for the organic matter stability in the Terra Preta soils (Glaser, et

al., 2000) and contained 70 times more BC than surrounding soils (Glaser, et al., 2001). C¹⁴ dating also showed for the first time that these inclusions were between 1000 to 1500 years old and therefore had very high stability (Glaser, et al., 1998).

Initially Saldarriaga and West (1986) suggested that the origin of the BC sink had been deposited from Holocene wildfires burning large areas of woodland. This conclusion has been determined from the analysis of charcoal in woods across the world, including Australia, where charcoal generated by natural fires has been shown to constitute around 30% of the organic carbon content in soils (Skjemstad, et al., 1996), Siberia (Clark, et al., 1998; Czimczik, et al., 2003), Norway (Ohlson and Tryterud, 2000) and Canada (Lynch, et al., 2004).

Analysis of the boreal forests in Sweden showed that charcoal derived from forest fires had an important rejuvenation effect on primary woodland species of trees including *Betula pendula* and *Pinus sylvestris* as well as on mosses and ferns. When analysed, these species absorbed 6.22 times more nitrogen from the soil than soils without charcoal (Wardle, et al., 2004).

Before the onset of large scale land clearance for arable agriculture the majority of BC may well have been developed naturally but it would not have taken long for humans to increase the amount of charcoal present in the soils through the process of “slash and burn”. This process developed a sustainable agriculture through transforming soil horizons, improving nutrient availability and recycling natural components in a relatively organised manner. Erickson (2003, p201) states that *“Amazonian peoples developed complex societies, developed sustainable and an intensive agriculture”* and quite correctly states that a multidisciplinary approach to analysis of BC is essential.

In contrast to the forested areas of the world there are also anthropogenic soils with high quantities of BC which have not been formed by the intense burning of forest or woodland. Czimczik and Masiello (2005, p87) state that *“soils enriched in black carbon are not necessarily found in areas with the highest fire frequency or with the largest black carbon production (woody vegetation). Rather than high production, the accumulation of black carbon in soils requires that both input and protection are maximised”*. One

such area is the North American grasslands (Collins, 1990) where many large scale fires were deliberately started by humans to directly alter their environment and therefore one might expect large amounts of charcoal in the soil as a result. However, it is clear from soil and pollen analysis conducted on the Scottish Islands that carbonised material is also present within anthropogenic soils which have had little to no tree cover either today or in the past, and this occurrence must be may due to human intervention (Simpson, 1997; Davidson and Carter, 1998).

Similar research on the Xanthic Ferralsols and Fimic Anthrosols (Terra Preta soils) of the Amazonian Basin determined whether BC particles could increase plant growth (Glaser, et al., 2002). The results showed that charcoal additions increased crop outputs of rice by 17% in the anthrosols but that the Ferralsols appeared to be improved by elemental additions of P, K and Cu. Analysis of the BC particles was conducted using the Thermal and Ultra Violet Oxidation and the benzene polycarboxylic acids (BPCA) method (Glaser, et al., 1998), however, Simpson and Hatcher (2004) criticised the methods as creating drastic overestimations and unacceptable analytical errors affecting results and interpretations and suggested a sodium chlorite oxidation method as an alternative. Since 2004 the BPCA method of analysing BC particles has been amended several times to attempt to correct the methodological inaccuracies (Brodowski, et al., 2005).

Since the creation of the BC reference database and the move towards a multidisciplinary research agenda, there has been a major increase in the amount of research into BC (Hammes, et al., 2007). However, many basic problems of characterisation and quantification still remain in a number of the methodologies including UV photooxidation (Skjemstad, et al., 1999), thermal optical transmittance and reflectance (Schmid, et al., 2001), Acid dichromate oxidation (Song, et al., 2002), chemo-thermal oxidation (Elmqvist, et al., 2004), thermogravimetry coupled with differential scanning calorimetry (Lopez-Capel, et al., 2005). Quénée et al (2005) have also attempted to solve the problems of over and under estimation with a detailed analysis of BC particles in forest and cultivated sandy soils. The study focused upon Refractory Organic Macromolecular Materials (ROMM's) from the Landes de Gascogne region of

France. Quantification was conducted by chemothermal oxidation (CTO) but key to the investigation was the discovery of two types of BC highlighted through High Resolution Transmission Electron Microscopy (HRTEM):

1. Irregularly shaped with randomly orientated basic polyaromatic units. (Predominant)
2. Small spherical, highly organised, concentric “onion-like” microtexture.

Examination of the BC after the CTO process showed that the “erratic” less well structured BC had all but been removed leaving only the highly organised material. When analysed against the hand-picked samples for woodland versus arable soil there was a 60% difference in the arable soils suggesting that the unstable form of BC was of natural origin. Theoretically then the closer to the source area for BC, the more stable the polyaromatic BC becomes.

Quantification analysis was also conducted by Balabane et al., (2005) on agricultural soils containing coal fragments to gather data about the spatial distribution and morphology of BC. The research showed that four different morphological types could be classified according to their carbon content.

1.8 BLACK CARBONISED PARTICLES AND ARCHAEOLOGY

The amalgamation of scientific methods and archaeological analysis has greatly improved the current understanding giving detailed information on the formation, spatial variation, character and context within varying landscapes and sites. Within archaeological deposits and anthropogenic soils, artefacts and palaeoecological inclusions have been classified into three groups (Renfrew and Bahn, 2001) as follows:

1. Primary – Residues or refuse deposited within an activity area
2. Primary transported – Refuse deposited away from original area (rubbish dumped in the street)

3. Secondary use-related refuse – Removed and reused (infill of building or manuring fields)

Evidence of burning have been interpreted in a number of forms by archaeologists. Combustion features such as hearths, ovens and fires have been analysed (Meignen, et al., 2001) alongside the differences between floor space and from open areas (Cammis, 1994) and domestic and stabling landuse areas (Matthews, et al., 1997).

Within archaeology, the frequency, size and type of burnt materials have been used to determine anthropogenic effects on soils and interpret particular archaeological features. The varieties of burnt materials will depend upon the temperature of the fire in which they are combusted and the type of material burnt. The most common form of anthropogenic BC is large macro sized charcoal particles measuring millimetres and visible to the naked eye to excavators in the field.

During the early development of farming areas woodland needed to be cleared in order to conduct arable and pastoral agriculture. This process involved felling trees with stone, and later metal axes, but this was time consuming and was expediated with man's understanding of fire. The controlled burning of vegetation created open areas and provided nutrients to the soil in several forms. Carbon by-products formed from burning include: carbon dioxide and fine ash, which is lost as smoke into the atmosphere; coarser ash and charcoal deposited on the surface of the soil and burnt earth which is within the soil profile.

The process of burning can have a number of effects on the soil. On the soil surface the humus is dried and burnt; trees can be uprooted encouraging erosion; deep rooted plants can be burnt and increase leaching; and micro-organisms can be killed reducing the rate of organic breakdown. However, the benefits of burning include the creation a very organic, nutrient rich soil well suited for growing crops. The origin of small numbers of charcoal and ash inclusions within natural soils have been associated with natural forest fires started by lightning strikes, but usually carbonised deposits are found in distinct concentrations and are associated with deliberate woodland clearance.

Romans and Robertson (1975) have proposed that wood charcoal in buried topsoils is likely to be due to early woodland clearance for farmland and this was tested and reproduced in a simulation process at Umeå, an experimental farm in Sweden, in cultivated podzols (Cruise and Macphail, 2003). Extensive work has also been carried out on tree-throw features to determine whether they contain evidence of deliberate felling. Concentrations have been located which contain considerable burning and charcoal evidence which suggests that *in situ* burning was carried out in the past (Barclay, et al., 2003).

1.9 BLACK CARBONISED PARTICLES AND MICROMORPHOLOGY

Of all the methodologies employed, micromorphology is widely considered to constitute the best tool with which archaeologists and soil scientists can, through a multi-disciplinary approach, determine micro scale contexts for soils (Stoops, 2003). The results from micromorphology can be integrated with those from other techniques to form detailed local and regional interpretations. Initially utilised by Harrison (1933) to analyse weathering processes it was really pioneered by Kubiëna (1938) who advanced the understanding of soil formation processes (Kubiëna, 1970). Between the 1970s and the present micromorphological analysis and description has been developed with important systematic amendments from Bullock et al., (1985), Courty et al., (1989), FitzPatrick, (1993) and Stoops, (2003).

Micromorphology has been utilised to analyse carbonised layers within prehistoric cave deposits (Karkanas, et al., 1999; Macphail, et al., 1997) The occupation of caves in the Palaeolithic period led to the development of distinctive anthropogenic soils which have been excavated throughout the Middle East (Goldberg and Bar-Yosef, 1998) and South Africa (Marean, et al., 2000). These horizons are typically very dark coloured, organic rich soils and contain large quantities of charcoal and ash along with mineral, bone fragments and burnt earth (*terra rosa*) (Sherwood and Goldberg, 2001). Prominent archaeological features such as hearths and firebases have been interpreted through the discovery and analysis of burnt soils and the recording

of soil texture, colour and inclusions can indicate the type of feature present and the range of materials burnt, the duration and intensity of burning and the redeposition of burnt residues (Meignen, et al., 2001).

The development of more complex settlement sites, such as tells, occupied in the eastern Mediterranean during the Neolithic and Bronze Age resulted in incredibly complex soil stratigraphies. Ongoing occupation over thousands of years has led to the cyclical building and destruction of houses, and this process has been interpreted as the creation of the occupation mound (Davidson, 1973). Micromorphological analysis at Çatal Höyük in Turkey has illustrated compacted floor sequences indicating a complex history of occupation as well as domestic, agricultural, industrial and ritual activities (Matthews, et al., 1996; 1997).

At Tofts Ness on the island of Sanday, Orkney turf material was burnt and then deliberately added to arable soils as part of the manuring process utilised in the northern isles of Scotland. The carbonised fragments were found with burnt oxidised stones which indicates that the burning of vegetation as a method of clearance was carried out before turf stripping but were also incorporated with fine ash deposits from domestic hearths indicating that the raw turf was also being collected and used for fuel (Simpson, et al., 1998a). On the island of Papa Stour, Shetland, numerous carbonised and non-carbonised fragments were found in the arable soils and these were identifiable by their distinctive internal structures as peat and peaty-turf fragments and indicates the use of these raw materials as a fuel source. The inclusion of mineral fragments of rhyolite within the carbonised particles suggests that the source of the peaty turf fragments was from the island and had not been imported since rhyolite is found almost nowhere else in Shetland other than Papa Stour (Davidson and Carter, 1998).

At Quoygre, Orkney carbonised and non-carbonised peat fragments were analysed, using micromorphology, alongside bone, phytoliths and diatoms to determine the origin of a fish midden deposit and farm mound (Simpson, et al., 2005). In the fish midden the carbonised particles were in the form of fine grained calcium carbonate amorphous crystals associated with peat ash residue from burnt plant organics. The distribution of these crystals

through the deposit was found to be randomly orientated, and dusty coatings found upon the particles indicated post burial movement through the soil profile. In the farm mound there was a larger range of coarse and fine carbonised particles typically black in colour and a number of uncarbonised reddish-brown organic fragments interpreted as peat and turf fragments due to their distinctive internal structure and mineral content (Simpson, et al., 2005).

Date	Tofts Ness (Orkney)		Old Scatness (Shetland)	
	Soils	Middens	Soils	Middens
Neolithic	0.5 – 5% charred peat/turf fragments and very rare wood charcoal	2-5% charred peat/turf and very rare wood charcoal	Charcoal from burnt peat and/or turf throughout the deposit 5 – 15% trace amounts of wood charcoal	-
Bronze Age	<0.5-15% peat ash and 0-2% woody charcoal	-	Charcoal from burnt peat and/or turf throughout the deposit 5 – 15% trace amounts of wood charcoal	-
Iron Age	Sandy soils with charred peat 0.5-5% and <0.5% wood charcoal	Large quantities of charred peat 5 – 30% and wood charcoal 0.5 – 2%	0.5 – 2% charred peat/turf fragments with unburnt peat and shell sand which includes <0.5% fine charred material	Large proportion of charred peat 2-5% 3 samples 5-15% 5 samples 15-30% 3 samples

Table 2, Summary of the distribution of carbonised particles from anthropogenic soils and middens from two multiperiod settlements from the Northern Isles of Scotland (Adapted from Simpson, et al 1998a; Davidson and Carter, 1998)

Experimental work on the sources of components found in anthropogenic soils was conducted at Sanday, Orkney and Tofts Ness, Shetland. Alongside organic fragments of peat, turf and sheep and cow dung; carbonised fragments of peat ash, charred peat fragments, coal ash were

catalogued along with peaty turf particles created by burning at 400°C and 800°C to represent an open fire and industrial hearth context. This work was conducted to try and quantify the types of organic fragments in a range of archaeological deposits and to aid interpretation (Guttmann, et al., 2006).

The incorporation of a suite of carbonised particles allowed vital interpretations to be made about arable soils and midden archaeological deposits found during excavation (Table 2). Distinctive differences in the amounts of carbonised particles were found within the soils and middens from both sites. Peat and turf were the main materials burnt but in many of the soils peat ash was also identified by micromorphological analysis as a light yellow fine grained deposit, and at both sites there was very little wood charcoal suggesting peat and turf were the main fuel sources. The arable soils contained less carbonised particles than the middens in each period, however, at Old Scatness the Neolithic to Iron Age soil had a considerably higher percentage than Tofts Ness.

Carbonised Particles Area (10⁵µm²)	LANDUSE			
	KALEYARD	RIG	PLANTICRUE	GRAZING
Bragasetter	39.3	20.6	6.2	1.6
The Biggins	46.8	28.2	17.4	8.6
Hamna Voe	148.4	28.9	26.8	51.9

Table 3, Summary of the areas of carbonised particles from four landuse areas across three farms on Papa Stour, Shetland (Adapted from Adderley, et al., 2006)

The black carbonised particles and inclusions of other domestic waste products including bone, shell and excremental pedofeatures suggested that the midden had been incorporated into an arable field system in a change of

landuse and had therefore become incorporated into the arable soil. The largest quantities of black carbonised particles came from the Iron Age middens found at both sites which amongst other anthropogenic components includes between 2-30% charred peat fragments.

The use of image analysis to quantitatively assess different classes of manuring components has been conducted at three sites on Papa Stour, Shetland (Table 3) across a number of comparative landuse areas in order to interpret the manuring process (Adderley, et al., 2006). Four particular objects were chosen for analysis: carbonised organic material, rubified organic material and two forms of uncarbonised organic material. The analysis showed that there was a distinctive difference between the size of carbonised particles across each of the farmsteads and the four landuse areas reflecting the distance of particular areas to the source of domestic waste. Small localised difference represented variations in the historical manuring process and big anomalies like in the grazing area of Hamna Voe were ethnographically unexpected and possibly due to the burning of in situ organic material. Measurements of magnetic susceptibility expresses the 'magnetizability' of a material in minerals, rocks and soils which can be used to interpret environmental conditions at the time of deposition (Thompson and Oldfield, 1986). The magnetic susceptibility of a sample is calculated by determining its attractiveness to a magnet but size, shape and mineralogy is of great importance to the result and various soils and sediments have a number of levels of magnetic behaviour.

Of all the levels of magnetism the paramagnetic category occur most commonly in soils and sediments and include a range of particles with Fe^{2+} , (Ferrous) Fe^{3+} (Ferric) or Mn^{2+} ions in a variety of sizes from very small clay particles (chlorite, smectite and glauconite), iron and manganese carbonates (siderite) and ferromagnesian silicates (olivine, amphiboles and pyroxene). Primary anthropogenic activities can also lead to increases in magnetic susceptibility within individual houses and settlements and fields where in situ increases in magnetic susceptibility occur (domestic and industrial fires and agricultural burning) and through secondary redistribution of domestic refuse

(charcoal, ash and burnt bone, pottery, smelting) on to agricultural areas as part of a manuring regime.

Organic Manure Components	Temperature	
	400°C	800°C
Humic Peat	Dark red/brown/black colour with rubified texture and structural disruption. Frequent phytoliths and few diatoms	Totally combusted fragments very dark brown to black. Very few phytolith and diatom inclusions
Mineral Rich Turf	Dark red/brown colour with rubified structure, very few phytoliths and very few diatoms	Totally combusted fragments, very dark brown to black colouration. Very few phytolith and diatom inclusions
Sheep Dung	Fine mineral material light brown (ppl), grey (oil)	Very fine mineral residue grey colour (ppl) white/grey (oil)
Cow Dung	Distinctive black isotropic organic material with rough to serrate edges	Very fine mineral residue grey colour (ppl) white/grey (oil)
Birch (<i>Betula pubescens</i>)	Frequent charcoal fragments, rod like and rounded shape. Dark grey to brown (ppl) fine mineral material.	Fine grained pale brown (ppl) and light grey (oil)
Willow (<i>Salix lanata</i>)	Macro charcoal fragments, with porous structure. Dark grey to brown (ppl) fine mineral material.	Fine grained pale brown (ppl) and light grey (oil)

Table 4, Summary table of micromorphological descriptions of ash residues from historical fuel resources (Adapted from Simpson, et al., 2003)

Mineral magnetic measurements associated with black carbonised particles have been used to develop a technique for identifying particles formed by natural fires versus anthropogenic burning (Bellomo, 1993). The development of a suite of results has been used recently to provenance the

organic materials used as possible fuel sources. Samples of peat turf, fibrous peat, well humified peat and wood were burnt and the magnetic susceptibility of the resultant ashes and carbonised residues was tested and placed in a bioplot to enable comparison with samples from archaeological sites and ascertain a provenance (Peters et al., 2001). The susceptibility bioplot was tested against carbonised particles from an Iron Age hearth and medieval hearth and floor from a multidisciplinary site on the Isle of Lewis (Church and Gilmour, 1999). In each occasion the bioplot suggested that the carbonised material consisted of well humified peat and small quantities of peat turf both present in large quantities on the island and fits with a historical manuring tradition found elsewhere in the northern and western isles of Scotland.

Magnetic susceptibility, gradiometry and archaeomagnetic data has been used for site prospection, dating and modelling of anthropogenic amendment across large multiperiod archaeological sites to interpret changes in landuse (Batt and Dockrill, 1998). At Old Scatness magnetic susceptibility was used to provenance burnt material found in Iron Age and Pictish middens. Both features contained dark grey fine organic and carbonised particles but the Iron Age feature also contained thin bands of red/orange layers and the analysis of these together with a series of organic analogues suggested that the features consisted of mainly burnt turf and peat (Dewar, et al., 2002).

Fuel ash residues were analysed from several middens at two sites in Iceland and compared to a series of carbonised organic deposits taken to try and provenance fuel material (Table 4). At the high status site of Hofstadir analysis indicated that the fuel sources consisted of peat, mineral based turf and birch wood were used early in the development of the site but later there was a shift to wood ash residues from birch and willow for both low and high temperature burning. Peat was used in large quantities for high temperature burning throughout the settlement history. In contrast the low status site of Sveigakot initially utilised mineral based turf and some wood material but then shifted to burning cow and sheep dung with a complete absence of peat burning. Simpson et al., (2003) suggests that the change in fuel resources can indicate changes in the prosperity of sites. The eventual demise of Sveigakot

can be seen from the switch from a similar fuel source seen at Hofstadir to a considerably poorer source of fuel from animal dung.

1.10 KEY RESEARCH THEMES

It is clear that there is a fundamental link between black carbonised particles and elemental concentrations within natural and anthropogenic soils and archaeological features. However there are a number of key questions which require analytical attention and are the key themes of this thesis. Firstly, it is important that the various forms of BC should be categorised and quantified. Detailed descriptive micromorphology, zone count analysis and experimental work have shown that black carbonised particles within anthropogenic soils consist of charcoal and carbonised organic manure components however there are also a large number of black carbonised and black amorphous inclusions which remain unidentified and these inclusions require further analysis to determine their form and function within the soils.

The identification of charcoal and carbonised particles forms the main part of the identification of archaeological features in soils. In many cases they are primarily inclusions associated with anthropogenic deposition within in situ features such as hearths, ovens, open fires and the destruction of structures by fire (Courty, et al., 1989). However they can also be secondary deposits associated with deliberate dumps in pits, middens and agricultural spreads attributed to the manuring of arable land.

In the macro form archaeologists can easily identify carbonised particles by their black coloration and granular form, but micromorphology is needed in order to sub-categorize carbonised particles further. This is an essential practice in order to determine what materials have been burnt and to identify possible source manure materials.

Charcoal is the most recognised carbonised particle in anthropogenic soils and well preserved fragments typically have a sub-rectangular shape and contain detailed internal structure. This structure takes the form of well ordered circular to semi-ovoid void spaces of progressively larger size (Plate 1) which fossilise the original anatomical structure of wood of the burnt fragment.

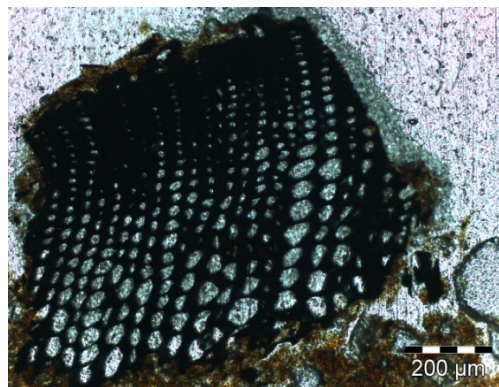
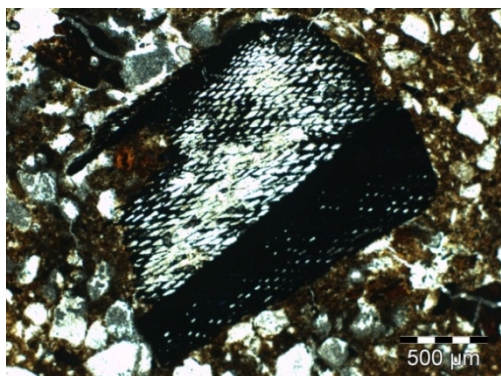


Plate 1, Two distinct charcoal particles (ppl)

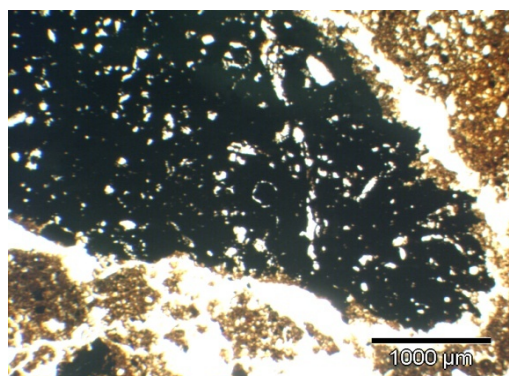
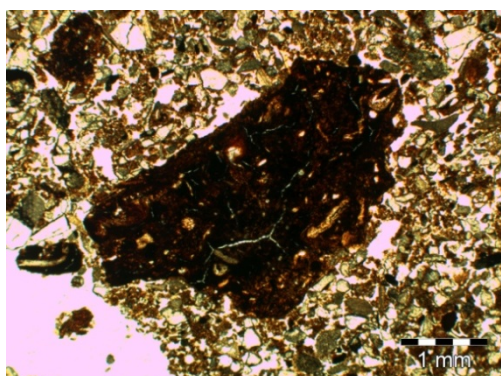


Plate 2, Turf and carbonised turf fragments (ppl)

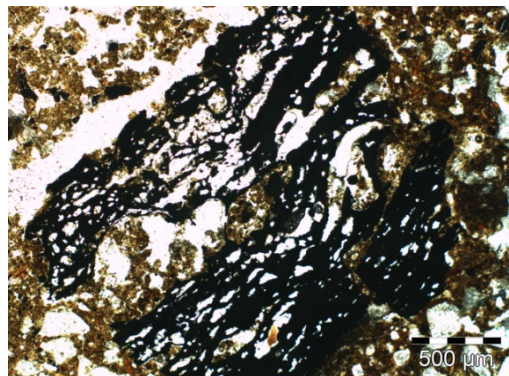
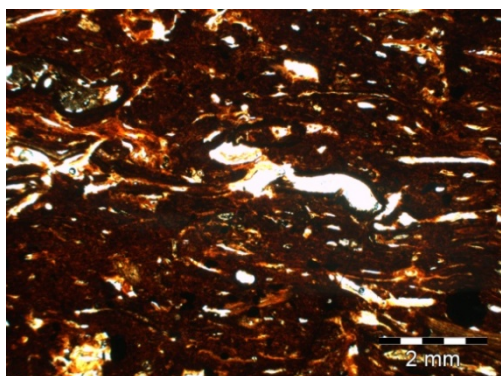


Plate 3, Peat and carbonised peat fragments (ppl)

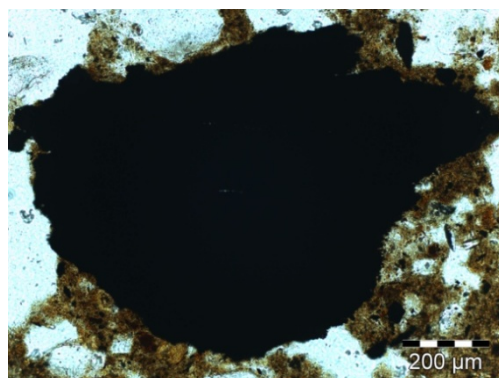
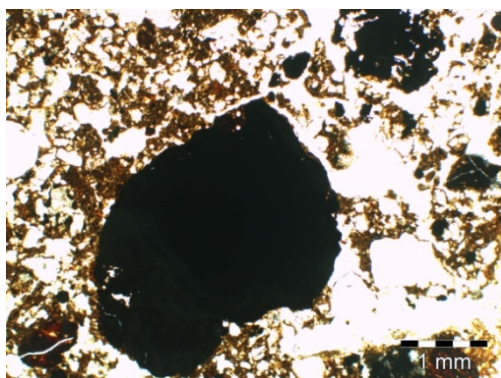


Plate 4, Two samples of amorphous black fragments (ppl and xpl)

In contrast the turf and peat fragments (Plates 2 and 3) contain irregularly shaped, elongate voids positioned in a roughly linear orientation. This arises from the compaction of organic material during the formation process and can contain inclusions of phytoliths, diatoms and spores. Detailed analysis of carbonised peat and turf fragments in the Northern Isles of Scotland has shown that these particles are particularly resistant to post burial pedogenesis and so the distinctive internal structure is retained (Davidson and Carter, 1998; Carter, 1998, Canti, 2003a). Previous work on these particles has shown that alongside the identifiable inclusions of carbonised particles there are also a large number of black amorphous particles (Plate 4) which have also been used to interpret past land practices (Davidson, et al., 2007). The categorisation and identification of the amorphous particles has also been analysed by experimental methods in order to try and replicate the carbonised particles as well as to understand the processes by which the particles were created (Simpson, 1997 and Guttman, 2001).

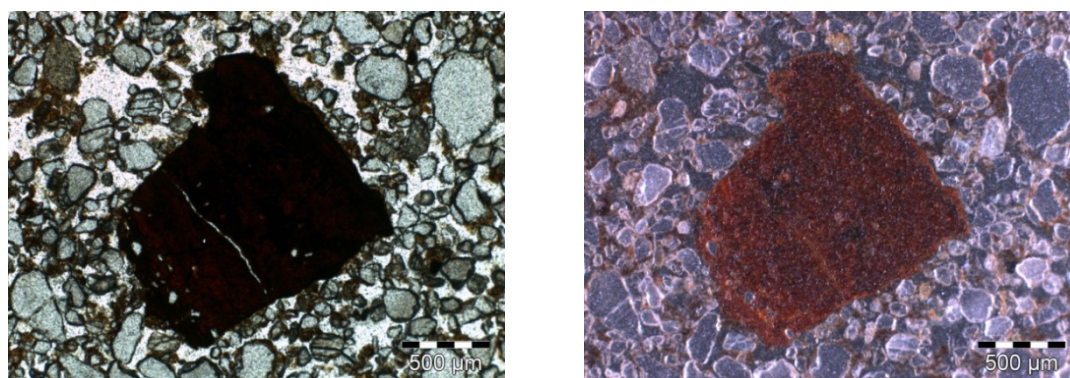


Plate 5, A fragment of burnt mineral material; black in plane polarised light (ppl) but red/orange in overhead incidental light (oil)

The rarest forms of carbonised particles and the hardest to identify are the fragments of burnt/charred plant material and ash layers because of their structural delicacy. Very careful analysis of micromorphological samples can reveal discrete burning evidence in the form of very fine grained yellow concentrations with small charred particles (Guttman, et al., 2006). However, it is far more common to find concentrations in middens and rubbish pits than anthropogenic soils (Carter, 1998) because of post burial reworking by

ploughing, leaching and biological consumption (Courty, et al., 1989). The addition of plant ash can be determined by the presence of microcrystalline, elongate silica crystals or vesicular, glassy slag remnants formed during the burning process (Canti, 2003b). The presence of these silica inclusions in large numbers has been used to interpret the clearance of vegetation by burning for arable agriculture (Simpson, et al., 1998). Interpretation of carbonised particles becomes extremely difficult when there is no internal structure. This can arise because of the way the slides have been produced and the cross section exhibits a slice of an inclusion in between void spaces or simply because the particle never contained any internal detail, either way this makes identification and interpretation extremely difficult and in many cases these particles are merely classed as amorphous black particles (Plate 4). The lack of internal detail can also lead to the misinterpretation of particles without proper descriptive analysis. Plate 5 also shows a black particle with little internal detail when viewed under plane polarized light (PPL) and interpretation at this stage may lead to the erroneous view that it was a fragment of BC. Under oblique incident light (OIL) however the fragment clearly has a reddish/orange colouration showing partial heating or burning and more of the internal detail is revealed indicating the mineral nature of the particle.

Alongside detailed micromorphology, point counting and image analysis the form, provenance and nature of the black carbonised and black amorphous inclusions can be determined using elemental analysis. Specific elemental analysis of organic and inorganic inclusions has derived from the elemental analysis of anthropogenic soils. Anthropogenic manures, especially from settlements, contain distinctive concentrations of elements and therefore their addition to anthropogenic soils can aid the interpretation of the formation and development of soil horizons. On a broad scale the detection of Ca from the Irish Plaggen soils has been linked to the addition of beach sand (Conry, 1971), and high P, N and K levels have indicated the addition of organic rich domestic manuring components (Holliday and Gartner, 2007). Elemental analysis has, however, also been utilised in a number of geoarchaeological problems to aid site prospection (Aston, et al., 1998; Schlezinger and Howes, 2000) as well as determining archaeological features including domestic areas

(Middleton and Price, 1996), hearths (Pierce, et al., 1998) and industrial areas (Eschel, et al., 2002). Elemental analysis has also successfully been applied to the interpretation of landuse areas and manuring processes (Entwistle, et al., 1998 and 2000; Wilson, et al., 2007) as well as the development of anthropogenic soils (Carter, 2001; Davidson, et al., 2006 and Davidson, et al., 2007). Research into the significance of particular concentrations of elements and possible function areas has suggested that Ba, P and Ca are particularly good for identifying organic waste disposal areas, and have been studied in detail from both anthropogenic dumps and archaeological features (Parnell, et al., 2002) and manured arable soils (Wilson, et al., 2005; 2006 and 2008) whereas concentrations of Ca and Sr have been shown to occur commonly in hearths and Pb in hearths, middens and houses (Wilson, 2005). Particular elements have also been identified as being of minimal use in functional interpretation, namely Ti, Zr and Al (Wilson, 2005), but it is still important to test for these elements as there are a number of post depositional soil processes along with the effect of geology and hydrology which can all create a false impression of enhancement (Wilson, et al., 2008).

Elemental analysis with scanning electron microscopy (SEM) has been used in the past to determine between organic and mineragenic sources (Skjemstad et al., 2002), the analysis of BC morphology in natural environments (Goldstein et al., 1992; Rose et al., 1994), oxygen:carbon ratios (Stoffyn-Egli et al., 1997) and trace element content (Stoffyn-Egli et al., 1997; Meharg et al., 2006; Wilson et al., 2008).

For the Terra Preta soils analysis showed that the particles made up over 35% of the organic component and were responsible for organic matter stability (Glaser et al., 2000) as well as containing over 70 times more BC particles than surrounding soils (Glaser et al., 2001). Experimental work conducted to determine the benefits of BC to plant growth in Xanthic Ferralsols and Fimic Anthrosols showed that charcoal additions increased crop outputs of rice by 17% in the anthrosols and that the Ferralsols appeared to be improved by elemental additions of P, K and Cu (Glaser et al., (2002).

Elemental analysis of the anthropogenic soils on the island of St Kilda illustrated distinctive concentrations of Pb and Zn and the results were linked to

the use of peat and turf ash especially in the kaleyard areas, because of a limitation in manuring components (Meharg et al., 2006). The research also suggested that the high levels of metallic elements was a rare occurrence among the islands of Scotland as few other surveys had discovered such high levels of elemental contamination (Meharg et al., 2006). However, higher levels of As have been identified in peat soils manured with seaweed (Castlehouse et al., 2003). Black carbonised particles identified in urban Scottish soils have also demonstrated high amounts of P and Ca associated in anthropogenic soils with high Sr, Hg, Zn, Cu, Ba, Cr, As and Pb (Davidson et al., 2006) alongside sites in Norway (Tijhuis et al., 2002) and China (Lu et al., 2003).

Following the success of the research into identifying elemental differences from contrasting functional areas of small farmsteads (Wilson et al., 2005), further research has been conducted upon the elemental concentrations within bone and black carbonised particles (Wilson et al., 2008). The results highlighted high levels of Zn and Cu in bone and mineral inclusions but only P and Ca in the carbonised particles even though the manually extracted charcoal inclusions from soils contained sources of Ca, Ba, Cu, Sr, Zn and Pb. Scanning electron microscopy analysis of charcoal inclusions did contain a wider suite of elements but these inclusions were old carbonised particles and considerably lower levels were found in more recently deposited charcoal inclusions leading Wilson (2008) to suggest that there was a significant level of post-depositional uptake.

Clearly this is of great importance, as is the understanding of soil processes over time and the effects of leaching and podzolisation need to be considered alongside further research into the elemental loadings of the many forms of black carbonised particles. As Stoffyn-Egli et al., (1997) states, however, the greater challenge is to distinguish between BC particles and organic matter and more analysis and interpretation is required on the elemental content of black carbonised particles within anthropogenic soils to increase understanding of formation through history.

It is felt that a reanalysis of anthropogenic and amended arable soils across a wider regional and European context is needed, and one which utilises a distinctive interdisciplinary approach; combining geoarchaeology,

environmental science and agrarian history in order to fully understand their form and function at a macro and micro analytical scale.

1.11 THESIS AIMS

1. To develop the understanding of knowledge of the spatial distribution of anthropogenic and amended arable soils across local and regional areas of NW Europe
2. To clearly understand the soil formation processes, provenance of organic and inorganic input materials and the soils present state. This will allow clearer comparison and contrast between local and regional sites.
3. To develop a more complete understanding of the form and function of anthropogenic and amended arable soils at a microscopic level. In particular a detailed analysis of the form and function by identification and analysis of organic and inorganic manuring components alongside post burial soil processes.
4. To understand in more detail the role of black carbon particles present within anthropogenic and amended arable soils and determine their importance to local/regional manuring strategies; ability to provide palaeoenvironmental information regarding the soils form and function and their role as retainers and transporters of key elements.

The main aims of the thesis will be answering a number of localised, site based objectives which will develop the understanding of the form and function of anthropogenic and amended soils but will also allow the main aims of the thesis to be addressed.

The first objective of this thesis is to spatially understand the soils present in a range of landuse areas at three small marginal farms across north west Europe. The sites will be located at Shirva, Fair Isle; a small marginal, isolated croft farmstead, part of the Shetland group of islands and is an ideal example of an island landscape. The second site is Olthof, in the Netherlands a marginal, continental site with an excellent historical record of plaggen

manuring and recent archaeological and geoarchaeological investigation. The third site is at Caheratrant, County Kerry, Ireland. The site is a marginal, coastal area on the Dingle Peninsula with a history of organic manuring especially with calcium carbonate sands a process distinctive to SW Ireland.

Each site was chosen in order for a direct comparison of the soils associated with three main landuse areas the kaleyard or garden area, the arable infield area defined by historical and cartographical documentation and arable evidence of the ground surface including field boundaries, rig and furrow and local history sources.

The anthropogenic soils discovered on Orkney and Shetland have been found over 1.25m deep in places and yet unlike Papa Stour (Bryant and Davidson, 1996; Davidson and Carter, 1998), Fair Isle has been under explored even though the historical facts indicate that during the Viking and Norse periods the island was an important trading point between people travelling between Scandinavia, Iceland and Greenland. Analysis conducted on the island in 1994 showed that prehistoric anthropogenic soils were present to the north of the island (Chrystall, 1994) however, historical sources show that occupation since the Viking has been confined to the southern half of the island (Hunter, 1997), an area never analysed for deepened anthropogenic topsoils. The key questions for Fair Isle are therefore:

1. Do deepened topsoils exist in the southern half of Fair Isle where settlement has been present and arable agriculture conducted in the past?
2. What is the form and spatial distribution of any anthropogenic soils on Fair Isle, and how do they compare with spatial, chemical and physical analyses from Orkney, Shetland and the Western Isles?
3. Are there any fragments of charcoal, black carbonised and black amorphous inclusions and what do these indicate about manuring practices?

In the Netherlands extensive anthropogenic soils, formed by the traditional plaggen process, have been found across large areas of the country

and are in some areas over 1.5m deep (Pape, 1970; de Bakker, 1979; van Smeerdijk, et al., 1995, van Mourik 1997). The initial mapping of the plaggen soil identified two distinct types; the brown plaggen soil and the black plaggen soil indicative of the application of two different types of manure (Pape, 1970). At Olthof, despite multiple archaeological excavations, the plaggen soils have not been thoroughly assessed in the context of the settlement history (Appels, 2003), however, geochemical and physical analysis was conducted on the soils in the context of modern day landuse areas to determine differences in the manuring inputs (Dercon, et al., 2005). The key questions for Olthof, the Netherlands are therefore:

1. Do brown and black plaggen soils exist at Olthof and what is their form and spatial distribution in relation to natural heathland and meadowland soils?
2. How do the plaggen soils at Olthof compare with the spatial, chemical and physical analyses from other areas of the Netherlands?
3. Is there any macro evidence of organic or inorganic inclusions of anthropogenic origin and what can these indicate about input from settlement centres?

Extensive field analysis in Ireland has lead to the discovery of anthropogenic soils across the south and west of the country (Conry, 1971) especially with calcareous beach sand and organic material. Early analysis however focussed simply upon the identification and did not take into consideration the spatial distribution, form or function of the soils (Conry, 1971). At Caheratrant anthropogenic soils were identified through minimal fieldwork (Conry and Mitchell, 1971) and therefore a number of key research questions are still to be answered:

1. Do the Irish anthropogenic soils constitute plaggen soils as determined in the Netherlands and Orkney?
2. Do anthropogenic soils exist across large areas of Caheratrant farm or are the soils restricted to Conry's sample area?

3. Is there any spatial pattern of anthropogenic input between the settlement centre and arable land at the hinterland of farming areas?
4. What macro evidence exists of organic and inorganic inclusions to the soils?

The second objective is to determine the physical and chemical state of the identified soils in the contrasting landuse areas in order to fully understand the complexities between human additions and natural variations. This would be done by analysing:

Soil pH:

To ascertain the present state of the soils and determine the influence of anthropogenic additions and parent material upon the soils at each of the sites and within the varying landuse areas.

Loss on Ignition:

To determine the different quantities of soil organic matter present in the soils and to indicate the possible addition by manuring.

Particle Size Analysis:

To determine the nature and texture of the anthropogenic soils and compare them with other organic and natural soil horizons and sediments. The analysis would also indicate differences in the physical nature of soil e.g. structure, drainage, organics which in some cases can be attributed to human action.

Magnetic Susceptibility:

Conducted on a range of soils at the three sites in order to determine the extent of anthropogenic addition in and around the settlement centres, and to compare and contrast the different anthropogenic soils and landuse areas.

Multi-Element Analysis:

Conducted on a range of soils from the three sites to determine the concentration of key elements (Ca, P, Pb, Na, Mg, K, Fe, Al, Ba, Cd, Co, Cr,

Cu, Mn, Ni, Sr, Ti, V, Y, Zn, As) which can indicate the addition of organic and inorganic materials to the soils and therefore can be used to interpret of the formation and development of soil horizons.

The third objective of the thesis is to analyse the micromorphology of the soil horizons from the three sites in order to describe the overall texture, composition and characteristics of the soils and quantify a full range of organic and inorganic inclusions. This will allow the following key questions to be analysed:

1. How does the soil micromorphology compare and contrast between individual horizons and landuse areas at the three sites?
2. Is there more evidence of organic and inorganic manuring inclusions in the areas closest to the centre of settlements versus outfield arable areas?
3. Does the micromorphological evidence at Fair Isle indicate similarities in manuring methods and inputs found on other isolated Scottish Islands?
4. What are the key micromorphological similarities and differences between the Dutch black plaggen and brown plaggen soils?
5. How widespread was the use of calcareous sand across the farm of Caheratrant and is there any micromorphological evidence of mixing with organic material?

Zone count analysis of the soils will also be used to quantify a range of organic and inorganic inclusions including peat, turf, amorphous red/brown fragments, mineral inclusions and plant inclusions. This will illustrate the key manuring materials used in various soil horizons and in different landuse areas. The same analysis will also be used to quantify the range of black carbonised and black amorphous particles including charcoal, burnt peat, burnt turf, amorphous black particles and black minerals and this will also aid the interpretation of the soil formation processes and input materials. The black carbonised and black amorphous inclusions will also be quantified using image analysis in order to create a data suit of inclusions to compare and contrast

with the zone count and micromorphological analysis. These methodologies will allow the following key questions to be answered:

1. What are the densities and sizes of key organic and inorganic inclusions at each of the sites and are there any variations between soil horizons, landuse areas and sites?
2. What are the densities and sizes of black carbonised and black amorphous inclusions in soil horizons, landuse areas and between the three sites?
3. What are the density and sizes of void spaces in black carbonised particles and what does this suggest about input materials?
4. Are there any significant similarities between the density and size of black carbonised and black amorphous inclusions as determined by the zone counting and image analysis?

A fourth objective of the thesis is to determine the elemental composition of the black carbonised particles, black amorphous particles and organic inclusions. This will be of specific importance in characterising the very small carbonised and amorphous particles which cannot be identified through the zone counting or image analysis process. Importantly though the elemental analysis will also highlight differences in beneficial and detrimental elemental loadings. Results from these particles will be compared with other organic inclusions, and the matrices of the soils to ascertain the extent of elemental transfer between black carbonised particles and soil. This will allow the following key questions to be analysed:

1. What are the relative densities of organic and inorganic black carbonised particles?
2. What are the key elemental compositions of the black carbonised and black amorphous inclusions and how do they compare to the elemental results of other organic and inorganic inclusions and the bulk multielement results?

3. Do the black carbonised particles contain higher concentrations of elements associated with anthropogenic activity than black amorphous inclusions?
4. Do the black carbonised particles within soil horizons in the kaleyard/garden areas contain higher elemental concentrations than carbonised particles in landuse areas further away from the farm centre?
5. Are there higher concentrations of Ca in black inclusions at Fair Isle and Caheratrant because of the use of calcareous beach sand?

1.12 METHODOLOGIES

1.12.1 FIELDWORK

At each site the spatial distribution of soils across the farms was analysed by conducting a detailed auger survey at 100m intervals, except where more detailed profiles were required, in gardens, kaleyards and small enclosures; in these instances the interval was reduced to 50m or 30m. Since no previous work had been conducted on the identification of anthropogenic soils in the southern arable area of Fair Isle the auger survey was conducted on three farmsteads; Shirva, Leogh and Taing to determine whether any anthropogenic soils were present in the agricultural areas and if so to determine their extent. Shirva and Leogh were chosen as these had reasonably well documented histories and were regarded as original foci of settlement for over 1000 years since the Viking occupation. They were also located to the west and south west of the island within traditionally the best agricultural land. In contrast, Taing was selected because it has a considerably shorter settlement history, from its foundation between A.D.1836 and A.D.1845 and its desertion around 100 years later and was located on much poorer land to the east. The spatial distribution of the soils on Fair Isle was then compared to the soils present at Olthof, the Netherlands and Caheratrant, Ireland.

At each site the auger surveys were located to analyse the soil profiles across a number of landuse areas with distance from the settlement nuclei. On

Fair Isle and at Caheratrant the farms were divided into the kaleyards, the arable infield and outfield and upland areas, whereas In the Netherlands the sampling areas were divided into the garden, adjacent to the main farm buildings, an arable infield area and the upland area.

After the auger survey was conducted a series of nine test pits were excavated in a range of landuse areas to enable the detailed recording of the soil horizons present. The test pits measured 1m x 0.5m² and were excavated down to the natural soils or geology, when the depth of the soil horizons exceeded 1.20m the test pits were extended to 1m² in accordance with the health and safety mitigation. At each test pit the soil horizons, Munsell colour and presence of organic and inorganic inclusions and charcoal were recorded, bulk samples taken and Kubiena tins for micromorphological investigation. Complementing the test pits was a series of samples taken with a 'Dutch' auger at metre intervals radiating out from each side of the test pit. The samples were taken every 200mm (one auger head) until the natural subsoil was found. Contamination was limited by removing any outer soil from the core and only taking the internal soil.

Site	No of Satellite Cores	% of Total	No of Bulk Samples	% of Total
Fair Isle	171	18.36	39	28.05
Netherlands	467	50.16	57	41.00
Ireland	293	31.47	43	30.93
TOTAL	931		139	

Table 5, Breakdown of the bulk sampling numbers from three study sites

1.12.2 SOIL pH

In total 1070 bulk soil samples were taken with 139 from the 30 test pits and 931 from the 120 satellite cores with between 4 to 7 samples per test pit and 5 to 11 samples per core (Table 5). All the soil samples were transported back to the University of Stirling air dried and sieved to less than 2mm for laboratory analysis. The soil pH was determined by following the methods of

Avery and Bascomb (1982) and the University of Stirling. A 10g sample of air dry soil was weighed and placed within a 50ml beaker. To this 25ml of distilled water was added, stirred and allow to stand for 30 minutes. Whilst the suspension was standing, the pH meter was calibrated using the pH 4 and pH 7 buffer solutions. Extra care was taken to make sure that the temperature setting of the meter was at the solution temperature. The electrode was placed into the beaker of pH 7 buffer and adjusted until the calibration control on the meter read 7. It was then withdrawn, rinsed with distilled water and inserted into the pH 4 buffer and adjusted to check that the meter read 4. If it did not, the temperature control was adjusted accordingly. After 30 minutes the soil samples were restirred and the electrode carefully placed into the suspension. The pH readings were recorded to 1 decimal place once the reading became stable. The electrode was then withdrawn and rinse with distilled water before placing into the next sample.

For particularly peaty soil horizons, the pH was determined on fresh soil material. A sample was weighed and a mass of moist soil equivalent to 2.5g dry soil was determined by calculating the percentage moisture content. To this 50ml of distilled water and 4ml calcium chloride solution was added, stirred and left to stand for 30 minutes. The pH was calculated as determined above.

1.12.3 SOIL ORGANIC MATTER

Alongside soil pH analysis of soil organic matter (SOM) was also determined to ascertain variations in different landuse areas and identify areas of organic addition by manuring. The measurement of soil organic matter (SOM) has traditionally been done in several ways, either through acid digestion or by weight loss on ignition. The first method known as the Walkley-Black method is very good for measuring the organic content of soils with less than 2% organic material but for soils with over 2% a process of measurement by loss on ignition is the preferred method.

Loss on Ignition (LOI) involves taking an oven dried soil and subjecting it to high temperatures. The resultant weight loss can be correlated with oxidisable organic carbon and water, even though there is no direct

relationship between level of organic matter and soil organic carbon (Ball, 1964). In this thesis the (LOI) was conducted using the standard methodology of the University of Stirling.

A 10 g subsample of air dry fine earth was oven dried at 105°C for 4 hours and stored in a dessicator before use. A clean and dry porcelain crucible was weighed to an accuracy of 0.01g (W1), filled with oven-dry soil and reweighed (W2). The filled crucible was then placed in the furnace set to 450°C and left for a 4¹/₂ hour cycle. The crucibles were then transferred to a dessicator with tongs until cool before finally reweighing (W3). The LOI was determined using the equation: %LOI = $(W2 - W3) / (W2 - W1) \times 100$

Great care was taken not to test the soils at too high a temperature as clay particles may be altered, affecting weight loss and resultant soil organic content. Extreme temperatures have also been recorded altering soft calcium carbonate mineral components affecting organic matter results (Rowell, 1994).

1.12.4 PARTICLE SIZE ANALYSIS

The particle size analysis was conducted at two levels, initially as part of the textural recording of the soils found in the excavations, and this allowed the analysis of horizons at each landuse area as well as between the three sites. To assess the amount of clay present within samples and the overall micro texture of the soils a more detailed analysis was needed. Air dried bulk soil samples were taken and sieved to <2mm, then placed in the oven for 4 hours at 350°C to remove the organic content but not breakdown the delicate clay micelles. 50ml of distilled water was added to the soil along with 2ml of sodium hexametaphosphate (Calgon) solution to disaggregate the soil into its individual textural components and this was gently agitated for 2 hours. Small samples were then carefully placed into an LS230 Coulter Counter in order to measure the diffracted light from the particles. There are a number of methods for measuring particle size analysis e.g. sieving through progressively sized sieves, pipette analysis and image analysis (Allen and Thornley, 2004) but the laser granulometry method is able to detect particles to 0.004µm making it especially good for fine grained silty clay soils. However, there has been a

great deal of debate over the validity of the results from laser granulometry because of the underestimation of fine clay in relation to pipette analysis (Beuselink, et al., 1998) and Konert and Vandenberghe, (1997) have suggested that the variation was due to the non-sphericity of fine particles. What was clear, however, was that the laser granulometry method was considerably quicker than the hydrometer method, which can take up to 8 hours depending upon the rate of settling, and therefore more samples could be tested in a shorter period and a greater range of results gathered on the micro-textural features of the anthropogenic soils. In archaeology particle size analysis has been utilised to determine environmental conditions on sites (Catt, 1999) and to characterize and interpret domestic deposits from complex microstratigraphical domestic layers (Macphail, 2003) to extremely large tell structures (Davidson, 1973 and Rosen, 1986).

1.12.5 MAGNETIC SUSCEPTIBILITY

Magnetic susceptibility was conducted at the three sites in order to determine the extent of anthropogenic addition in and around the settlement centres, and to compare and contrast the different anthropogenic soils and landuse areas. The measurement of magnetic susceptibility can be conducted in the field at very close intervals (2cm) using a field probe and this has revealed human addition in midden and pit sequences (Dewar, et al., 2002 and Batt and Dockrill, 1998), however, accuracy and precision with results are maintained more easily from laboratory tested sieved dry soils (Dearing, 1999). The bulk samples were collected from the sample test pits and cores in order to keep the results comparable with the other bulk analysis, micromorphology and especially with the analysis on the black carbonised particles, due to their direct influence on magnetic susceptibility.

Small samples (10cm³) were tested using a Bartington MS2 dual frequency susceptibility meter on both the low and high frequency setting in order to detect the total concentration of ferrimagnetic minerals as well as the ultrafine ferromagnetic minerals present, which was not available on the field probe. From the data collected the frequency-dependant susceptibility was

calculated illustrating the ultrafine ferromagnetic minerals within a larger superparamagnetic grain size. The results are displayed as mass specific magnetic susceptibility ($\times 10^{-6} \text{mg}^3 \text{kg}^{-1}$).

1.12.6 SOIL MULTI-ELEMENT ANALYSIS

Soil multi-element analysis was conducted on 500 bulk soil samples to determine the elemental distributions and concentrations across the three study sites and across the different landuse areas, including natural samples. A process of Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) was chosen for the analysis as previous projects have shown that the method offers the best combination of ultra-low detection limits, rapid analysis of a range of elements and low interference levels. This technique was used in order to determine whether the anthropogenic and amended arable soils at the three sites contained characteristic elemental signatures aiding provenance of manure material, whether there were distinctive patterns in elemental loading in settlement centres compared to outfield areas and most importantly, the chemical relationship between the soil and the black carbon particles (chapter 7). Each of the sample soils were sieved to <2mm and oven dried at 105°C for four hours before a 5g sub-sample was removed and digested in 5ml concentrated nitric acid at 120°C for one hour before being filtered and made to a 100ml solution with distilled water. The prepared solutions were then analysed in the geochemistry laboratory at Royal Holloway, University of London using a Perkin Elmer Optima 3300RL ICP-AES for the detection of 21 elements (Ca, P, Pb, Na, Mg, K, Fe, Al, Ba, Cd, Co, Cr, Cu, Mn, Ni, Sr, Ti, V, Y, Zn, As). Standard reference samples from all the elements and three external reference solutions were also taken alongside blank samples and replicates chosen at random in order to maintain analytical quality control.

1.12.7 SOIL MICROMORPHOLOGY

Alongside the bulk soil samples a total of 75 undisturbed soil samples were extracted in 80mm by 40mm Kubiena tins from the three landuse areas at

the sample sites and micromorphological slides were produced at the University of Stirling. The Kubiena samples taken were acetone dried, impregnated with epoxy resin then cut and bonded to glass slides. These were then lapped until a thickness of 30µm and finally polished using 3µm diamond paste but no cover slips were applied to enable elemental analysis with a scanning electron microscope. This follows the standard method of production at the University of Stirling (<http://www.thin.stir.ac.uk/methods.html>).

Each of the slides was described with an Olympus BX50 petrological microscope at six magnifications (x1.25, x2, x4, x8, x10 and x40) and with a range of light (plane polarized (ppl), cross polar (xpl) and oblique incident (oil). The range of light sources was selected in order to identify the coarse rock and mineral components, coarse and fine organics, pedofeatures, microstructure, fabric arrangement, groundmass and relative soil distribution. Background soil descriptions are illustrated in twelve summary tables (Appendix **) Descriptions of the slides were based on Bullock, et al., (1985); Fitzpatrick, (1993) and Stoops, (2003) and important textural and contextual images were taken using AnalySIS v.3.0 © and saved in JPEG and TIFF formats. Key images are displayed within the text and also in the appendix.

1.12.8 ZONE COUNT AND IMAGE ANALYSIS

In order to identify and quantify inclusions within the soils a process of zone counting, image acquisition and colour based thresholding were conducted using optical microscopy and image analysis software. The three quantification methodologies were conducted on 25 3 x 3mm (9mm²) sample squares randomly selected by Random Number Generator for Excel v:2.1.5.25 (<http://www.ablebits.com/excel-random-generator-assistant-free-addins/index.php>). This sample area equates to a 15 x 15mm (225mm²) area or 5.5% of the total slide 75mm x 55mm (4125mm²) slide. This sample size area was selected to enable a fair analysis of each of the anthropogenic/amended soil horizons alongside natural soils.

18sq (55mm) x
25sq (75mm)

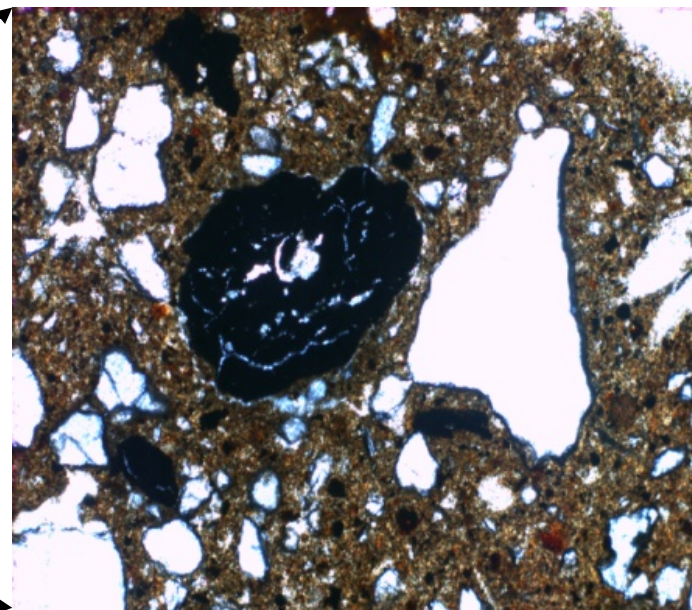
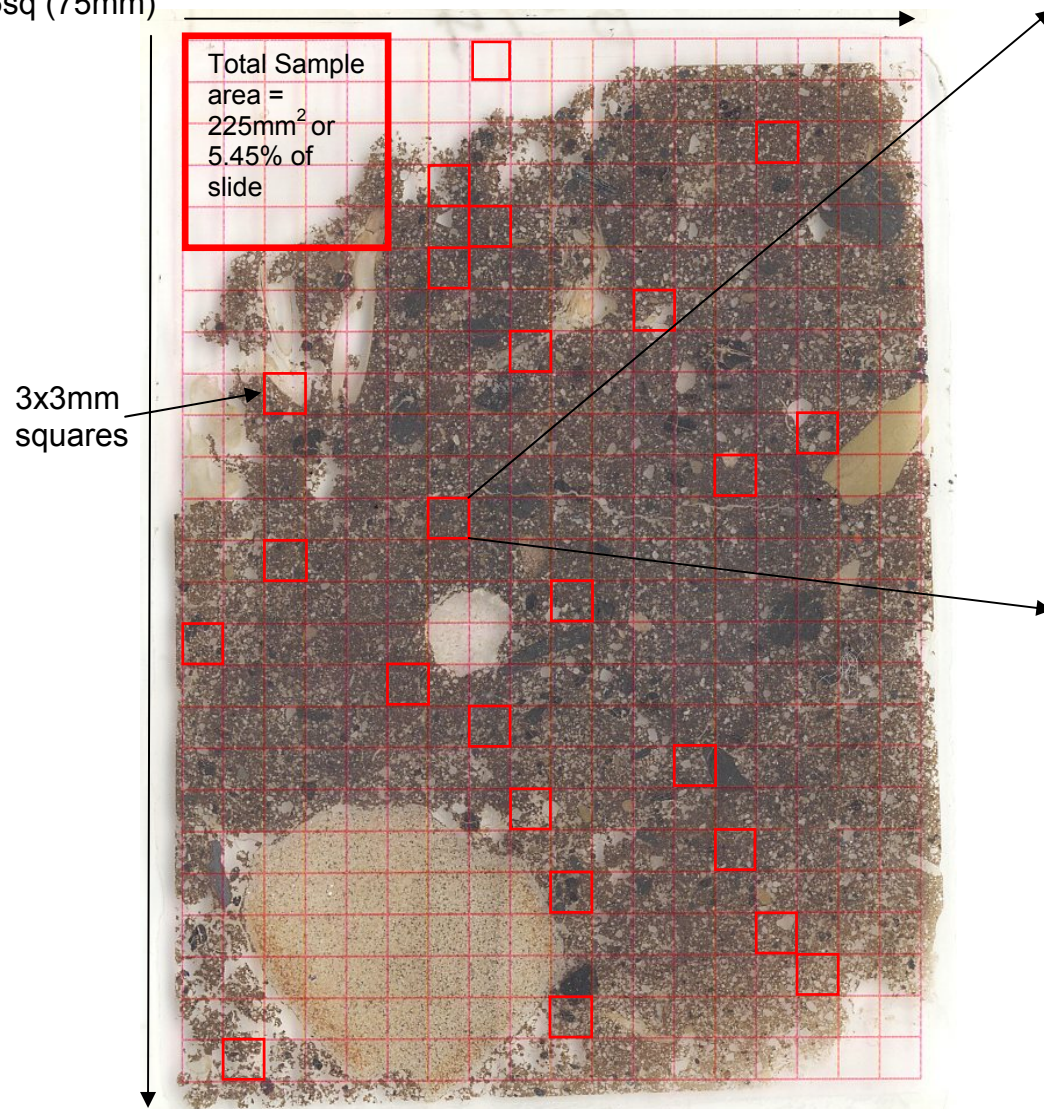


Fig 4a
Grid square L7
analysed with
zone count

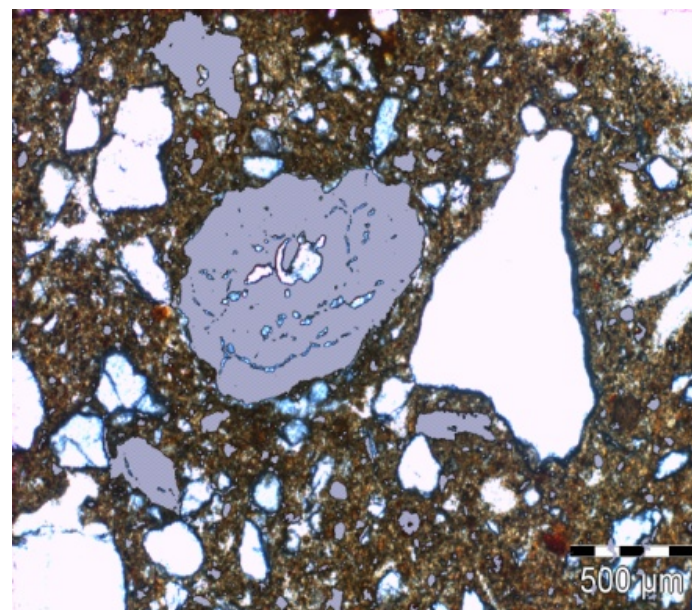


Fig 4b
Grid square L7
analysed with
image analysis.
The resultant
black carbon and
black amorphous
inclusions are
shaded grey

Fig 4, Micromorphological slide (18 x 25sqs; 55 x 75mm) gridded up into 3 x 3mm² squares for zone count and image analysis

Figures 4, 4a and 4b illustrate how each of the micromorphological slides were subdivided for each the two analyses. Each used a fixed setting of x4 magnification with strict regulations on the intensity of light, the aperture, diaphragm and lbd (light balancing daylight) filters were all equally set. The grid squares were coloured red to ensure the AnalySIS software did not include black grid lines in the data set. In each analysis the grid squares were positioned using the motorised stage facility to ensure exact replication of analysis areas.

The zone count process identified and quantified nine classes of organic and mineral inclusions. These include organic fragments: peat, turf, red/brown amorphous and plant material; carbonised fragments: charcoal, burnt peat, burnt turf and black amorphous material; and inorganic mineragenic inclusions. The zone count quantified these inclusions and was recorded using mm^{-2} .

Figure 4a represents the sample square area 'L7' and includes several very large carbonised fragments of peat and charcoal alongside clear quartz mineral, unburnt peat, red/brown amorphous material and void space. Figure 4b shows the same square with the black carbonised and black amorphous inclusions identified by the AnalySIS software. The use of both quantitative (image analysis) and qualitative (zone counting) data collection in the same squares allowed constant monitoring of the two methodologies. In both cases however a minimal data size of $500\mu\text{m}^2$ was set to reduce human error in the data set. The image analysis was used to quantify the density ($\mu\text{m}^{-2}/225\text{mm}^{-2}$) and area (μm^{-2}) of black carbonised and black amorphous inclusions and the density ($\mu\text{m}^{-2}/225\text{mm}^{-2}$) and area (μm^{-2}) of internal void space which might assist with the identification and provenance of the inclusions.

1.12.9 SCANNING ELECTRON MICROSCOPY ANALYSIS

The uniform sample area developed for the zone counting and image analysis was also used to determine the detailed elemental identification of a range of organic and inorganic inclusions. In total 1548 fragments were analysed including 1250 black carbonised particles and black amorphous inclusions that exceeded $500\mu\text{m}^2$ as well as 61 organic inclusions, 87 mineral fragments and 89 soil matrices samples. 57 resin samples were also taken to

compare and contrast the elemental results with background elemental readings (Table 6).

A set of 19 elements were gathered from selected from uncovered micromorphological slides from the kaleyards of the three sites on a Jeol 6460 LV SEM-EDS linked to an Oxford InCA X-sight EDX detector with a silicon/lithium film window at the University of Stirling. The elemental data was captured using the 'spot' and 'surface area' function in order to gain accurate results for the determination of oxygen:carbon ratios analysed using the methods set out by (Stoffyn-Egli, et al., 1997) and the elemental composition of the inclusions which might indicate possible areas of provenance and data which could be compared and contrasted to the bulk soil elementary results.

The usual procedure of coating samples with carbon to reduce surface charging was omitted as this would have seriously affected the results, however if charging was still a problem it could have been solved with gold coating but after a number of tests on uncoated samples it was decided that charging was not a serious problem.

Site		Black Particles <500µm ²	Black Particles +500µm ²	Organic	Mineral	Matrix	Resin
Fair Isle	Shirva	95	276	14	14	25	11
	Busta	78	279	8	12	11	11
	Leogh	68	216	18	23	27	7
Netherlands	Olthof	37	41	0	19	12	13
Ireland	Caheratrant	52	112	21	19	14	15
TOTAL (1548)		330	924	61	87	89	57
%		21.5	59.6	3.9	5.6	5.7	3.7

Table 6, Number of inclusions analysed with Scanning Electron Microscopy (SEM) from a kaleyard and garden areas

2 STUDY SITE 1: FAIR ISLE, SCOTLAND

2.1 INTRODUCTION

Fair Isle, or *frioar-øy* from the Old Norse, is located in the North Atlantic Ocean, 26 miles from the southern end of mainland Shetland and the island of North Ronaldsay, Orkney (Fig 5). The island is 3 miles (4.8km) long by 1.5 miles (2.4km) wide with a total area of 1402 acres (768ha). Before John Hunter's 1997 book entitled "*Fair Isle: The Archaeology of an Island Community*", Fair Isle had received very little analysis compared to the Shetland and Orkney Islands where there is a wealth of historical, archaeological and pedological material with which to analyse and interpret past land use history (Fenton, 1978).

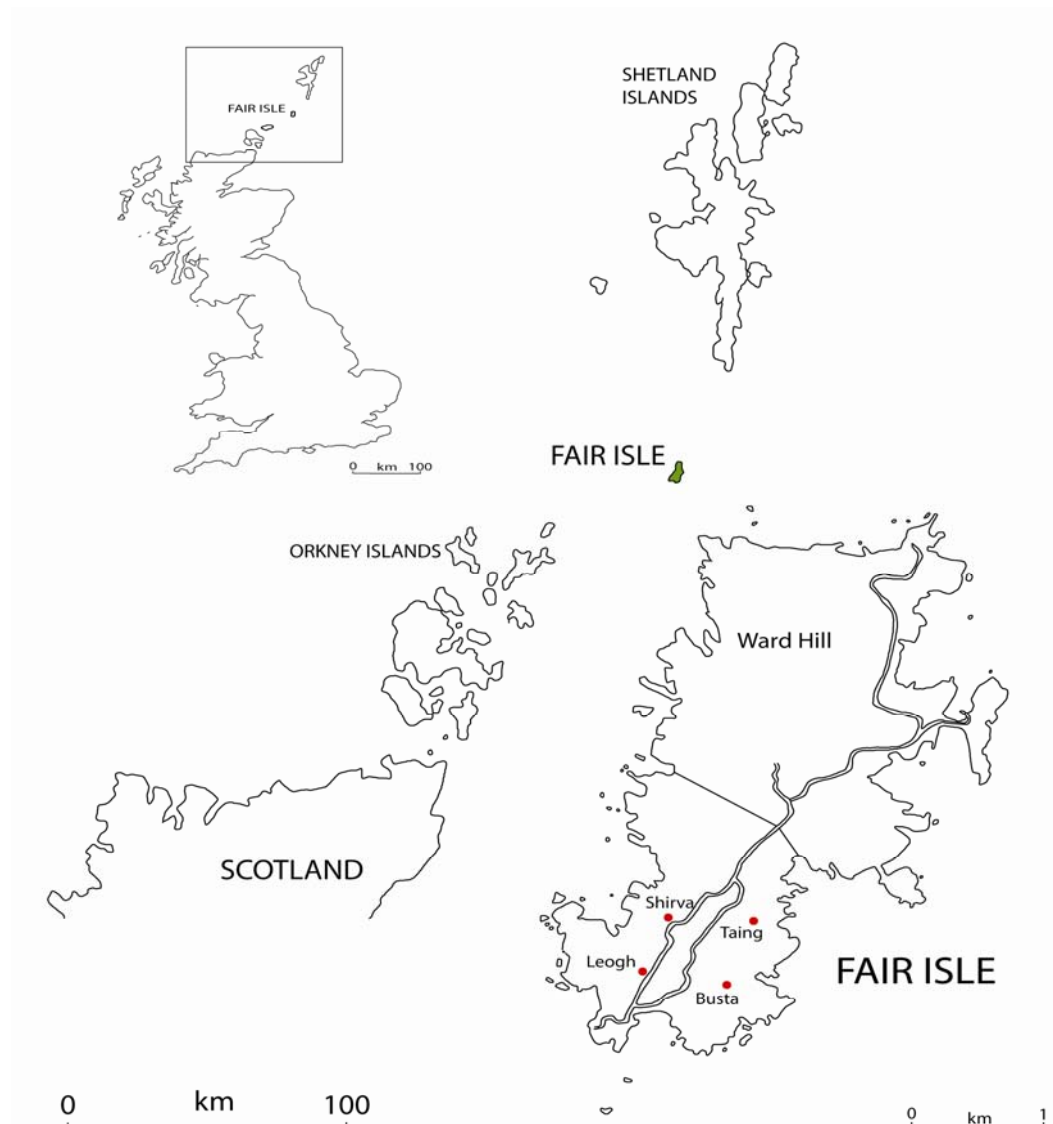


Figure 5, Location map of Fair Isle and the Orkney and Shetland Islands

2.2 THE GEOLOGY AND SOILS OF FAIR ISLE

The island's geology (Fig 6) was originally studied in 1879 by Heddle who mapped the rock formations. More recent geological fieldwork showed that the majority of the central area of the island is composed of a fine grained, quartz rich, sandstone. Around the west and north east edges of the island are deposits of a more resistant pebbly sandstone and conglomerate. Both deposits were identified as belonging to the Lower to Middle Old Red Sandstone series of Devonian age (408 – 374 ma) called the Downtonian Series (Mykura, 1972 and Mykura et al., 1976). Drift deposits were identified and analysed around the same time and identified as glacial tills with reddish, brown colours deriving from later Permo-Triassic Sandstones (Flinn, 1970). The island contains over 15 transcurrent faults which run roughly north west to south east but the Old Red Sandstone's existence is due to crustal movement in the Walls Boundary Fault which runs northwards through Shetland and to the south east of Orkney and into mainland Scotland, as a possible extension of the Great Glen Fault (Flinn, 1961).

The soils of Fair Isle (Fig 7) were mapped in the early 1980s by the Soil Survey for Scotland (SSoS) who categorized the soils into two types both of the Skelberry Association. In the northern area of the island soils are typically peaty podzols and peaty rankers which occur on hill sides with steep and very steep slopes which are moderately to very rocky. These soils typically have North Atlantic heather moorland heath and blanket peat with some grass. To the south the soils are peaty gleys, noncalcareous gleys with some peat and saline gleys. These occur in the undulating lowland with gentle to strong slopes which are slightly rocky. The vegetation on these soils is typically North Atlantic heather moor, arable and permanent pasture and swampy areas (Soil Survey for Scotland, 1982).

Importantly the SSoS also mapped areas of deepened topsoils on West Mainland, Orkney which were characterized by dark organic soils in excess of 750mm deep. Similar soils identified on other Orcadian Islands; North Ronaldsay, Sanday and Stronsay (Simpson, 1985) and Shetland Islands; Scatness, Papa Stour (Davidson and Simpson, 1994) and Unst (MacKenzie,

2006) have been interpreted as anthropogenic soil due to the inclusions of organic and domestic inclusions (Davidson and Simpson, 1984).

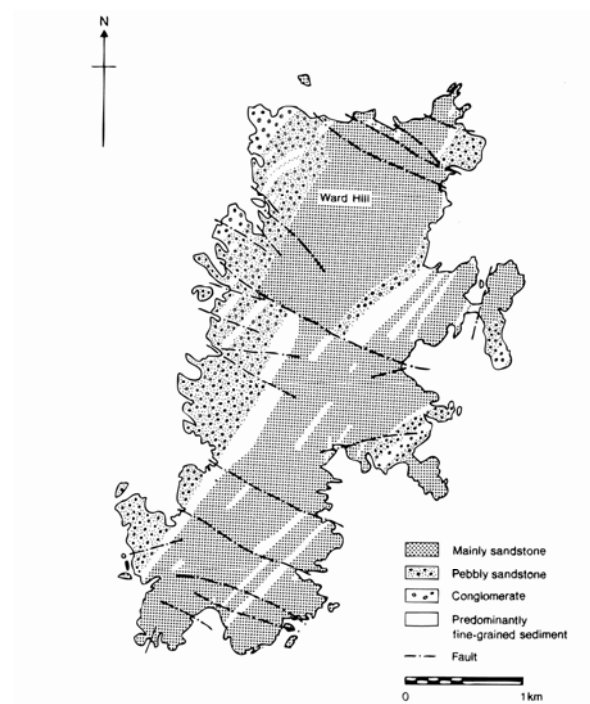


Figure 6, Solid geological map of Fair Isle (After Mykura, 1972)



Figure 7, Soil map of Fair Isle (Soil Survey for Scotland, 1982)

2.3 THE HISTORY OF FAIR ISLE

2.3.1 EARLY ACTIVITY AND SETTLEMENT

The history and archaeology of Fair Isle has been analysed in great detail over the last 20 years which has resulted in John Hunter's book "*Fair Isle: The Archaeology of an Island Community*". Sections 2.3 and 2.4 illustrate a summary of this work. Human activity on Fair Isle during the prehistoric period is expressed in dykes, field boundaries, burnt stone mounds and house platforms. The best preserved evidence survives in the northern half of the island where there has been no later disturbance by settlement or agricultural practice, however the intensive removal of peat for fuel throughout Fair Isle's occupation may have inadvertently removed evidence leaving only a fraction of what was originally present. By far the most distinctive feature, which has played an important role throughout the island's history, is the *feelie* dyke. This runs for 1.2km across the centre of the island, from Gunnawark to Haswalls, and separates the upland area from the lowland. Today it is an impressive feature 8m wide by 2m high and, as Hunter (1997) suggests, may well have been considerably larger in the past and its construction required major planning and organisation with a suitably sized population.

Field systems and settlement evidence are concentrated into four areas on the island. Three of the areas are north of the *feelie* dyke and the fourth is to the east of the lowland area. The first area, Ferny Cup, is on the eastern side of the upland area and has a clear area of prehistoric houses with small tracts of relict landscape including lynchets, field boundaries (for terracing) and cairns. The houses in the south of the island have a well planned design and are typically 'figure of eight' shaped with varying wall thickness, averaging 1.5m. Similar houses were identified at the Scord of Brouster (Whittle et al., 1986), an important Neolithic settlement site on mainland Shetland. To the west is a third possible prehistoric foci, at Burrashield. There are a large number of burnt mounds, over 20 small rectangular enclosures (averaging 5m by 3m) and two large parallel boundary ditches, possibly land divisions as well as a small cairn. However, there is also a great deal of post medieval disturbance which has hampered interpretation of this landscape. Excavation

of one of the enclosures showed no evidence for early activity (Hunter 1997). The fourth area analysed by John Hunter is called 'The Rippack' and is to the south of the *feelie* dyke and provides a good contrast with the other three areas. The evidence includes field boundaries, cairns, planticrues and a likely settlement location within the southern arable agricultural zone. There are a number of burnt mounds which might well be the only remaining evidence of prehistoric activity in the area. Hunter does outline three other possible intense activity areas in the south of the island at Vaasetter, Pund and The Houll but all of these sites show no physical evidence and any earthworks which are present are likely to have been used in later settlement development or destroyed by intense agricultural activity (Hunter, 1997).

Prehistoric and Bronze Age evidence is present but its fragmentary nature and lack of material culture makes interpretation very difficult. In the north of the island constant degradation of the peat resources has removed a great deal of evidence whilst in the southern zone occupational and agricultural changes to the landscape have left only islands of information.

Towards the end of the Bronze Age the climate of north west Europe changed dramatically forcing the population of Fair Isle to move to the south of the island, inhibiting growth. This translocation fossilised the Neolithic and Bronze Age features to the north of the *feelie* dyke with the majority of Iron Age evidence lying to the south. The limited amount of excavation of Iron Age features, like the earlier periods, makes it very difficult to analyse the landscape in the period but there are features which have been postulated as of this period (Hunter, 1997). The most common evidence is walling from field systems and enclosed pasture, most of which is likely to be late Iron Age/Early Viking period and is located to the south of the island but there are smaller concentrations at Burrashields and the Bunes Peninsula, possibly in association with the Landberg prominantory fort (Lamb, 1980). The Landberg prominantory fort is the only obvious broch site, with other possible sites likely to have been heavily disturbed by later activity. The site is located to the east of the island on Bunes, measures 45m by 12m (430m²) and was excavated in the 1970s by Lamb. There are a number of extensive earthworks, now heavily eroded, towards the landward side, interpreted as ramparts and within the fort

several possible hut depressions, and a larger building possibly of later date, as suggested from pottery remains. In the north east corner there is an area of deepened soil, around 1m thick, derived from a series of middens (Hunter, 1997).

The coming of the Vikings coincided with the earliest written documents which mention Fair Isle and its positional importance between Orkney and Shetland. A written document called 'Njal's Saga' indicates that there is permanent occupation on the island prior to the occupation by the Vikings one particular reference in the document suggests that the island is "*home to David the White who wintered with Kari*" (Magnusson and Pálsson 1960 p135). However, the majority of the historical references at the beginning of the 11th century are within the 'Orkneyinga Saga' written in the 13th century. It illustrates the feuding between Earl Paul of Orkney and Earl Rognvald of Shetland for control of Fair Isle (Pálsson and Edwards, 1978).

The importance of the island for both men of the island can be seen from two separate incidences both involving the beacon on Ward Hill. The first saga involves a farmer on the island called Dagfinn Hloduissón who was placed in charge of the beacon on Ward Hill by Earl Paul to warn the Orkadians of an impending attack by Rognvald's men. At this stage the island was under Orkadian control, however Rognvald was able to trick Dagfinn into lighting the beacon which alerted Earl Paul's men and ended with Thorstein, of North Ronaldsay, murdering Dagfinn. The second saga is also concerned with the beacon and Shetland gaining control of the island. Rognvald went to Fair Isle with three men, supposedly his sons, and took a house with the express purpose of gaining the confidence of the beacon keeper, Eirik. One of the men, Uni, doused the beacon so as to make it useless and Rognvald was able to travel unseen by Earl Paul. These important early documents show that Fair Isle was a busy inhabited island which because of its important geographical position, commanded significant control of key fishing grounds and trade links between Scandinavia and Greenland. Viking settlers must therefore have been encouraged to inhabit Fair Isle and the place names given to their villages and farms remain to this day and indicate early occupation sites.

2.3.2 PLACE NAME EVIDENCE FOR THE THREE STUDY SITES

The names of all the settlements analysed in this thesis are discussed in John Hunter's book "*Fair Isle the Archaeology of an Island Community*" except Taing, which is interestingly overlooked possibly because of its generalistic terminology. On both Shetland and Orkney the name derives from (*Tangi* ON) means 'rocky' or 'a tongue of land' and is commonly found in rocky, coastal areas. Its use on Fair Isle may refer to a particular area of coastline, the adjacent Sheep Rock or as a reference to shallow, rocky, poor quality agricultural soils. The derivation of Shirva and Leogh also appear to have origins in the geography of their positions, Shirva or (*Skirva* ON) relates to 'rocky ground' and Leogh or (*Loekr* ON) means 'boggy or flat ground' (Hunter 1997), names which even today match closely the settlement locations. The name Busta has been interpreted in more detail and much like the continued evolution of the settlements on and around the same sites. It is thought that the name has developed equally possibly deriving from *bólstaðr* or *bustaðr*, the old Norse to Bouster or Bister meaning portion, lot, or dwelling place (Hunter, 1997). Further details on the settlements and population, however, are detailed in the documentary evidence (Section 2.3.3).

2.3.3 SETTLEMENT AND POPULATION IN DOCUMENTARY SOURCES

Although there is evidence for Prehistoric activity on Fair Isle there is general agreement that large scale permanent settlement began on Fair Isle around A.D. 800 and the sagas are the first written documents which give a vague indication of the likely population around the period A.D. 800 – 1050 (Hunter, 1997). It has also been assumed that the settlements under investigation in this thesis were founded around this time. Unlike Shetland and Orkney, no high status, multiperiod settlement site has been identified like the spectacular sites at Jarlshof (Hamilton, 1956), Underhoull (Small, 1966), Buckquoy (Richie, 1977), Birsay (Hunter, 1986) and Scatness (Dockrill et al., 1994). However small scale settlements are likely to have been founded around this time but detailed surveys failed to locate any evidence (Hunter

1997) suggesting existing settlements are upon the sites of earlier settlement foci (Table 7).

The first record of population on the island comes in 1588 after the wrecking of the 'El Gran Grifon', flagship of the Spanish Armada and the diary entries made by a survivor as to the state of the island (Ker, 1920). This and an early 17th century report by Richard James identified 16-17 houses but does not indicate the distribution of occupation (MacGillivray, 1953). Fenton (1978) suggests a population density on Shetland of between 6.6/6.8 per house; and Hunter (1997) extrapolates this interpretation to suggest a population of around 115. A more detailed description was written in 1680 by Kay who discusses population, settlement and landuse and states.

“ This Isle is indifferently fertile, so far as it is manured, yielding greater increase than any land in Zetland: but the cultivated ground is but little, lying altogether in the South end of the Isle: the rest they reserve for pasture and fuel, though the most part of the Isle might be made good corn land. There is no grain here but Oats and Beer whereof they seldom want as much as serves themselves.” (Bruce 1908 p55)

Late 18th century Laird's reports outline the island's struggle with poverty (Ballantyne, 1993) but also mention, for the first time, three settlements by name at Leogh, Shirva and Gaila/Busta combined. Hunter (1997) suggests that these settlements are the foci seen in the earlier accounts, which have undergone evolution. The documents outline the buying of the four settlements by James Stewart of Brough in 1766. An idea of the size may be interpreted from how much the tunships were bought for. At this time Shirva may have been the largest settlement as it was purchased for 48 Merks. Leogh followed and could conceivably have been half the size, as only 24 Merks were paid. If this is correct it would make both Gaila and Busta very small occupation sites and only worth 12 Merks each, and purchased together.

MAP & DOCUMENTARY EVIDENCE – 1588 TO 1891

MAP & DOCUMENTARY EVIDENCE – 1588 TO 1891																			
Demographic Data – Population & Settlement.	1588 – Population Report	e. 17 th C. James' Report	1680 – Kay's Description	1695 – van Keulen's Map	1750 & 1752 – Mackenzie Charts	1764 – Lairds' Reports	1771 – Robertson's Visit	L. 18 th C. 1 st Statistical Account	1790 – 1838 Rev. Mill's Diary	1804 – Fotheringhame's Visit	1814 – Scott's Visit	1836 – Thomas' Map	1845 – 2 nd Statistical Account	Census 1841 – 1891					
Population	Estimated 115	Estimated 115	-	-	-	-	170	220	230 - 250	230	230 - 250	-	232	POPULATION					
														2	2	1	2	2	2
														3	7	3	2	1	2
														2	9	8	6	4	3
YEAR																			
1	1	1	1	1	1														
8	8	8	8	8	8														
4	5	6	7	8	9														
1	1	1	1	1	1														
SHIRVA	N/R	N/R	N/R	N/R	N/R	*	N/A	*	N/R	N/R	N/R	8 houses	*	*	*	*	*	*	
LEOGH	N/R	NR	NR	NR	NR	*	N/A	*	NR	NR	NR	7 houses	*	*	*	*	*	*	
BUSTA	N/R	N/R	N/R	N/R	N/R	Busta & Gaila together	N/A	*	N/R	N/R	N/R	5 houses	*	*	*	*	*	*	
TAING	N/R	N/R	N/R	N/R	N/R	N/R	N/A	N/A	N/R	N/R	N/R	Single dwelling Unit	*	*	*	*	*	*	
Comments	Rough indication of the number of houses 16 – 17	Rough indication of the number of houses 16 – 17	Topographical & Landscape use description	1 st map Schematic overview of island	Schematic overview of settlement at Utra and Gaila	1 st to mention S.L and B by name	Population analysis. Settlements not mentioned	1 st definitive account of island	Population analysis	Population analysis	Population analysis	1 st detailed and reliable map	2 nd definitive account of settlement, population and land use	1. Population maximum. 2. 1891 census affected by lighthouse constructors.					

KEY = N/R – Not Recorded, * - Present

Table 7, Map and documentary evidence from Shirva, Leogh, Busta and Taing on Fair Isle 1588 - 1891

Further documentary evidence is provided with the report of a visit by James Robertson in 1771. Robertson noted the population at around 170 living in 4 tunships (Hibbert, 1822); these may well be the four suggested in the Laird's reports but they are not named within the document. The number of residents on a broad scale could be estimated at around 42 people per tunship and with 5 per household suggesting 8 or 9 houses in each, but if the settlement sizes were imbalanced as suggested through the purchase prices, then it would be considerably harder to estimate the population in any one of the tunships.

A clearer representation comes from the First Statistical Account (FSA) recorded in the 1790s. The population appears to have risen to around 220 occupying the same four tunships, highlighting internal expansion rather than the development of new settlement sites (Hunter, 1997). The document states that:

"The houses are confusedly thrown together as chance, whim, or conveniently directed, into four clumps or towns, under the fine sounding names of Shewah (Shirva), Lioh (Leogh), Bustah (Busta), and Gelah (Gaila) (sic). These four little towns, as they are called, contain the inhabitants, of which there are 32 families, about 7 persons in each; 106 males, and 114 females; in all, 220. (OSA XIX p436).

Between the 1790s and 1830s the island's population increased greatly and this was recorded through the documentary evidence of Reverend John Mills, Fotheringhame's visit of 1804 and Scott's visit of 1814 which indicated populations of in excess of between 230 to 250 people, but do not add to the understanding of the settlement organisation or location (Laughlan, 1982).

Although the population of Fair Isle was rising steadily in the early 19th century the increase of food imports from the mainland suggests that the islanders were finding it harder to feed themselves (Laughlan, 1982). This may well have been due to the new farms at Setter and Taing developed to reduce the numbers occupying individual farms. Although these new settlements had not been recorded before, Hunter, (1997), suggests that they

may well have been located upon considerably earlier settlements, possibly of Norse or Viking origin.

From 1841 onwards censuses were conducted on a 10 year cycle and they detail precise male and female occupants and settlement density. These accounts also break down the inhabitants for each of the settlements. Shirva had a population of 82 divided into 15 families, Leogh 50 people in 8 families, Busta 50 people in 5 families and Gaila 32 people in 8 families, however the outlying settlements at Taing and Setter are not mentioned. Their existence is in no doubt as they are clearly marked on Thomas's map of 1839. Later census illustrate more detail, in 1851 the census details individual dwellings and roads and the 1861 census, taken at the population maximum of 380, mentions a total of 53 units as well a large increase in the numbers of settlements. From 1861 onwards there has been a gradual decrease in population.

2.3.4 HISTORICAL & MODERN MAP EVIDENCE FOR THE STUDY SITES

The earliest map of the island was drawn by van Keulen in 1695 and this was followed by Mackenzie's map of 1750, which depicts 8 houses with a different building to the north, and Mackenzie's second map of 1752, which shows two houses at the southern end of the island and these appear to be located in the rough positions of the settlements of Gaila and Utra and are described as farmhouses. Considerable caution is needed when interpreting these maps as Mackenzie's maps illustrate a shrinkage in population and settlement size from 8 to 2 and yet late 16th to mid 18th century documentary evidence all show a stable or slowly rising population. The first map detailing demographic data was produced in 1839. Thomas's Map of 1839 shows the locations of Shirva, Leogh, Busta, Gaila, as well as Taing, Setter the school and church (Figure 8). Shirva contains 8 houses, six of which are in a clustered regular row orientated west to east behind two other buildings, more roughly aligned and distinctly separate from the nucleated arrangement. The organised settlement may be a result of expansion in the village with the older foci located further to the south towards 'The How'. The arrangement of Gaila

also shows irregular nucleation with five small buildings appearing to roughly encircle a larger rectilinear building. This may represent a large farmstead with associated outbuildings or possibly a misrepresentation of The Haa, a high status laird's house, with smaller houses as adjuncts located extremely close to Gaila. Both Leogh and Busta show regular cluster style arrangements with seven and five properties in each of similar size. The map clearly defines the settlements of Shirva, Leogh, Busta and Gaila within the south of the island in an area called 'cultivated land', but between the arable area and the now deserted upland area are two smaller occupation sites at Setter and Taing.

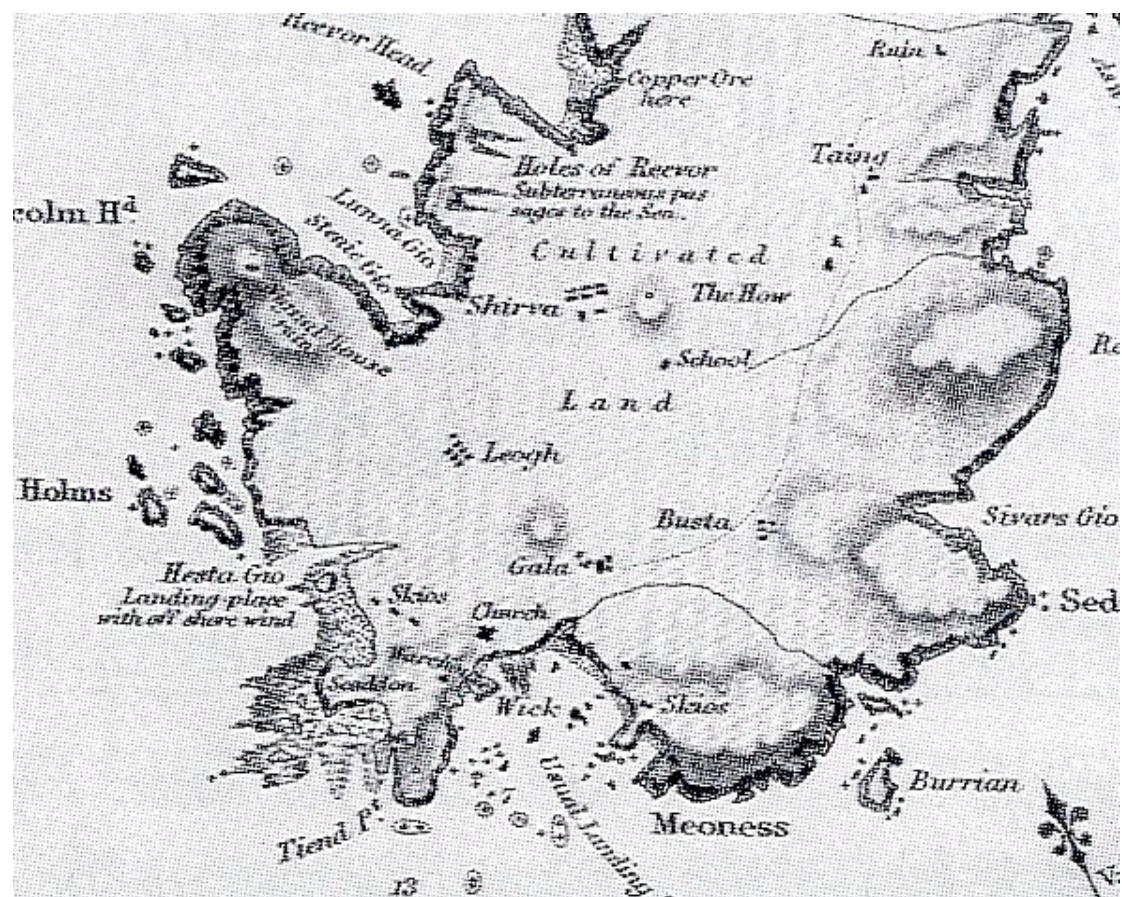


Figure 8, Thomas' 1839 map of Fair Isle showing the settlements of Shirva, Leogh, Busta and Taing (Thomas, 1839)

Both are likely to be isolated farmsteads as they only contain 1 or 2 buildings. A point to note is there are also two other possible settlements denoted as ruins on the map between Setter and Taing . They may, however,

be plantigrues or sheep enclosures which show as such features on later maps and may have been misinterpreted by Thomas during the drawing of the map. The modern Ordnance Survey map of the island (Figure 9) shows a drastic reduction in size of the original settlements. Shirva and Leogh are now no more than large croft/farmsteads sites with many old farmhouses recycled as outbuildings and barns. Of all the settlements Shirva has remained almost intact and has only shrunk as a direct result of the population decline. There are five buildings, four of which are part of Shirva croft but the fifth has been rented to other islanders.

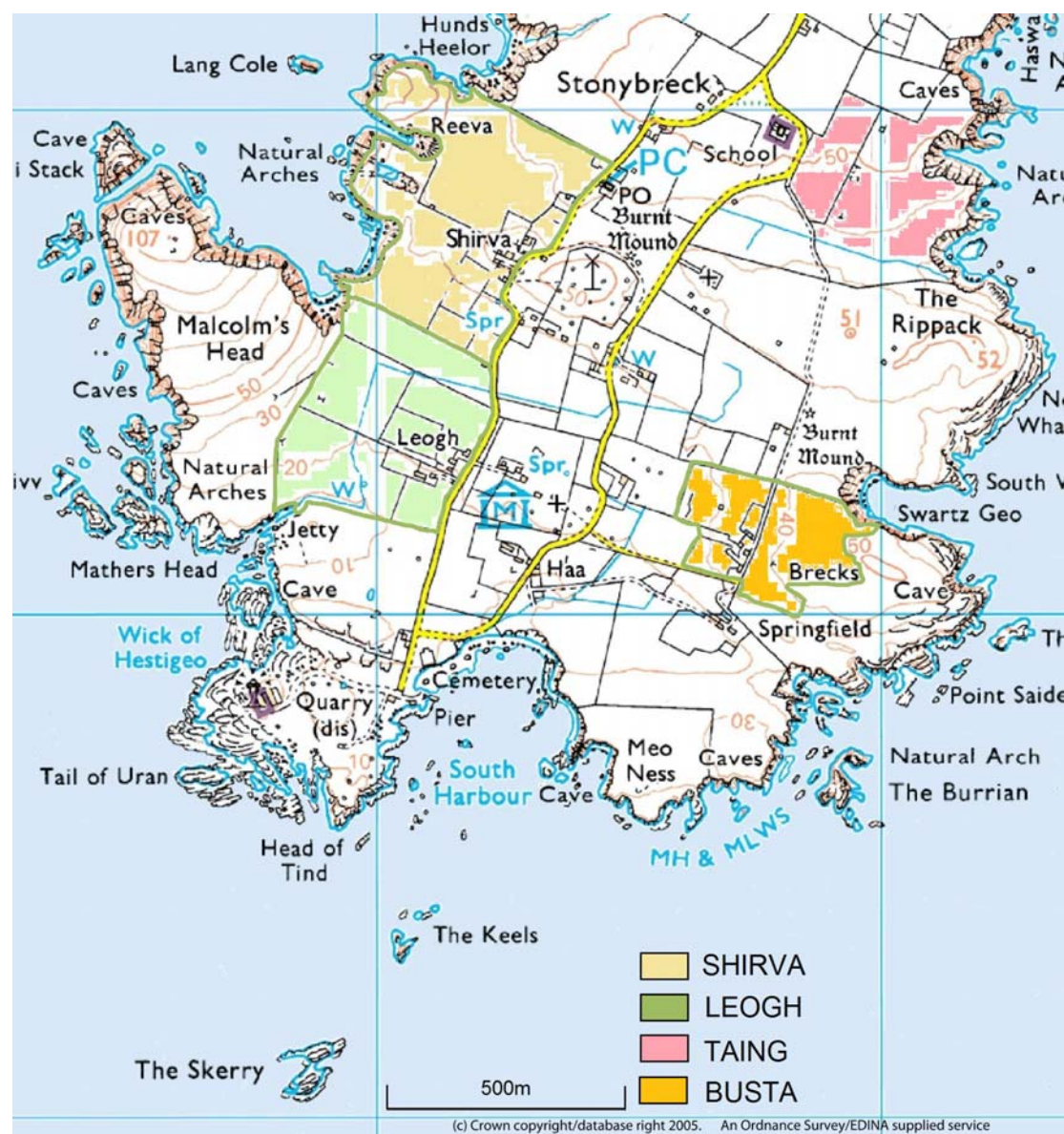


Figure 9, Ordnance Survey map of south Fair Isle including Shirva, Leogh, Busta and Taing (Ordnance Survey EDINA, 2005)

Leogh contains five buildings but these are split between Lower Leogh, Leogh and Upper Leogh, with a share of the original farmland for the grazing of sheep. Busta is still present as a small farm but not specifically marked on the map as the large farm of Springfield now dwarfs the once most dominant settlement on the eastern side of the island. The greatest change is evident at the now deserted settlement of Taing. Unnamed on the modern map it is marked simply as a cluster of building outlines (Figures 8, 9 and 11) which have been systematically surveyed in detail (Hunter, 1997).

2.4 ARCHAEOLOGICAL EVIDENCE FROM FAIR ISLE

2.4.1 FIELD SYSTEM EVIDENCE

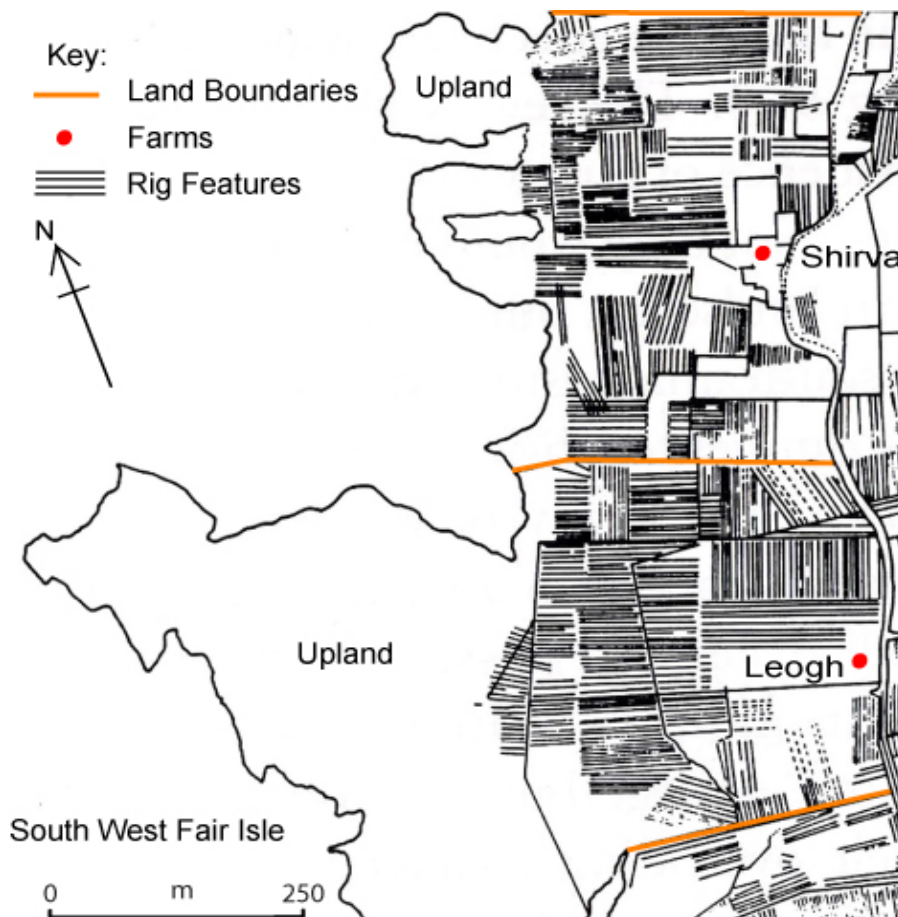


Figure 10, Extract from Hunter's survey of field systems across Shirva and Leogh (Adapted from Hunter, 1997)

The field systems on the island in the land of the four settlements were surveyed by Hunter between 1984 and 1987, and show distinctive characteristics (Figs 10 and 11). Overall there is a distinct concentration of rigs in the west of the island corresponding with the documentary evidence of the oldest settlements but the field system size and regularity increase towards the north from patchy irregular rig around The Haa and the now deserted settlement of Gaila to very large sub-rectangular arable plots around the modern farms of Setter and Field together with the area of arable expansion above the feelie dyke, a result of population pressure on the land.



Plate 6, Rig systems in former arable outfield at Shirva

The field systems associated with Shirva and Leogh (Plate 6) have the most clearly defined arable field system evidence with a mixture of distinctive north east to south west and north west to south east orientated areas of rig with remarkable similar shape. The largest rig systems occur in the outfield and areas with better drainage as can be seen in the southern end of the Leogh. However, this area may be the remnants of an earlier arable field system layout as the surface evidence is poorly preserved and where it can

be seen, the rig is very patchy and is in thinner, longer strips associated with earlier ploughing techniques.

In contrast to the western side of the island the rig and field systems on the eastern side are much sparser (Fig 11). Around Taing there is very little evidence of any arable field systems except for a large block of rig running north east to south west and several much smaller blocks running west to east. The age of the rigs is unknown but it is likely that these earthworks are the only remnants of a possible larger arable landscape created with the development of Taing. Indeed the overall lack of earthworks on the eastern side of the island suggests that the features that are present are associated with later settlements. The two surveys clearly contrast the difference between the old arable landscape and the existing pastoral landscape consisting of much larger fields and enclosures. However, the main boundaries between the farmland of each of each of the settlements have remained and been made permanent with the creation of fences.

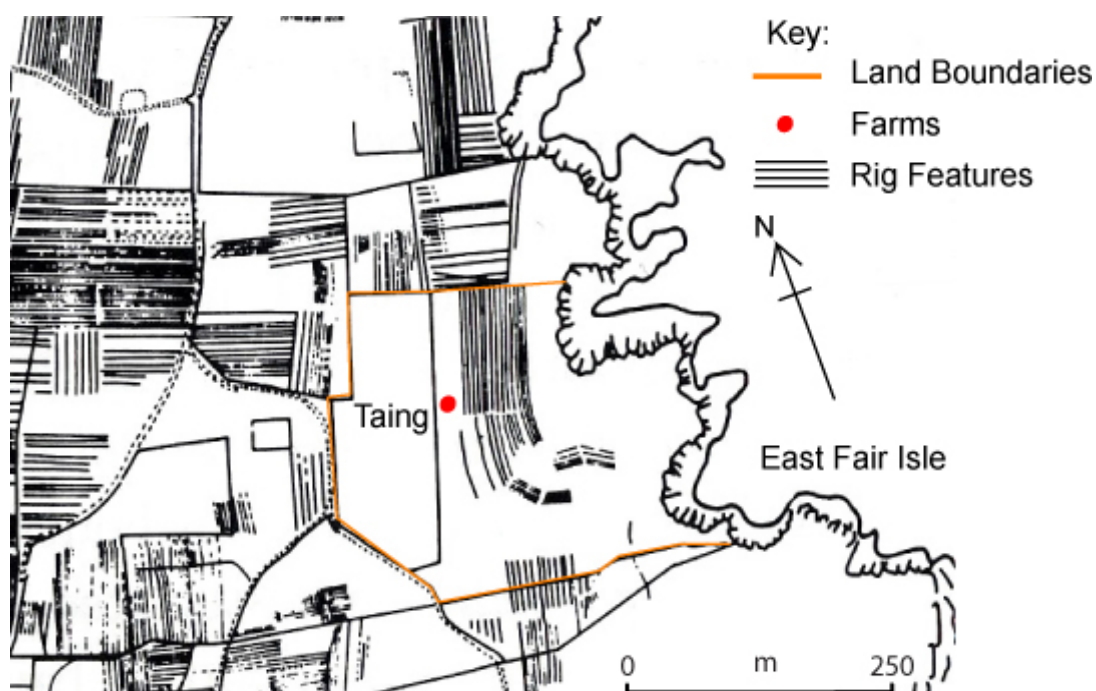


Figure 11, Extract from Hunter's survey of field systems across Taing (Adapted from Hunter, 1997)

2.4.2 SETTLEMENT EVIDENCE

Archaeological evidence of settlement on Fair Isle between the medieval, post medieval and modern periods has been interpreted by detailed earthwork surveys in and around the existing settlements compiled by John Hunter. Shirva has the most complex earthworks of all the settlements on the island, reflecting its complex morphology through history (Plates 7 and 8). Today there are three houses each comprising a small kaleyard and small infield areas, however, the earthwork evidence reveals that there were once six buildings to the east. These may well have still been present until the mid 1800s as the same number are denoted in Thomas's map. Three of the buildings are truncated by the modern road and appear to show no correlation with either the modern road or an earlier road further east and may therefore be earlier structures. Two further buildings are also present 60m to the north (Plate 10) and two 50m to the west (Plate 9). All the buildings have similar rectangular shapes, ranging from 10m to 20m long by 4.5m to 5m wide, with a mixture of bi-partite and tri-partite internal segmentation.



Plate 7, Earthworks to the west of Shirva



Plate 8, Earthworks of small tripartite building to the north of Shirva



Plate 9, Building with surviving masonry wall on the northern side of Taing surrounded by poor heath farmland

At Leogh no building earthworks are evident around the settlements of Upper and Lower Leogh but two structures were identified 150m to the south

and these consist of a tri-partite building 15m by 7.5m and a less distinctive structure possibly an outbuilding or wall for a kaleyard.

Taing has two buildings with more distinct rectangular form, foundations and a standing wall. The northerly building (Plates 9 and 10) is 10m by 2.5m with bi-partite internal partitions and a semi-circular structure interpreted as a corn drier (Hunter, 1997). To the north and east are two large square enclosures which may have been kaleyards or areas to hold livestock. The second building to the south is 11m by 3m with a bi-partite division and an additional square feature at the west end of uncertain interpretation. The earthwork survey failed to discover any buildings at Busta and as Hunter states this may well be because the existing settlements have evolved in the same locations destroying any archaeological evidence.

2.5 FIELDWORK RESULTS

Fieldwork on the island initially consisted of a detailed auger survey of three settlements; Shirva, Leogh and Taing to determine whether any anthropogenic soils were present in the agricultural areas and if so to determine their extent. Shirva and Leogh were chosen as these had well documented histories and were regarded as original foci of settlement since the Viking occupation (sections 2.3.1 to 2.3.4). They were also located to the west and south west of the island within traditionally the best agricultural land. In contrast Taing was selected because of a considerably shorter settlement history, between A.D.1836 – 1845 and its desertion around 100 years ago and was located on much poorer land to the east (section 2.4). The key fieldwork questions are outlined in section (1.11) and the methodology in section (1.12). The results section includes an analysis of the spatial distribution of the soils at Shirva, Leogh and Taing (section 2.6). There is a more detailed analysis of the texture and composition of the soils found in five landuse areas; buildings, kaleyards, infields, outfields and upland areas (section 2.7). The results are then analysed within the individual farm history and the geography on the island (section 2.8) and between other Shetland and Orkney Islands (section 2.9). (Raw data in appendices 1 and 2).

2.6 THE SPATIAL DISTRIBUTION OF SOILS IDENTIFIED IN THE AUGER SURVEY AT SHIRVA, LEOGH AND TAING

2.6.1 FARMSTEAD 1: SHIRVA

The first process to be conducted on the island was a detailed auger survey of three farms (Shirva, Leogh and Taing) in order to determine the range, texture, composition and distribution of soils and also to analyse the level of anthropogenic amendment to the soils. 56 cores were taken in total across the three farms. Shirva was then sampled in more detail with 7 test pit excavations to sample the soils in three comparative landuse areas (Fig 12).

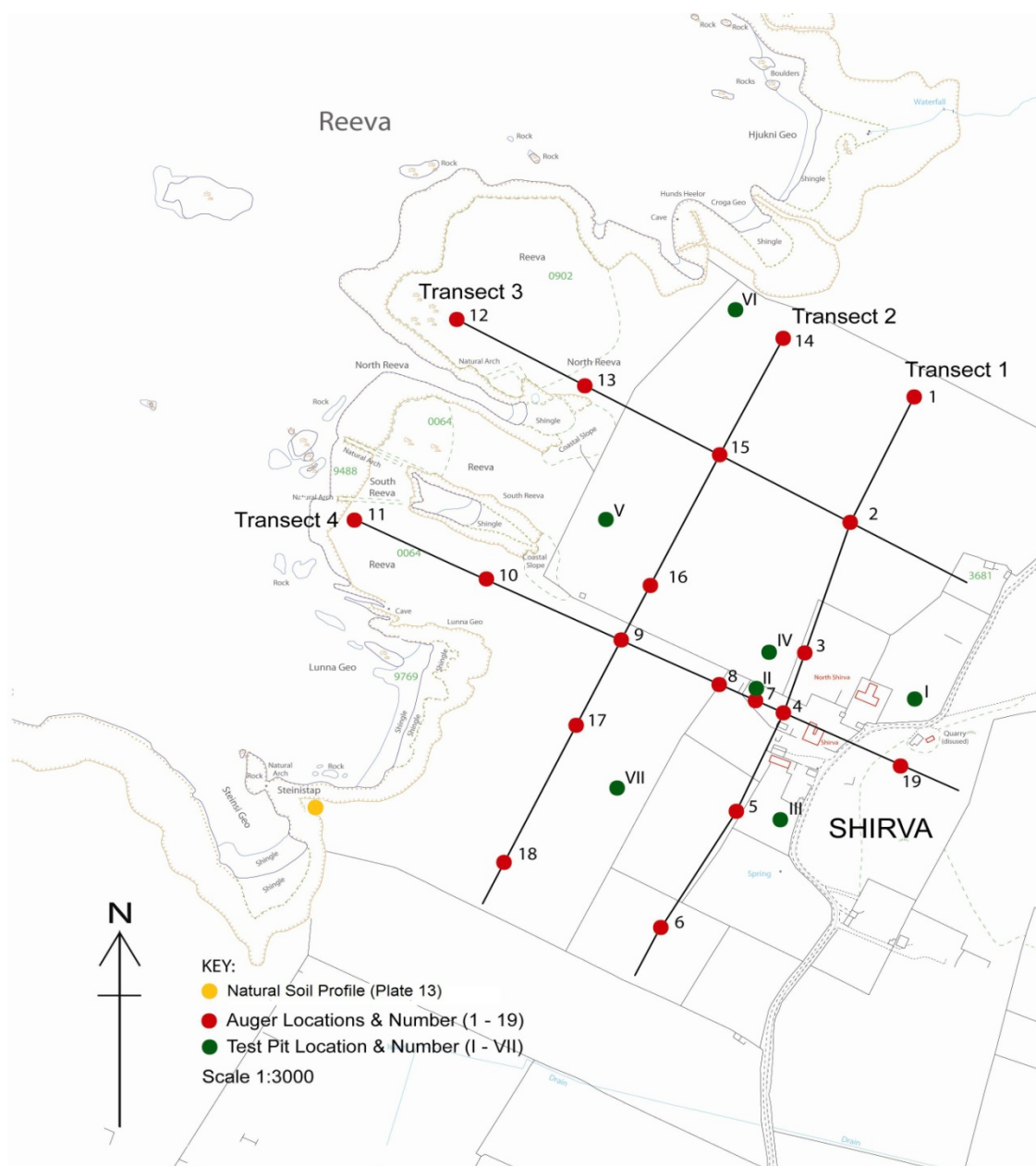


Figure 12, Auger and test pit locations across Shirva

Figure 12 shows the location of the 19 auger positions (2 kaleyard, 3 infield, 9 outfield and 6 upland) across the farmland of Shirva. Four transects have been created which display the soil horizons across the settlement. In transects 1 and 2 (Fig 13) soil horizons Ap 1 and 2 are fairly uniform across the site, ranging from 50mm to 80mm, and vary very little in texture and composition. The most extensive horizon, Ap 3, has a more variable depth ranging from 400mm on the top of slopes to +500mm in lower areas as a result of downslope movement. In two cores a buried peat soil (H) was identified and in the down slope of the infield and outfield area and these may be pockets of remnant peat soil. Transects 1 and 4 illustrate the spatial distribution of the soils across the three main areas of the farm. Interestingly the kaleyards actually contain a relatively shallow sequence of soils compared to the outfield area which suggests that if anthropogenic manuring is occurring then the emphasis appears to be in the main arable infield and outfield areas of the farm rather than the small garden enclosures. Sections three and four (Fig 14) illustrate the soil profiles on the western edge of the farmland and its relationship with the upland stratigraphy. In cores 12 and 13 of transect 3, the natural peat horizons were found along with a leached E horizon and a sandy B horizon and these horizons thin slightly downslope. The soils are heavily organic with rootlets and inclusions of quartz grains and some black amorphous particles. In core 10, transect four the upland area is less steep and partially terraced and the sediments appear to have been utilised for cultivation due to the presence of rig features. The texture and composition of the upland peaty soils (H1 to H3) also differ distinctively from the natural soils on the steeper slope to the south. On the whole the soils appear to have been initially upland peat horizons but the colours are generally darker ranging from a greyish brown to a dark greyish brown with a higher sand texture and black amorphous inclusions. A distinctive mottled horizon was also found which was greyish brown and heavily mixed with the H horizon through bioturbation or possibly ploughing but only small plough marks were identified. The organic Ap horizons are present in cores 15 and 10. The upper horizons are relatively uniform across the farm but the Ap-3 horizon is remarkably thick in places between 250 – 300mm and thins up the shallower eastern slope.

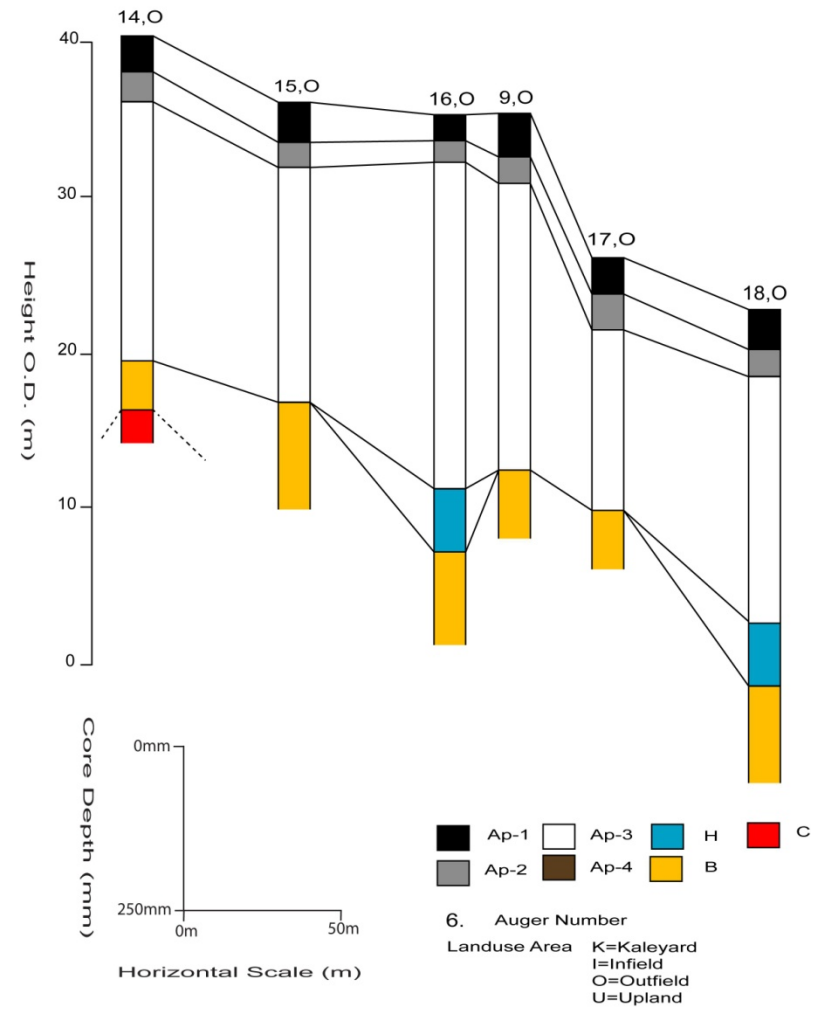
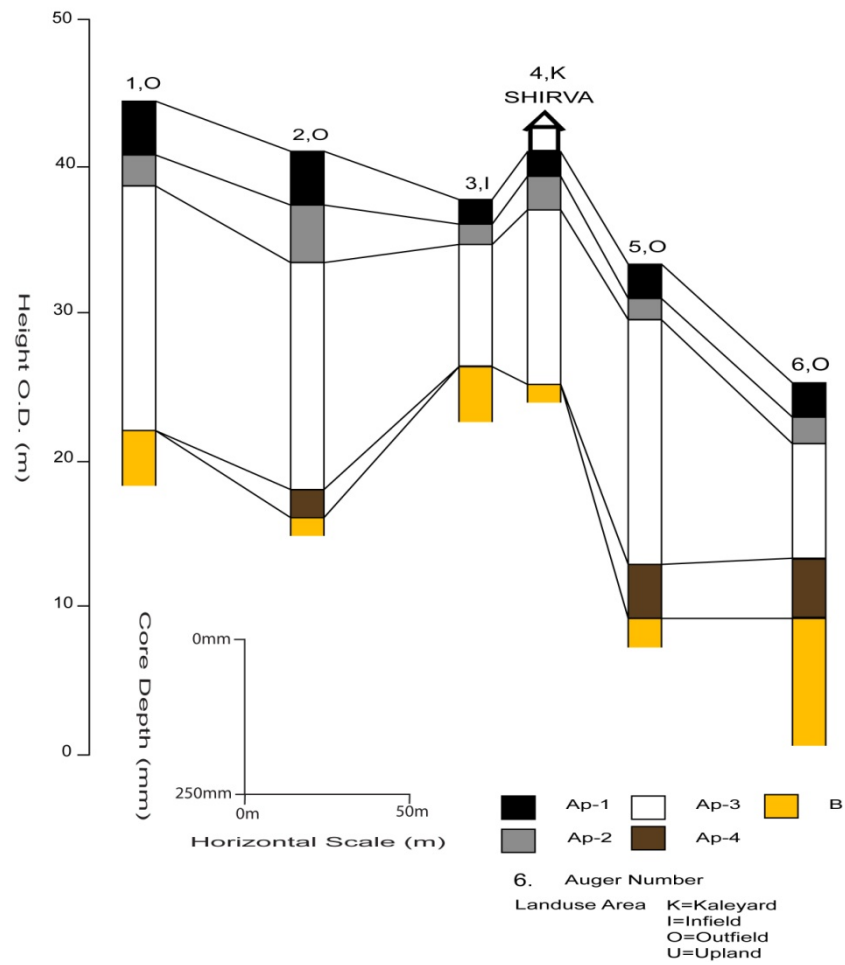


Figure 13, The distribution of soils across Shirva farmstead in transects 1 and 2

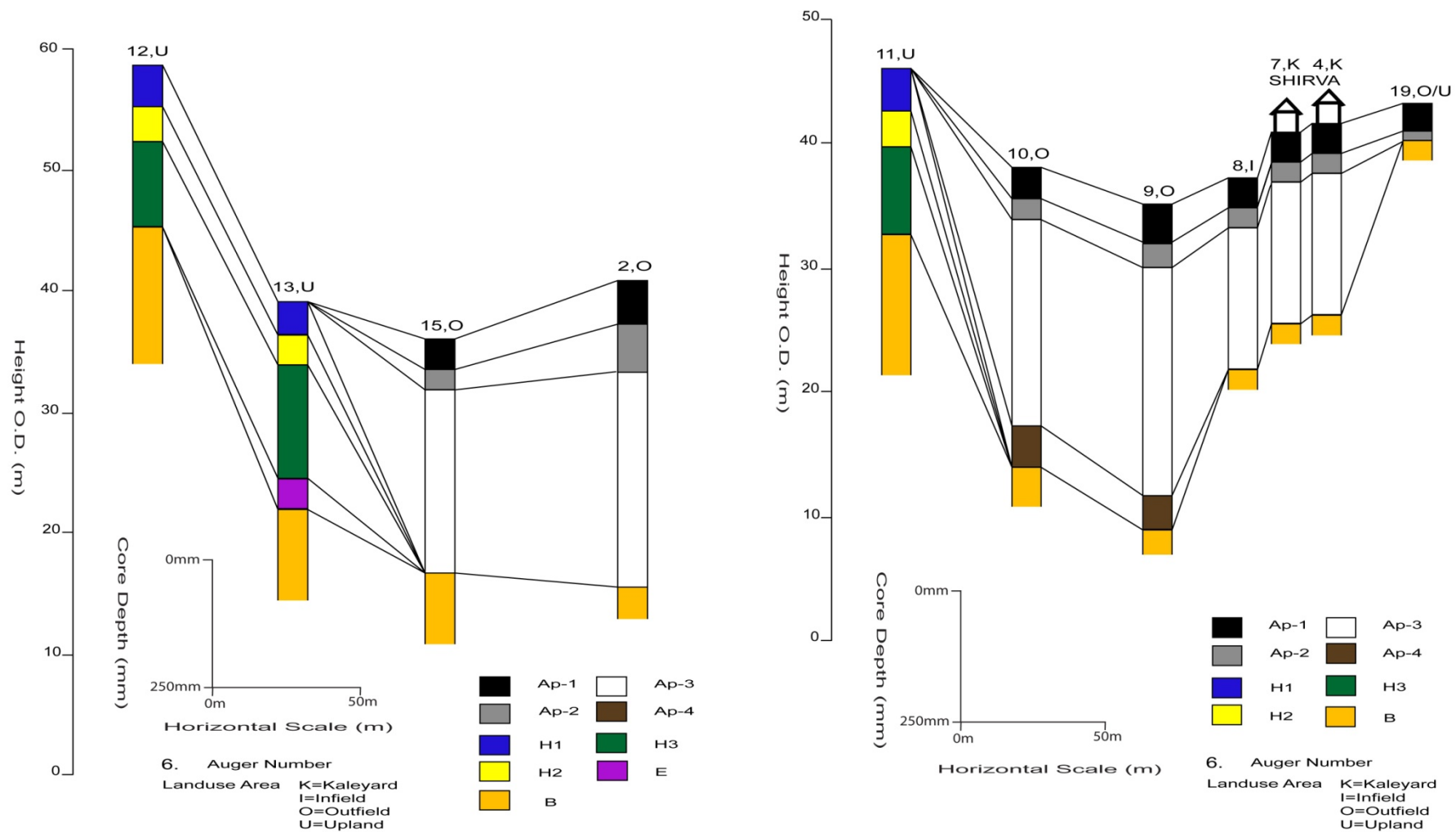


Figure 14, The distribution of soils across Shirva farmstead in transects 3 and 4

2.6.2 FARMSTEAD 2: LEOGH

At Leogh 20 cores were taken across the farmland with 3 in the kaleyard area, 3 in the infield, 11 in the outfield and 2 cores in the upland area (20-39) (Fig 15). Four transects were produced of the soil stratigraphy across Leogh (transects 5 to 8), (Figs 16 and 17) and transect 8 illustrates clearly the distribution of soil horizons across each of the landuse areas from upland to kaleyard.

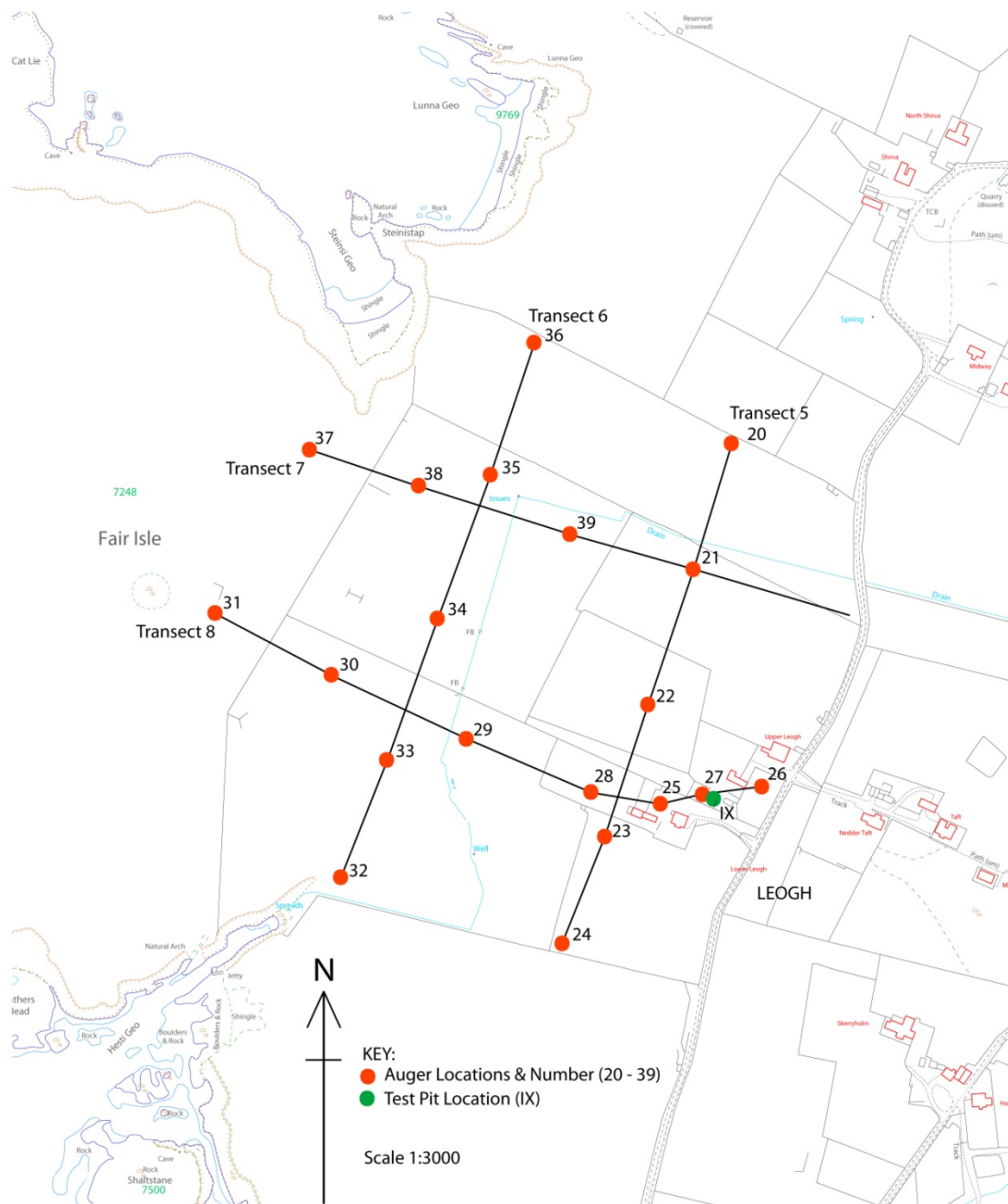


Figure 15, Auger and test pit locations across Leogh

There is a general increase in depth of the Ap horizons from the outfield to the infield areas and a further increase in the kaleyard possibly as a result of increased organic amendment to the soils. The variation is most clearly seen in the Ap-3 horizon as the Ap-1 and Ap-2 horizons vary very little across the farm

The Ap3 horizon ranges in depth from 150mm to 600mm and, as seen at Shirva, the depth increases downslope especially in transect 6 where the landsurface drops away to the south. In places, however, there are variations in the distribution of the Ap-3 horizon especially in transect 5.

Transects seven and eight (Fig 17) illustrate the variations in soil between the upland area and the lowland agricultural zone. The change in slope mirrors the change in landuse and this is also reflected in the soils. In cores 32 and 38 the soil horizons are very shallow and consist of a typical upland peat soil. In places these soils thin dramatically and are overlain by organically enhanced Ap horizons where cultivation has occurred in the past. Compared to the organic soils in the infield and outfield areas however there is only minimal evidence of agriculture in the marginal areas of the farm.

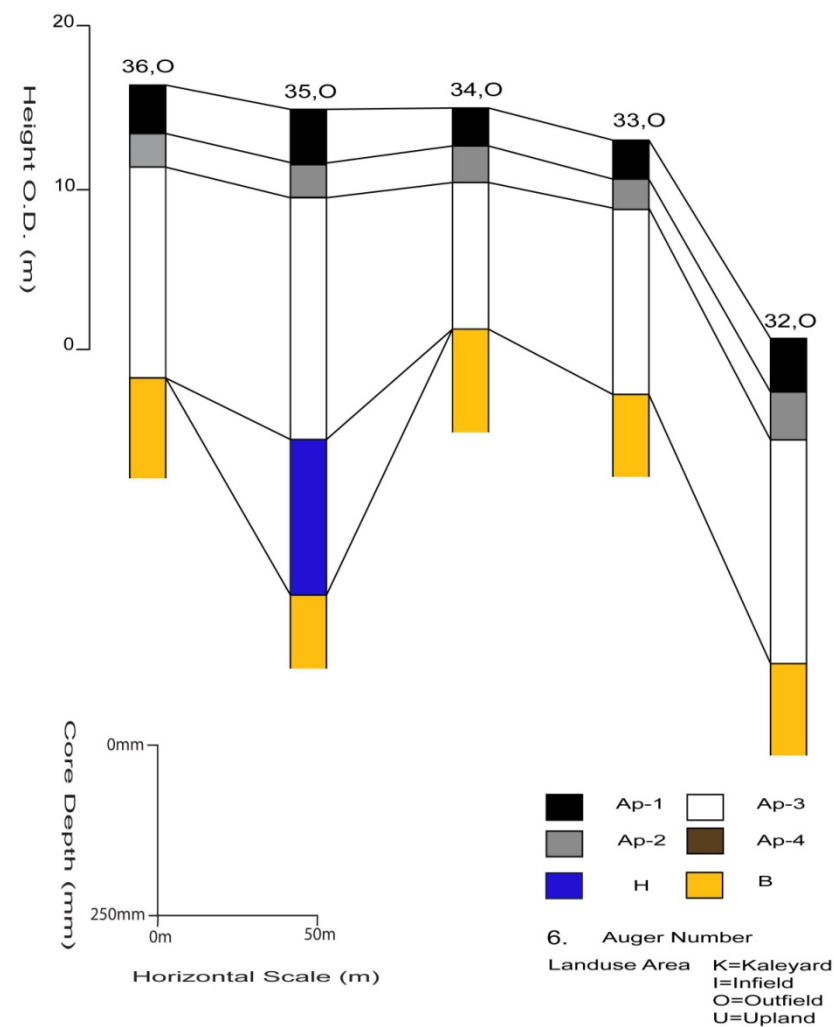
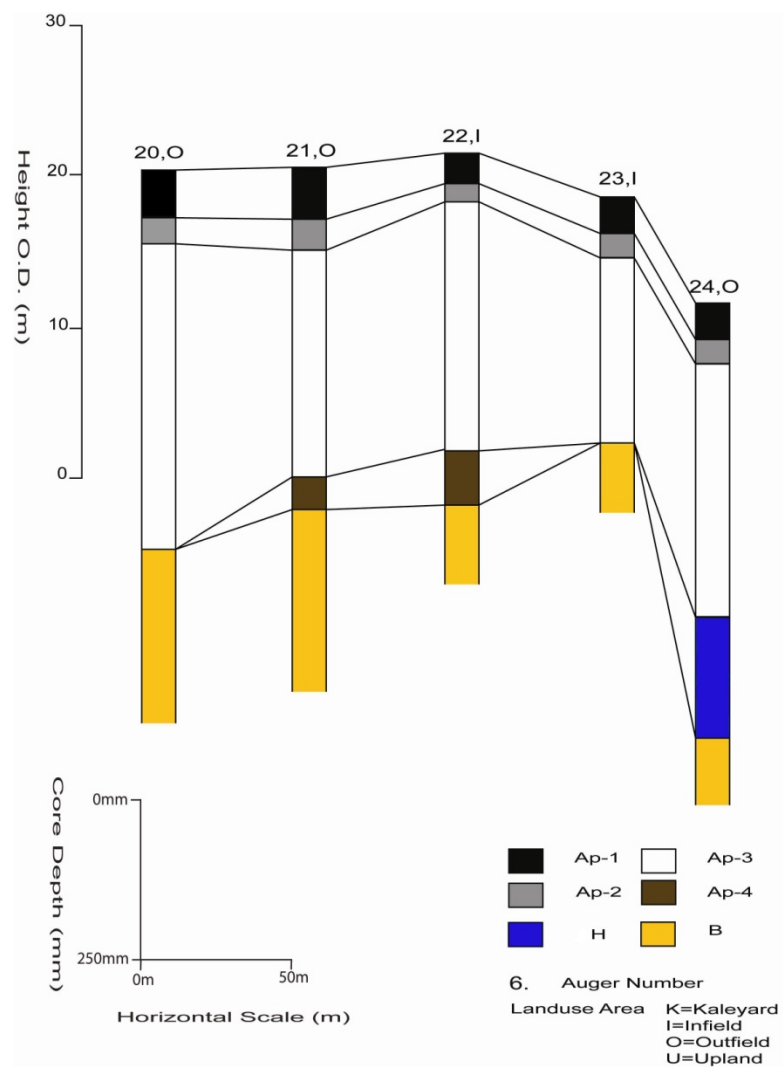


Figure 16, The distribution of soils across Leogh farmstead in transects 5 and 6

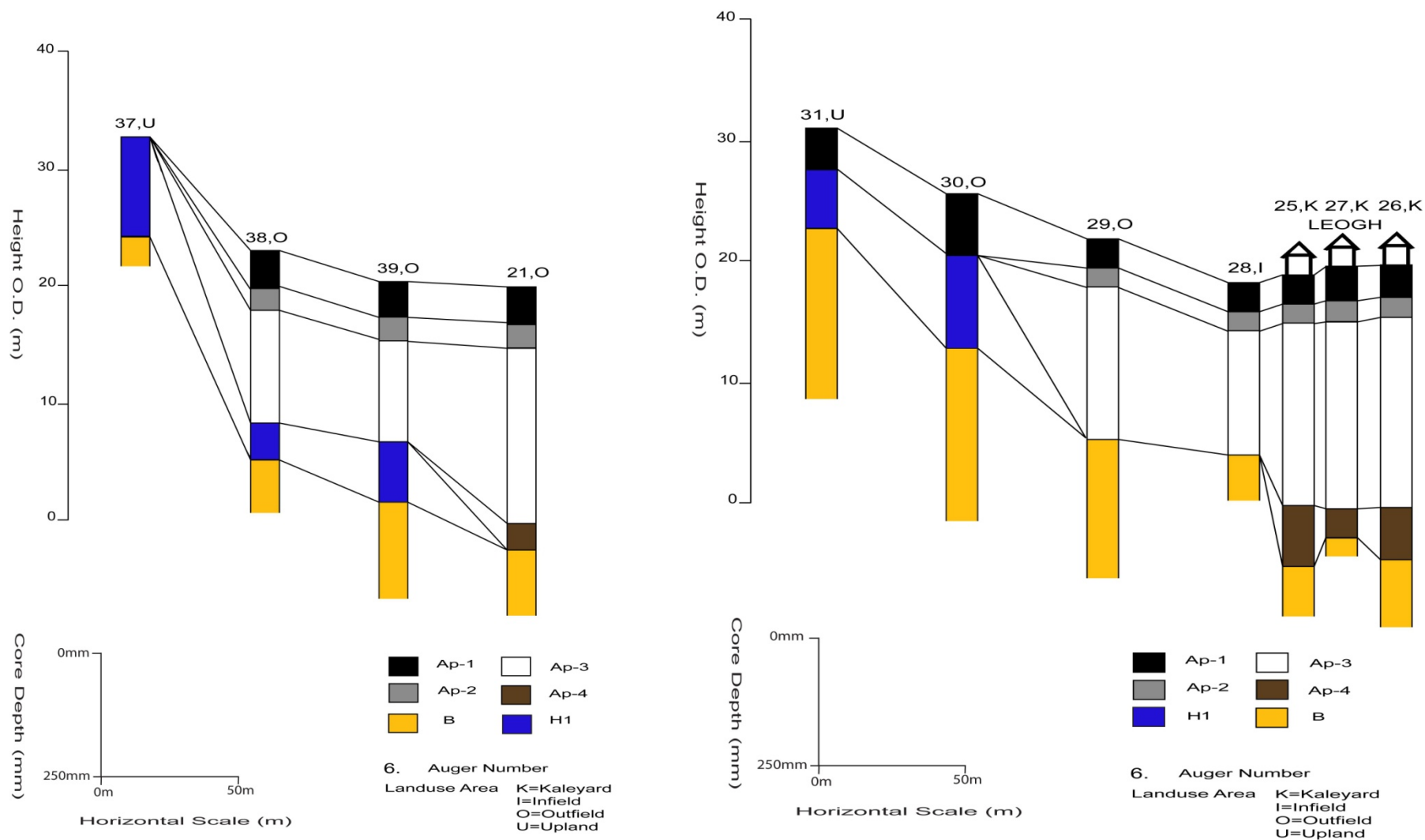


Figure 17, The distribution of soils across Leogh farmstead in transects 7 and 8

2.6.3 FARMSTEAD 3: TAING

At Taing, 17 cores were taken (40-56) with 2 in the building, to determine whether there were any occupation horizons, 4 in the kaleyard, 2 in the infield area, 7 in the outfield/upland area (Fig 18). From the data collected three transects were produced and these revealed a very different stratigraphy from the other two settlements (Figures 19 and 20).

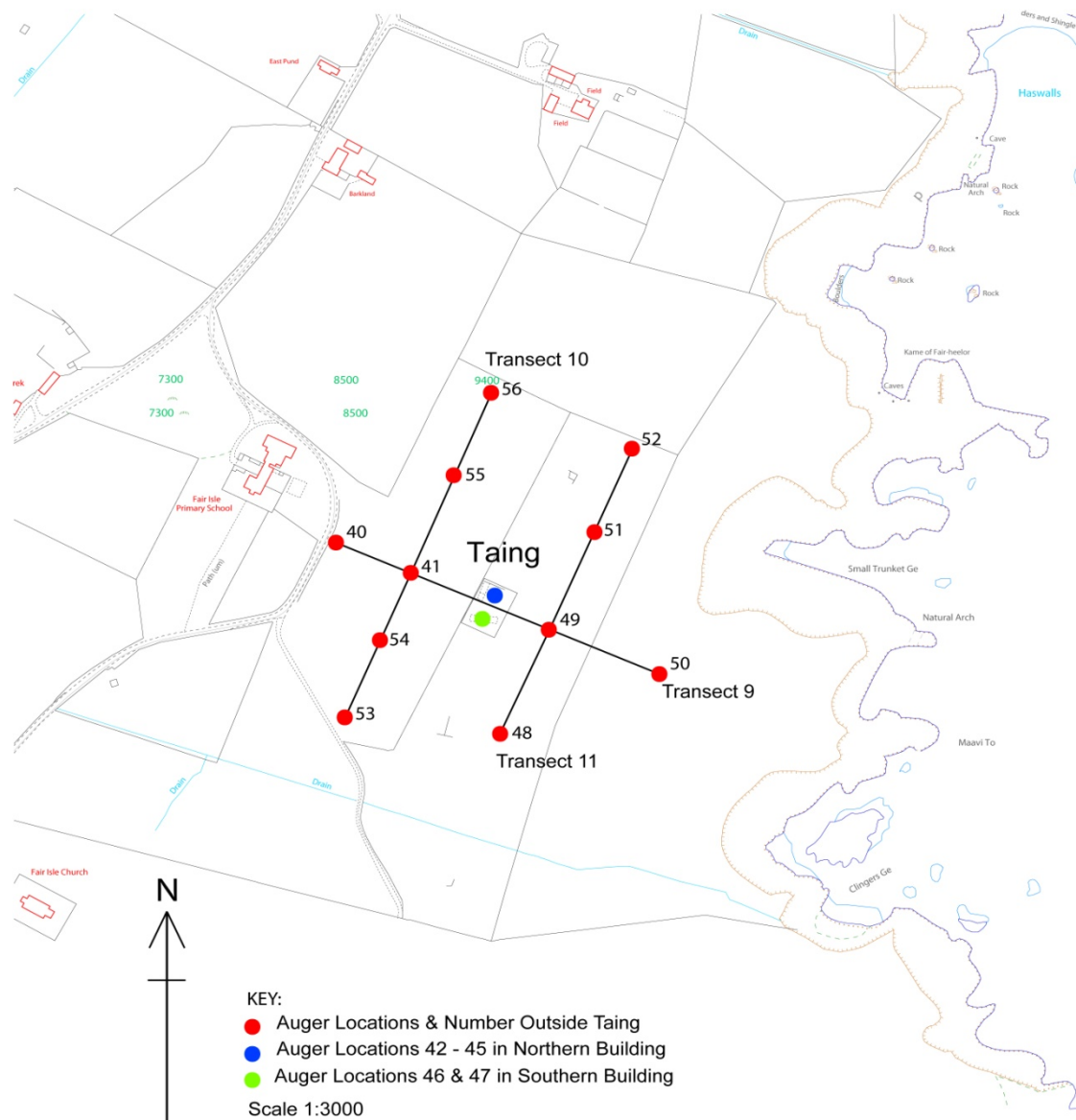


Figure 18, Auger locations across Taing

Only one Ap horizon was identified across the farm and it was considerably less widespread than in the other two settlements. The horizon ranges from 40mm to 70mm deep and consists of a greyish brown to brown (10YR 5/1 to 3/3) silty clay loam with rootlets, quartz and sandstone inclusions. Compared to the Ap-1 horizons from Shirva and Leogh the soil at Taing contained very little anthropogenic evidence and only few, small fragments of charcoal and black amorphous inclusions. Despite the shallow depth of the Ap soil horizon there is a slight increase towards the centre of the settlement which indicates minimal manuring, however there is also surface evidence that the natural peaty soils have also been used in the past for cultivation especially around the margins of the farm in all the transects but especially cores 40,48,50,52 and 56. Below the Ap horizon are a number of distinctive natural peaty horizons (H1 to H3) and these range in depth between 50mm to 350mm and have a distinctive dark brown to dark greyish brown colour (10YR 2/2 to 3/2) and have a silty sand clay texture with peaty inclusions along with some small quartz fragments.

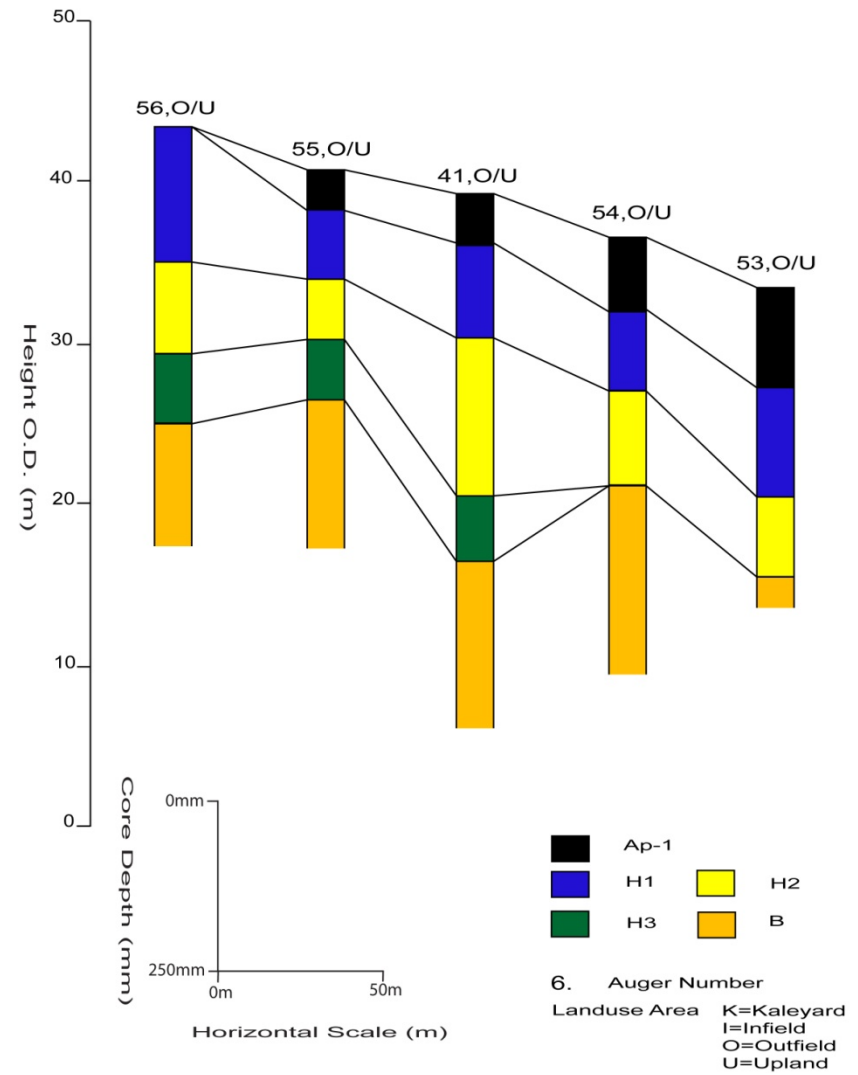
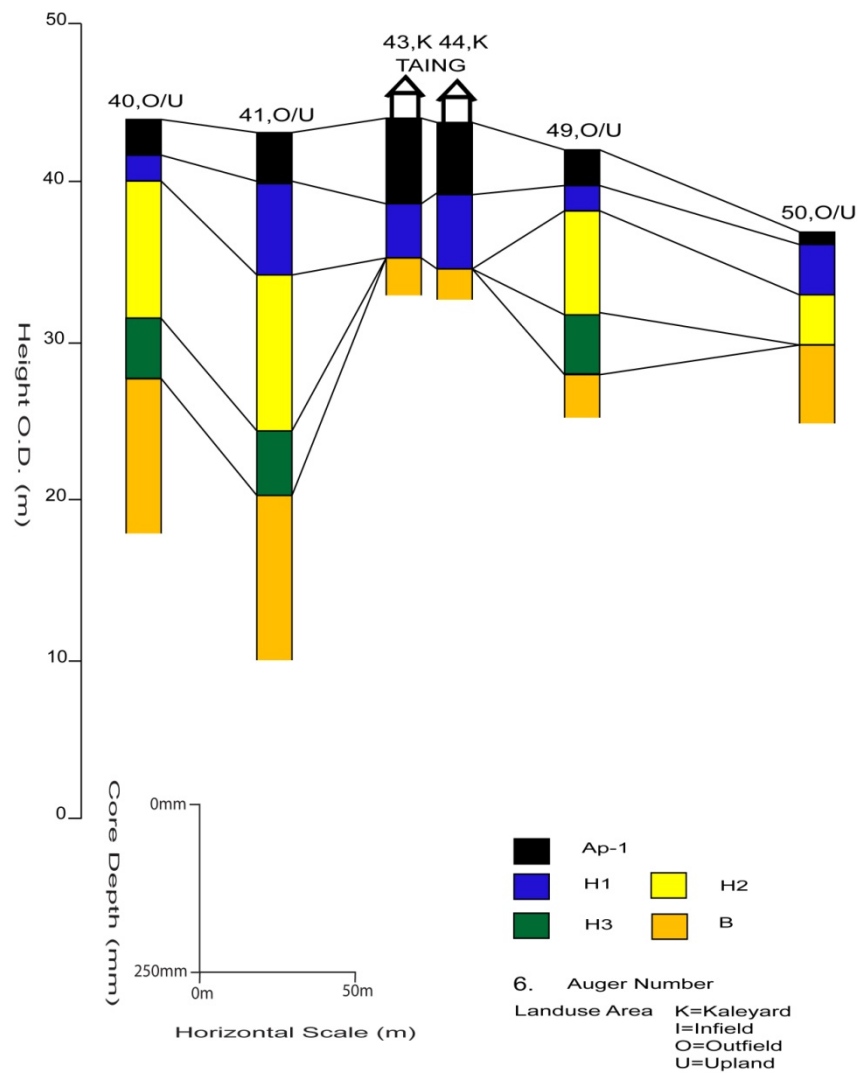


Figure 19, The distribution of soils across Taing farmstead in transects 9 and 10

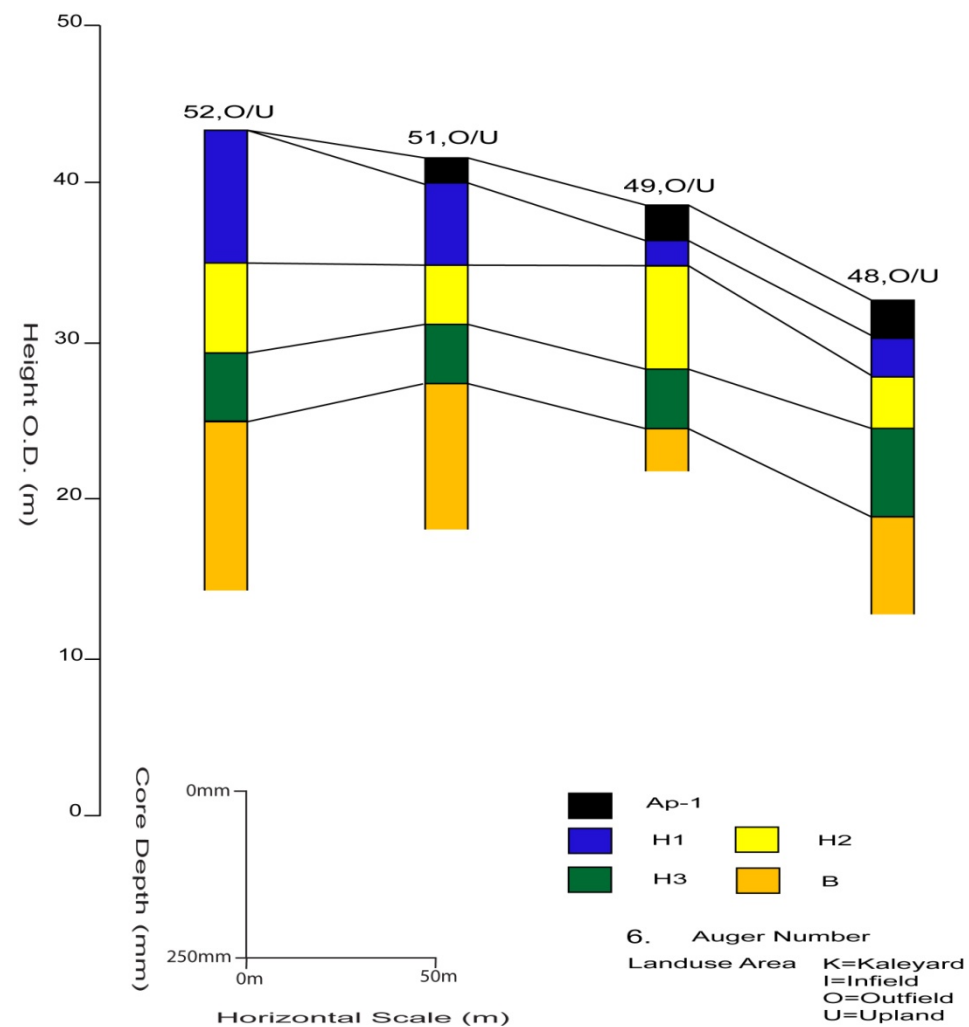


Figure 20, The distribution of soils across transect 11

2.7 THE DISTRIBUTION OF SOIL HORIZONS ACROSS FIVE LANDUSE AREAS

2.7.1 BUILDINGS

The majority of cores were taken from agricultural areas which are analysed below, however at Taing, two cores were taken through the southern building in two sections of the tripartite structure. This was conducted to determine the stratigraphy through a building and to see whether there was any evidence of burning or manure storage horizons or possible changes in landuse. No other buildings at Shirva or Leogh were sampled as no clear stratigraphy was evident.



Plate 10, Southern tripartite building at Taing

The building shown in plate 10 was sampled at the northern and southern end and is recorded in cores 47 and 48. The stratigraphy did not show any clearly definable burnt layers or compacted floor layers but did have a considerable depth of what appeared to be an amended soil suggesting the farm had been developed upon an area of arable farmland. The upper layers in the building (Ap 1 to 3) consisted of greyish brown to brown (10YR 4/2 to 3/3) and some dark grey (10YR 5/2) coloured silty clay loams with inclusions

of rootlets, quartz grains and charcoal/coal material. These soils were 220mm and 290mm deep at the two localities and most likely represent occupation deposits within the structures and sit directly upon the B horizon, a distinctive dark reddish brown to yellowish brown subsoil (10YR 4/4 to 5/6). At the boundary between the two soils, however, a mixture of coal and burnt clay was found which is the only evidence of a possible hearth although the inclusions were heavily fragmented and well rounded and therefore may represent the storage of manuring material rather than from in situ burning.



Plate 11, Test pit 1 showing pre and post excavation of stony horizon with post hole and overlying arable soils

At Shirva a distinctive archaeological feature was uncovered when test pit one was excavated (Plate 11). There was no trace of the structure on the surface as the feature had been buried below 340mm of anthropogenic soil which did show clear rig morphology orientated north to south. The absolute extent of the feature was undetermined due to the size of the exploratory excavation, however it was clear that there had been a sizeable structure on the site from the compacted stony deposit which was 600mm deep and was composed of a number of lithologies including sandstone, dolerites, mudstones, quartzites, schists and granite of various size and shape. Surrounding the large stones was a very dark humic soil with inclusions of plant material, building debris and charcoal. On the south side of the test pit a large post-hole was identified, 370mm in diameter with a sub-rounded to sub-

square shape and very distinctive sharp sides and a flat base which appeared to contain a number of tabular sandstone blocks not deliberately placed but acting as post pads. The feature was identified because of the fill of the post hole, a very distinctive dark brown to grey black coloured (10YR 2/2 to 3/1) silty sand loam, possibly originating from the later enhanced arable soil, with very small inclusions of quartz fragments and some charcoal (Fig 21).

Archaeological Features - Test Pit 1 Shirva Infield HZ 20318, 70716

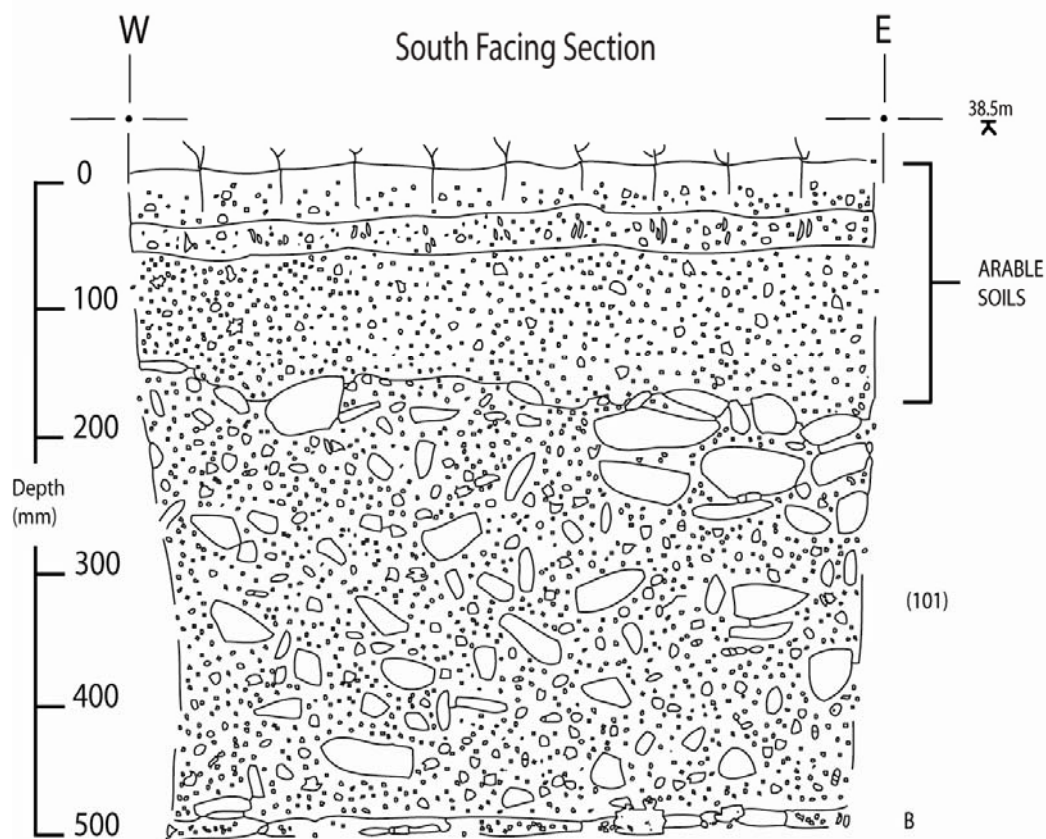


Figure 21, Section drawing of test pit 1 showing the dense stoney horizon and overlying arable soils

2.7.2 KALEYARDS

Four kaleyards were sampled by the auger in order to determine the range of depths of soils present and to assess anthropogenic influence upon

their origin and formation. Each of the kaleyards assessed are in different states, Shirva and Leogh are disused kaleyards within extant farmsteads, Busta has a kaleyard which is still used by the farm for growing vegetables (Plate 12) and Taing has a kaleyard located within a deserted farmstead.



Plate 12, Busta kaleyard looking west

The kaleyards were identified from maps and field walkovers and were typically small sub-square to sub-rectangular enclosed areas measuring on average 10 – 15m by 9 – 12m and associated with a croft building. In all but the Busta kaleyard the vegetation consisted of short grass, weeds and short tree species. The identification of kaleyards was also assisted by the changes in landsurface height. This was most evident at Shirva and Leogh where a difference of 300mm to 450mm was observed, however at Taing there was little to no variation with surrounding areas. At Busta, the kaleyard had a very subtle concave topography from the movement of soil by human and natural processes leading to degradation of soil in the middle of the kaleyard and a build up of soil towards the edges of the enclosure and an increase in ground level with the surrounding infield field system. This gave the impression of substantial depth, but sampling showed a depleted stratigraphy.

Shirva - Test Pit 2 HZ 20226,70718

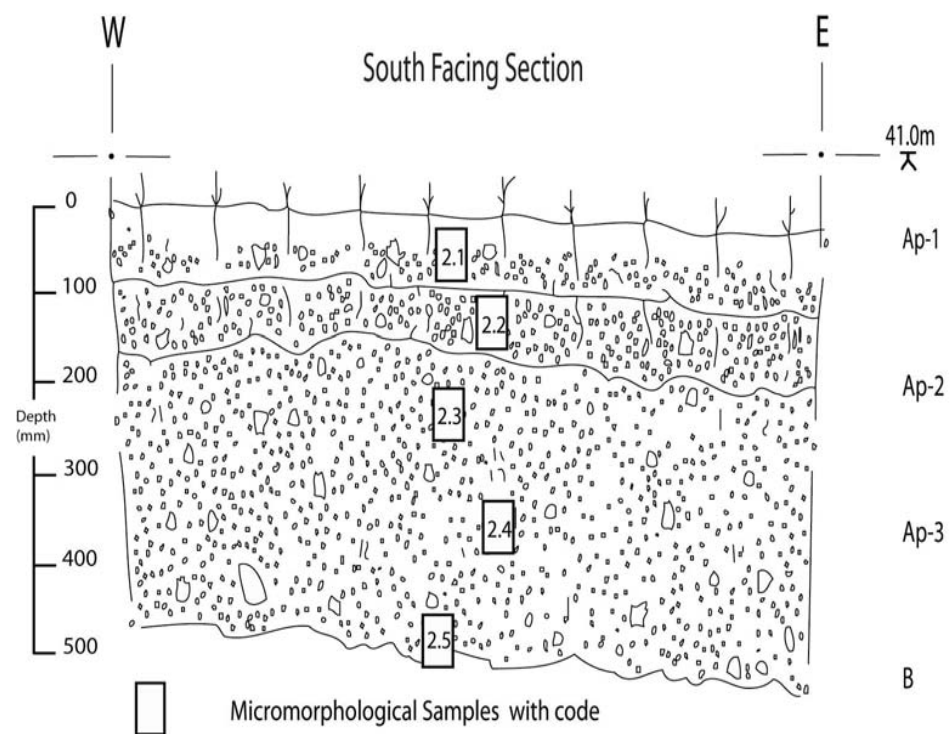


Figure 22, Section drawing and photograph of Shirva kaleyad soil horizons in test pit 2

Busta - Test Pit 8 HZ 20687,70108

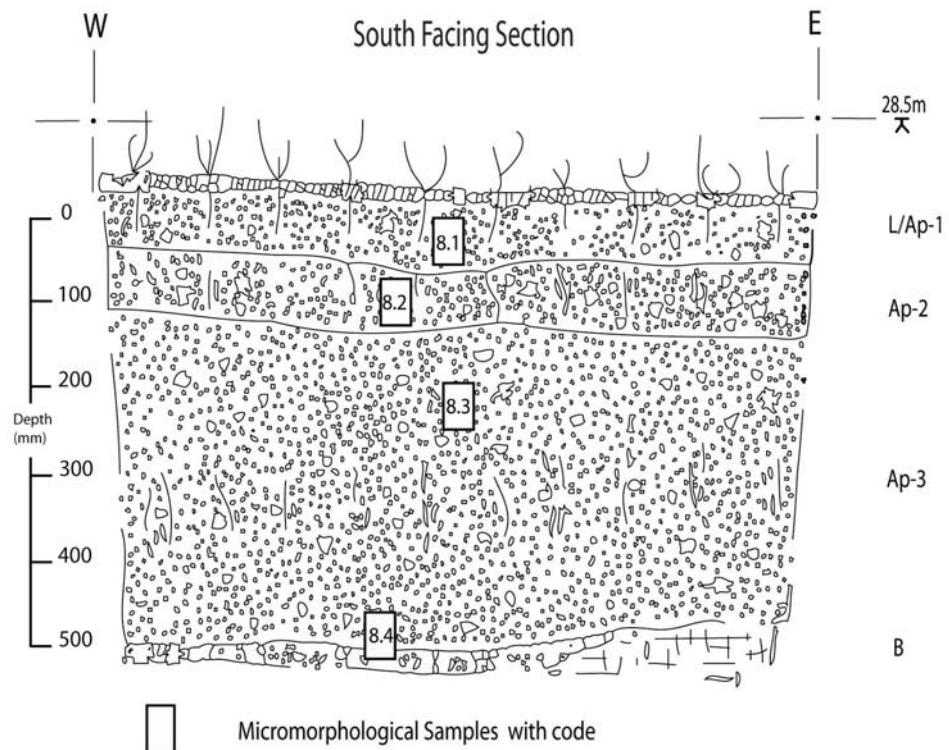


Figure 23, Section drawing and photograph of Busta kaleyard soil horizons in test pit 8

Leogh - Test Pit 9 HZ 20113,70275

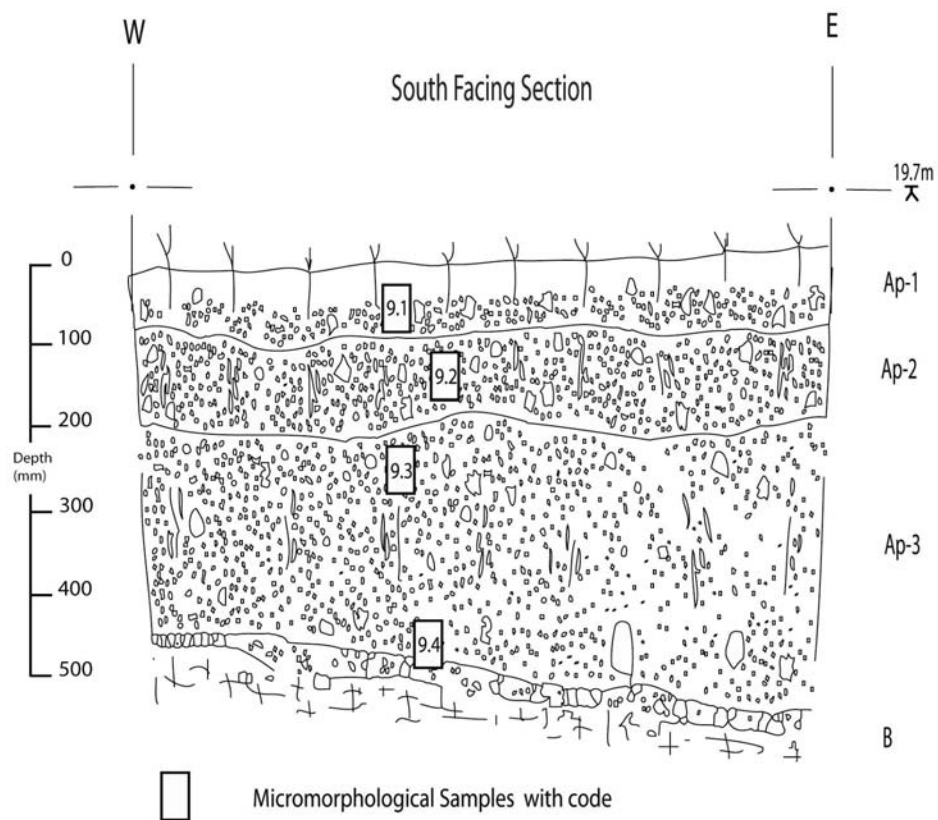


Figure 24, Section drawing and photograph of Leogh kaleyard soil horizons in test pit 9

The deepest arable horizons were located at Shirva, Busta and Leogh with just over 400mm of amended arable soils. Based upon the auger survey three test pits were excavated in the kaleyards at Shirva, Leogh and Busta (Figures 22 to 24) and these contain very distinctive soil horizons.

The upper soil horizon (Ap-1) consists of a dark brown to dark greyish brown (10YR 3/3 to 10YR 5/2) silty clay loam with large fragments of mineral and organic inclusions including medium sized charcoal and amorphous black particles along with highly degraded peat fragments and some modern brick, tile and ceramics inclusions. At each site the Ap-1 horizon had a very similar range of depths from 50 – 100mm with a very clear boundary with the layer below.

The Ap-2 horizon is also fairly uniform across each of the sites and ranges from 50 – 80mm. The horizon is a dark brown colour (10YR 3/3) with a silty clay loam texture and large quantities of organic material in the form of partially decomposed plant material, large peat fragments and some brick and post medieval pottery.

The most extensive horizon at all the sites is the Ap-3 horizon which is a dark brown to brown/grey colour (10YR 3/3 to 4/2) with areas of dark grey (10YR 4/1) and a silty clay sand loam texture. The soil horizon also contains inclusions of sub-rounded sandstone and quartz fragments, medium sized charcoal and amorphous black particles along with highly degraded peat fragments. The horizon ranges from 270 – 390mm with the deepest soils at Busta and slightly shallower deposits at Shirva and Leogh.

2.7.3 INFIELD AREAS

At Shirva three cores (3, 5 and 8) were taken and three test pits (1,3 and 4), (Figs 25, 26 and 27) excavated in the infield area. Three cores were located close to the settlement centre (3, 5 and 8) and they each had a shallow stratigraphy ranging from 350mm to 380mm in the north and 540mm to 570mm to the south, highlighting a deepening of soils towards the southern end and several large terraced fields.

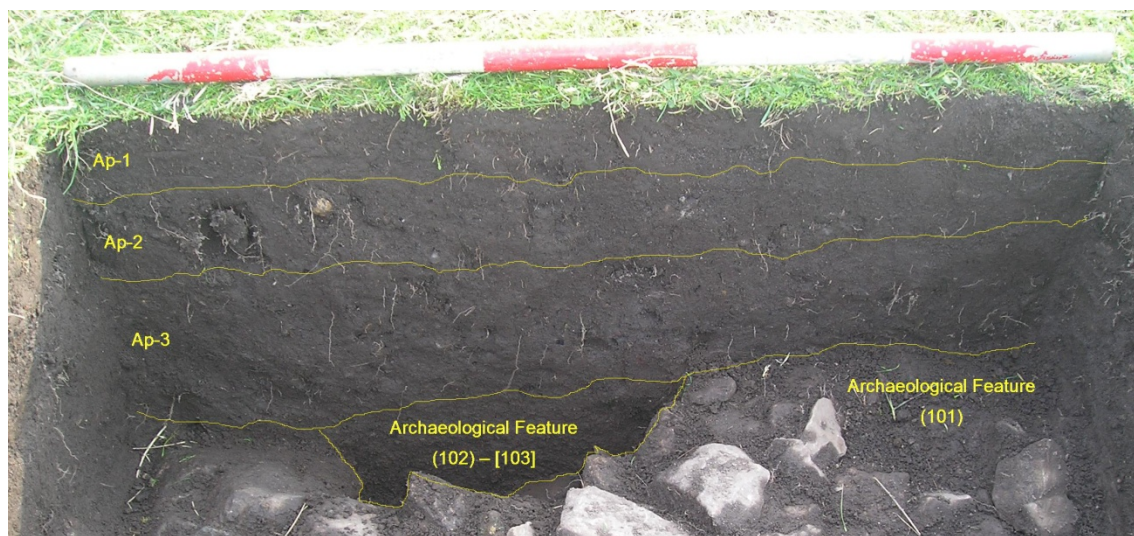
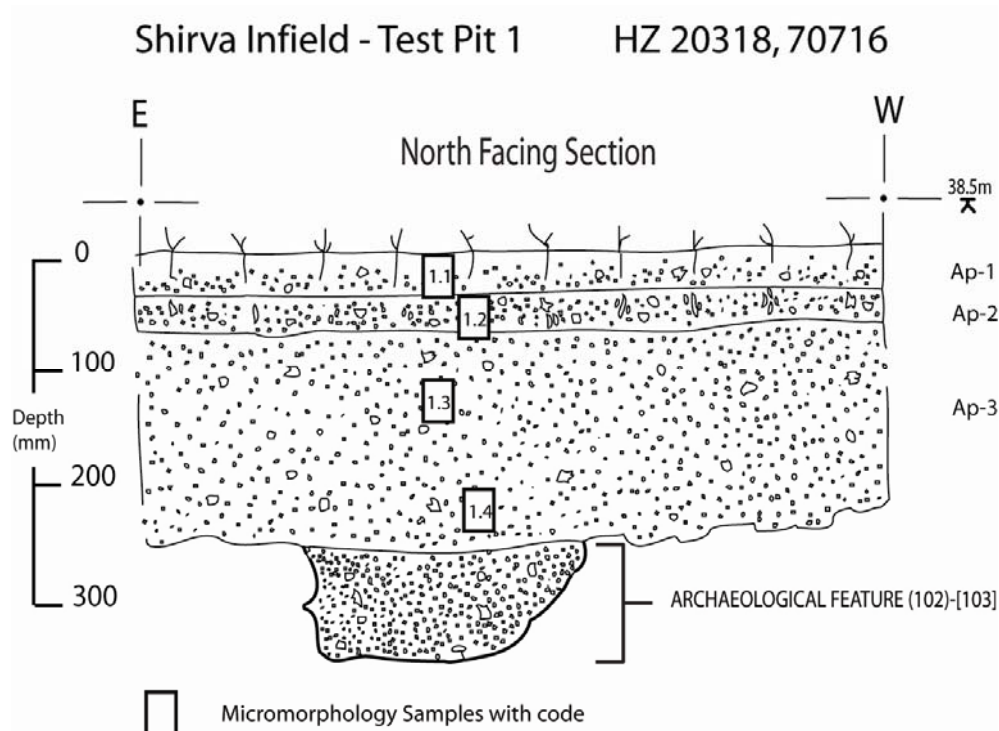


Figure 25, Section drawing and photograph of the soil sequence and archaeological features at Shirva in test pit 1

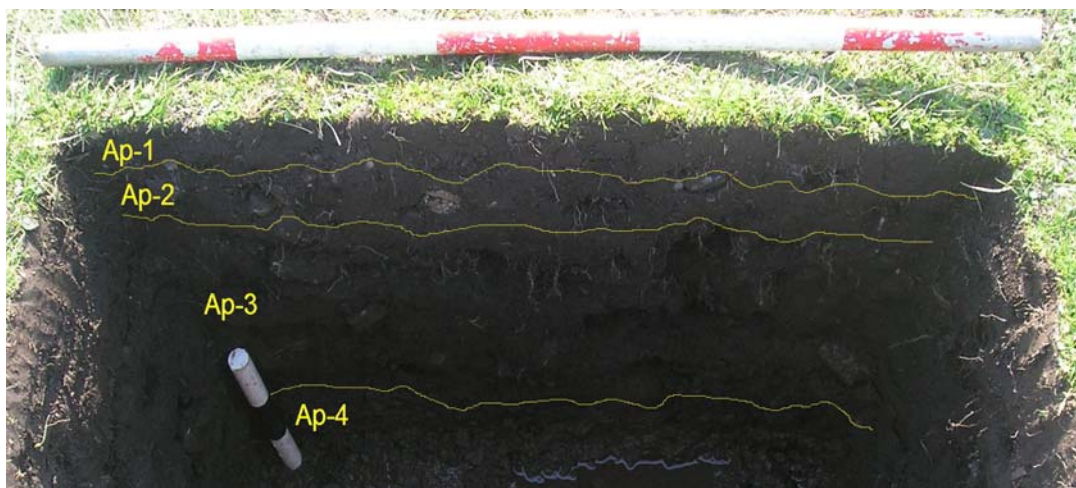
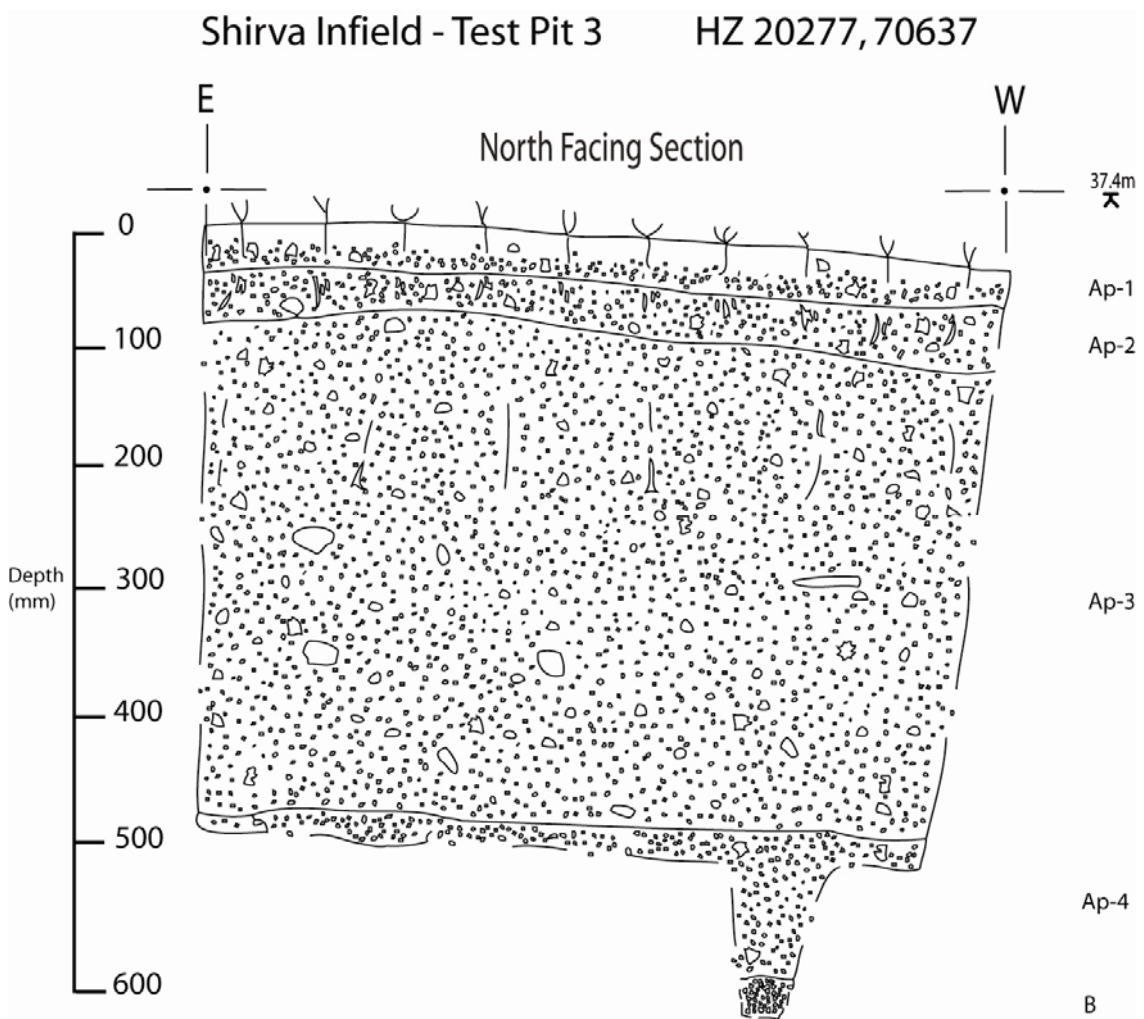


Figure 26, Section drawing and photograph of the soil sequence at Shirva in test pit 3

Shirva Infield - Test Pit 4

HZ 20231,70734

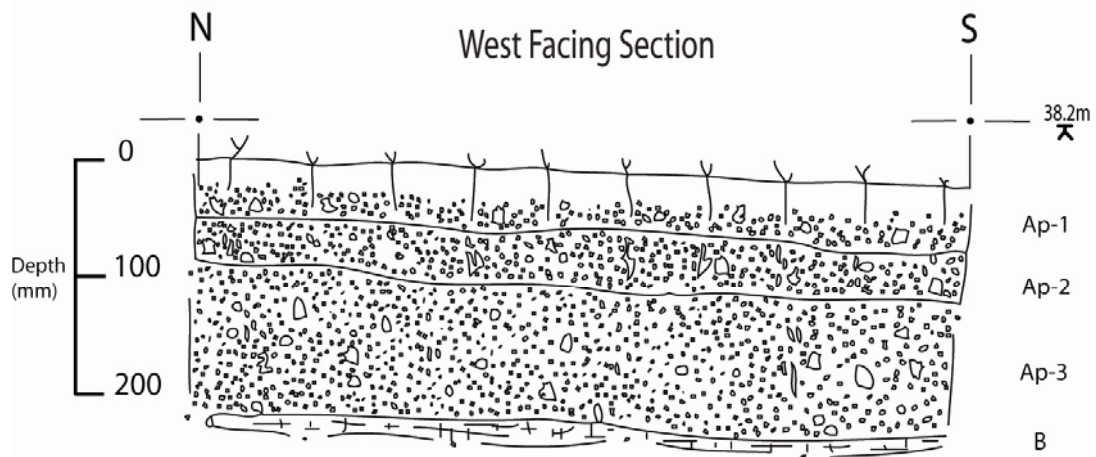


Figure 27, Section drawing and photograph of the soil sequence at Shirva in test pit 4

The Ap-1 horizon is 40mm to 60mm deep and consists of a brown to dark brown (10YR 2/3 to 3/3) sandy silty loam texture with quartz fragments, rootlets and charcoal inclusions. Beneath that is a similar Ap-2 horizon, typically 30mm to 40mm thick, and contains slightly less organic inclusions. To the south the Ap-1 and 2 horizons contain large peaty organic material.

The Ap-3 horizon is the deepest and ranges from 290mm to 420mm and is characterised by a dark grey to dark greyish brown (10YR 5/2 to 3/2) soil with areas of very dark brown and even black (10YR 2/2 to 2/1) especially towards the southern edge of the settlement. Throughout the horizon the texture is a distinctive sandy silt loam with inclusions of sandstone fragments, organic material, charcoal and some heavily degraded building material in the form of slate and brick. The Ap-3 horizon in the northern infield has a sharp boundary with the distinctive dark yellowish brown (10YR 5/6) silty sand clay subsoil (B) and there is substantial mixing.

2.7.4 OUTFIELD AREAS

At Shirva the three test pits (5,6,7) were excavated in areas identified as having the most extensive stratigraphy (Figs 28 to 30). Test pit 5 was located directly west of the farm complex in an area of broad distinctive rig. Test pit 6 was located in the north west corner of the outfield area in an area of narrower, less well defined rig orientated on a different alignment to the surrounding rig. Test pit 7 is located to the south of Shirva's outfield on a distinctive incline and amongst north to south orientated rig.

At each of the test pits, three distinctive soil horizons are present and these include an Ap-1 soil horizon, typically a dark brown (10YR 2/2 to 3/3) silty sand clay loam with quartz fragments and some organics with a uniform range across the site from 60mm to 90mm. Under the Ap-1 horizon is a second thin organic layer (Ap-2) which ranges from 50mm to 90mm and consists of a dark brown (10YR 2/2 to 3/3) silty clay loam with inclusions of organic peat fragments and small charcoal fragments together with sandstone lithics. The most extensive horizon, in the outfield, is a very organic Ap-3

horizon ranging from 230mm to 270mm in the centre to 310mm to 360mm at the southern end.

This horizon is typically dark brown to grey, black (10YR 3/3 to 3/2 and 2/1) colour with a silty clay loam texture and frequent organic peats, humified plant material and charcoal fragments. Within test pit 5 and 6 a less distinctive soil horizon (Ap-4) is present with a distinctive lighter brown to dark grey colour (10YR 5/3 to 5/1) and a silty clay sand loam texture with inclusions of organics and charcoal fragments and lithic material. In test pit 6 the horizon contains large pieces of fragmented peat from the H horizon below which has a very dark brown to grey black colour (10YR 2/2 to 2/1) with a loamy peat texture and possibly constitutes a buried podzolic soil which has been heavily disturbed by ploughing action and ranges from 120mm to 170mm. At each of the test pits the natural was identified as a light yellow, white to red orange (10YR 7/6 to 8/1) sandy soil (B) with a medium to coarse texture and heavy iron staining representing heavily weathered Old Red Sandstone.

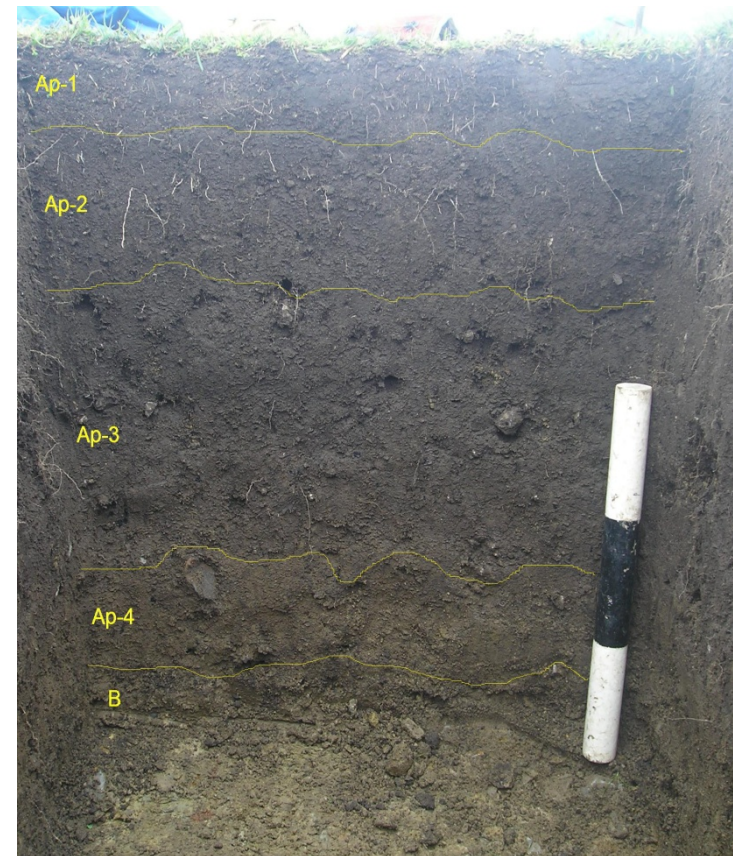
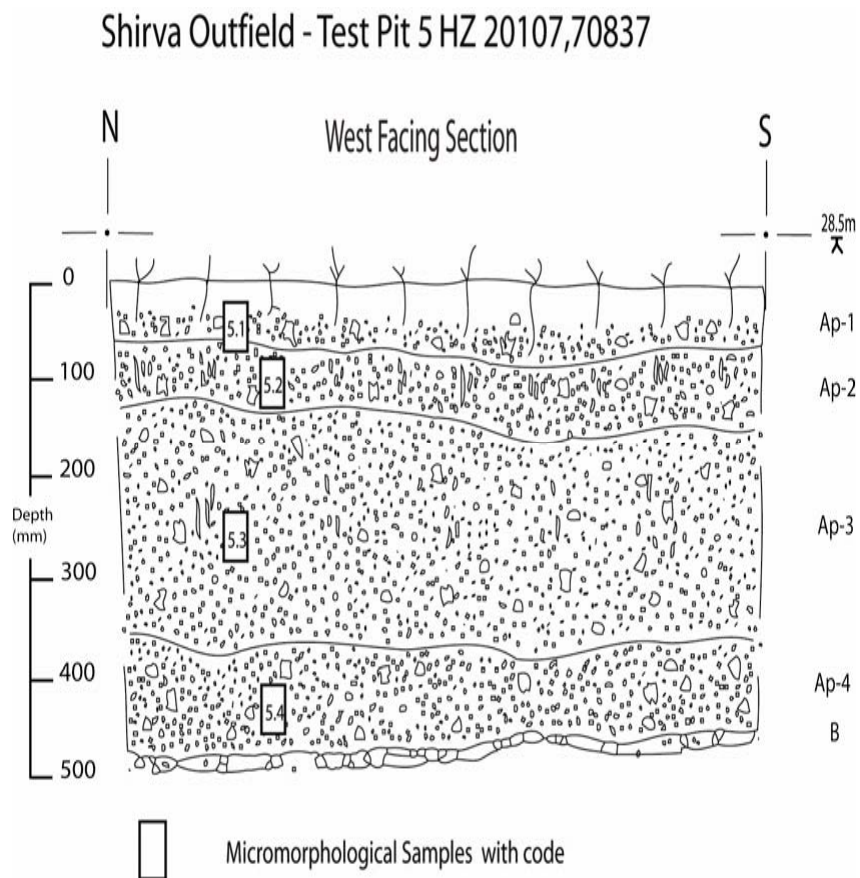


Figure 28, Section drawing and photograph of the soil sequence at Shirva in test pit 5

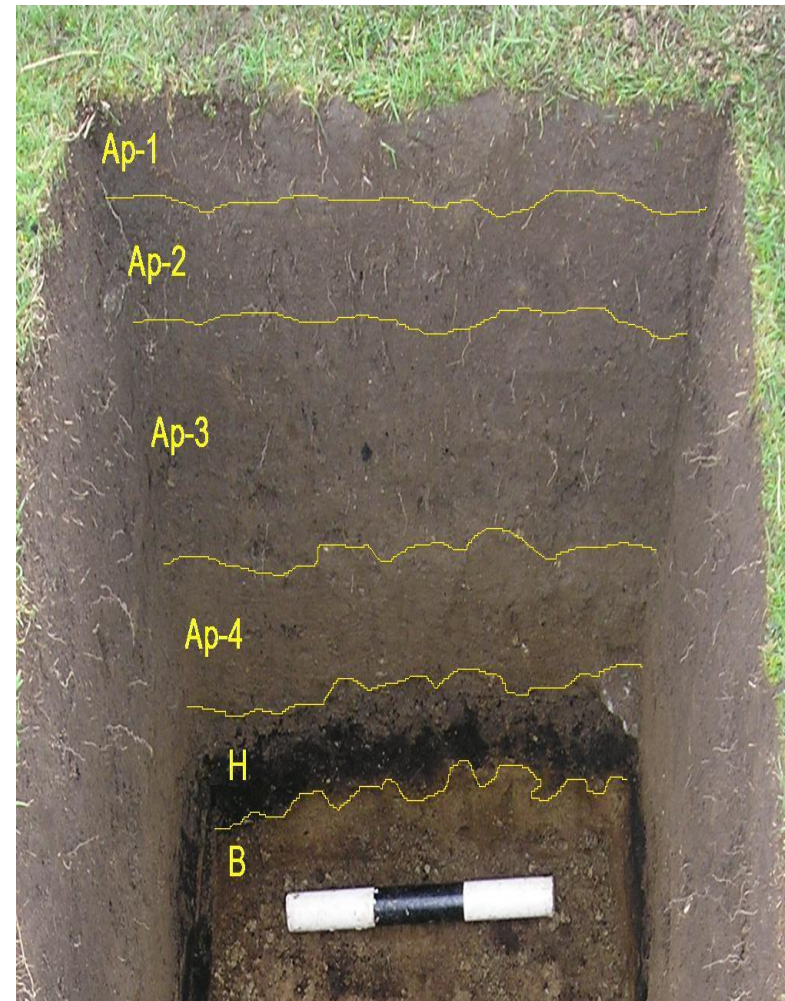
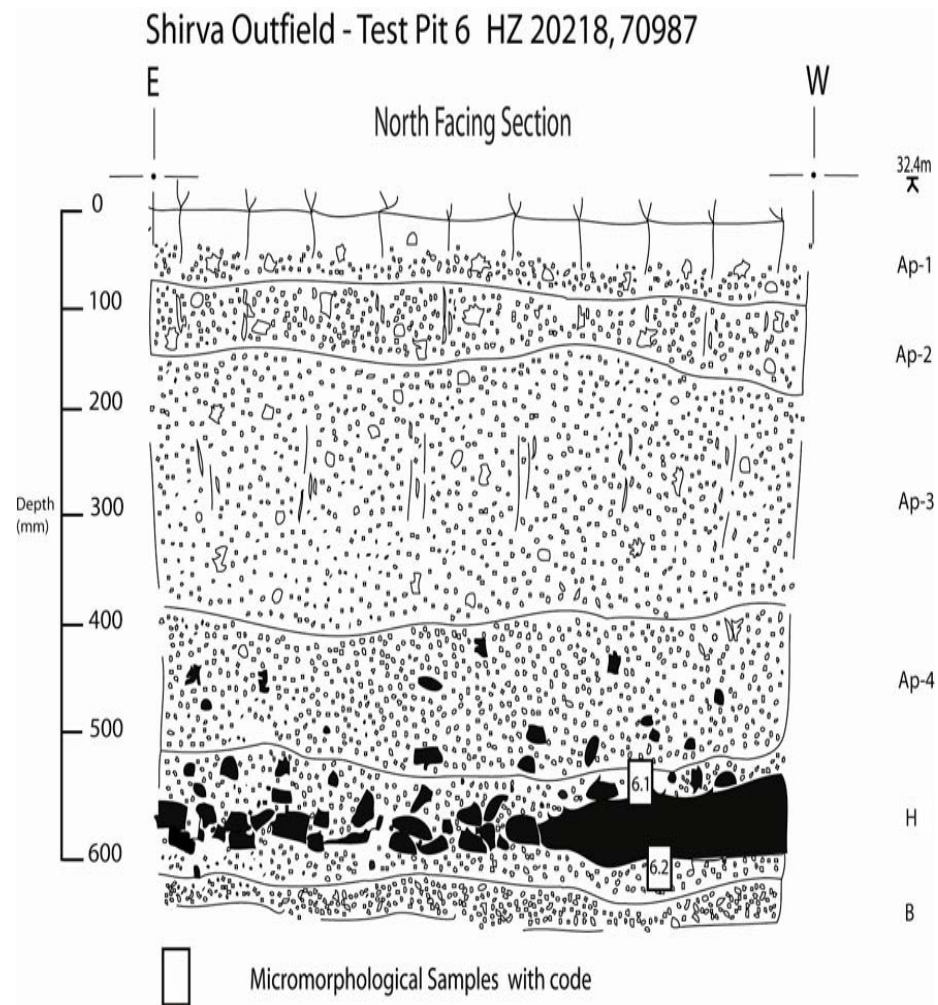


Figure 29, Section drawing and photograph of the soil sequence at Shirva in test pit 6

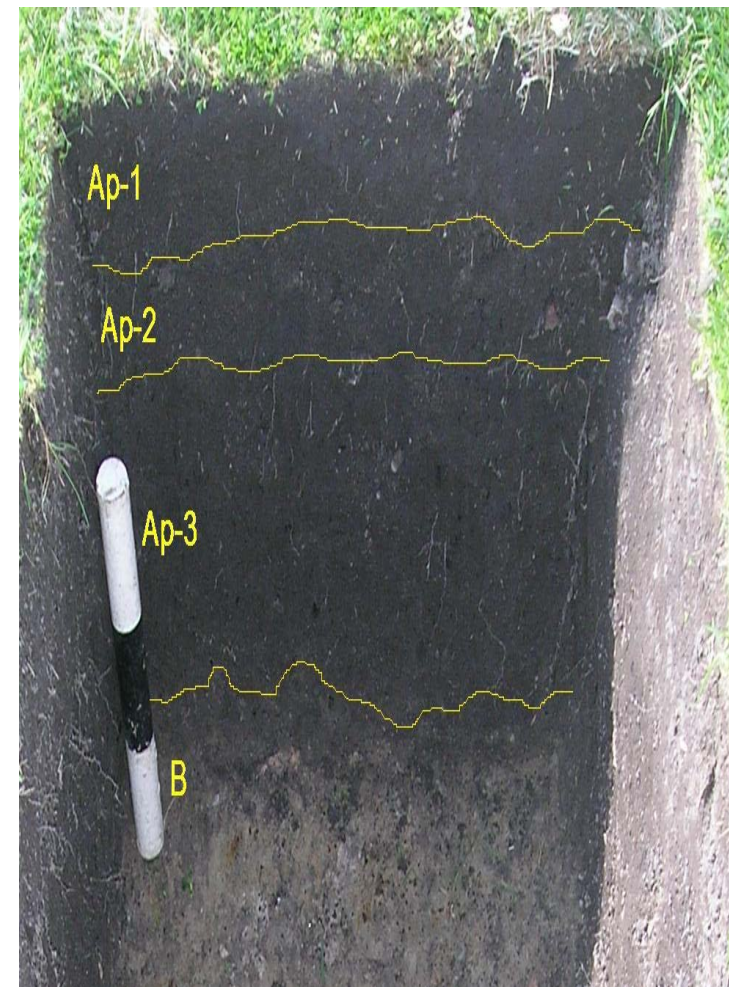
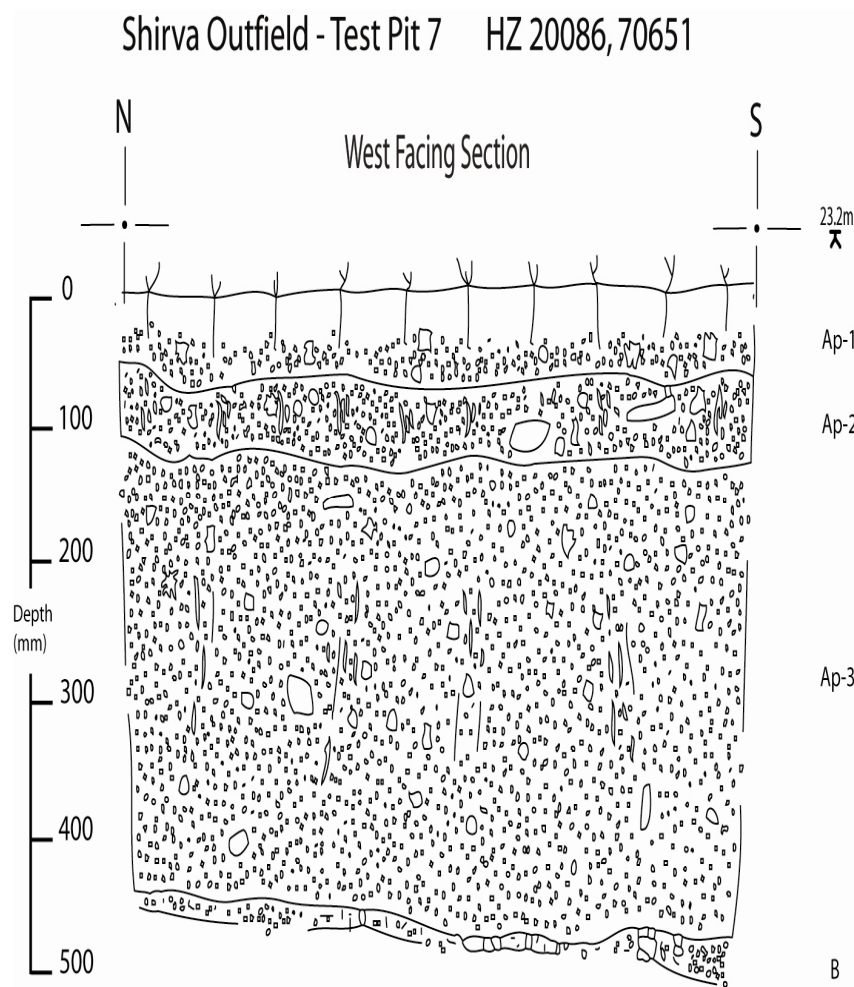


Figure 30, Section drawing and photograph of the soil sequence in Shirva in test pit 7

2.7.5 NATURAL SOILS IN UPLAND AREAS

In the upland areas of Shirva and Leogh where arable farming was not conducted, very distinctive peat soil sequences were found (H1 to H3). The peat horizons range from <100mm in the central and southern upland areas where considerable stripping has occurred in the past to over 1.5m deep at the northern end of the island stripping has not occurred.

In the upland areas around the southern agricultural end of the island the peat horizons are found alongside shallow soils of the Skelbury Association (Plate 13) these soils have a 100 – 120mm thick H1 horizon typically dark grey brown to brown coloured (10YR 4/2 to 3/2) with a silty sand texture. Beneath the H1 horizon is a thicker 180 – 220mm light yellow orange (10YR 5/6) silty sand and a 55 – 75mm dark grey (10YR 3/2) silty sand B1 and B2 horizons.

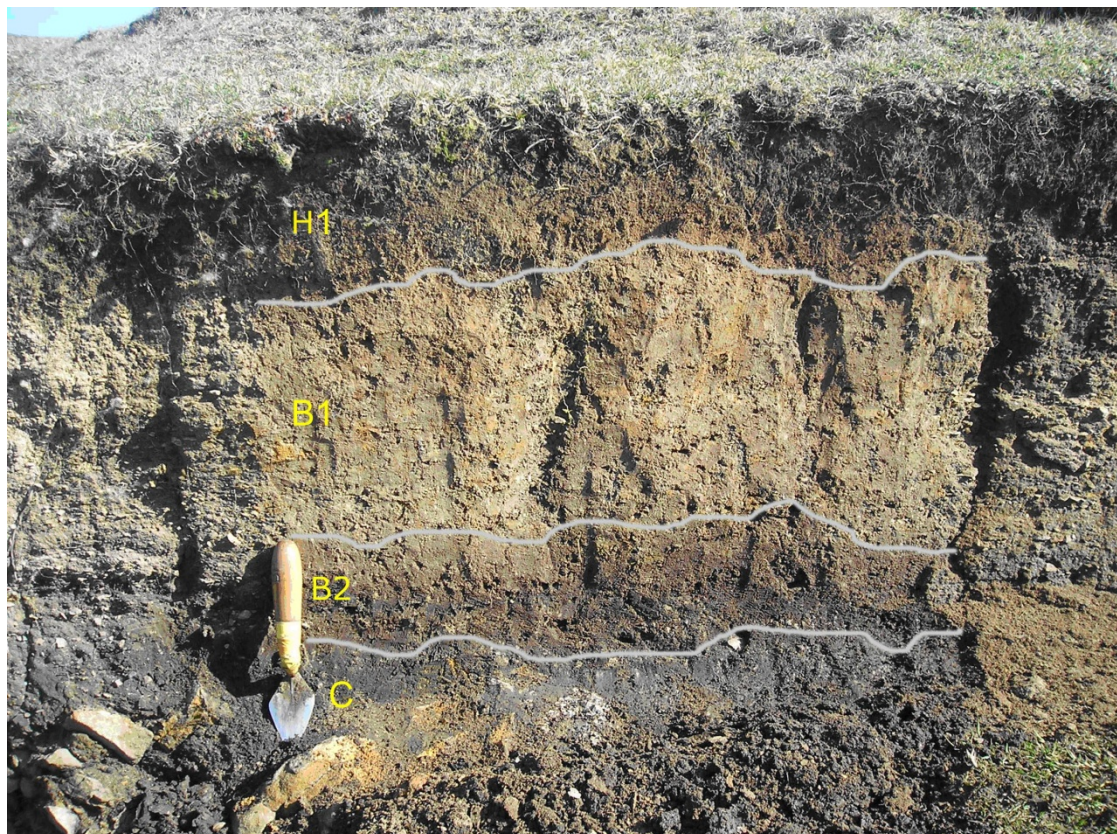


Plate 13, Natural soil sequence present on Fair Isle sampled from the west of Shirva (see Fig 11).

Context	Location			Description	Range of Depths (mm)
	Farm	Transects	Test Pits		
Ap-1	All	All	All	Silty sand loam with peaty organics and some clay in wetter areas. Dark brown (10YR 3/3) to dark greyish brown (10YR 5/2) with inclusions of quartz, charcoal, rootlets and lithics.	25 – 100
Ap-2	Shirva Leogh	1 to 8	All	Silty sand loam with peat areas. Dark greyish brown (10YR 4/2) to dark grey (10YR 4/1) and dark brown (10YR 3/3) with inclusions of sandstone and quartz, charcoal.	40 – 120
Ap-3	Shirva Leogh	1 to 8	All	Silty loam to silty sand loam with organics. Typically very dark brown (10YR 2/2), dark grey brown (10YR 3/2) with areas of very dark greyish brown to black (10YR 3/2 to 2/1) especially in kaleyard areas. Inclusions of charcoal, black amorphous particles, sandstone, peaty organics, lithics.	200 – 500
Ap-4	Shirva Leogh	1,2,3,5,7 and 8	3,5,6	Silty loam with large a large sand component and organic fragments with small clay quantities. Dark grey brown (10YR 4/2) to brown (10YR 5/3) and some areas of dark brown (10YR 2/2). Inclusions of quartz sand, sandstone, small lithic fragments. Contains remnants of buried peaty soils (AH horizon typically Black colour 10YR 2/1)	100 – 250

Table 8, Summary of all arable soils identified with auger surveys and test pits from three farms on Fair Isle

Context	Location			Description	Range of Depths (mm)
	Farm	Transects	Test Pits		
H	All	2,5, 6,7	6	Sandy loam with a large quantity of peat (+85%). Distinctive dark brown colour (10YR 2/2) with organic plant and peat fragments and inclusions of quartz sand grains and some foreign lithics.	100
H1	All	3,5, 7,8	/	Loamy peat soil with a distinctive dark yellowish brown (10YR 4/6) to dark brown (10YR 2/2) (7.5YR 3/2) colour with high organic component of roots and plant material and some inorganic mineral inclusions of quartz.	80 – 250
H2	All	3,5, 8	/	Loamy peat soil with patches of sandy and clay areas. With a very distinctive dark greyish brown (10YR 4/2) to greyish brown (10YR 5/2) and areas of very dark greyish brown to black (10YR 2/1 to 2/2). Inclusions of small sub-rounded quartz grains and peaty organics.	70 – 200
H3	All	3	/	Silty peat soil with sand and clay patches. Distinctive dark greyish brown (10YR 4/2) to greyish brown (10YR 5/2) colour. Contains inclusions of small sub-rounded quartz grains and peaty organics.	180
E	Shirva Taing	3, 11	/	Silty sand with a very light grey to grey colour (10YR 7/1 to 6/1) and in places blached white (10YR 8/1) no inclusions of any organics but some large inorganic fragments of quartz and lithics becoming coarser towards the base of the deposit.	130 – 150
B1	Shirva Leogh Taing	3,4,5 6,7,8,9 10,11,12	All	Clay silty sand soil with a distinctive dark yellowish brown (10YR 4/4) to yellowish brown (10YR 6/6) and in places light grey (10YR 6/1) colour. Seen in almost all the cores the deposit contains very little organic material save the material moved down by bioturbation. Large sandstone and lithic fragments +30mm and characteristic strong brown (7.5YR 5/8) coloured iron nodules.	+100
B2	Leogh Taing	6,7,8 10, 11,12	/	Silty sand soil with a light grey (10YR 6/1) to yellowish brown (10YR 5/6) colour. No organic inclusion contained within but does contain larger lithic fragments, quartz particles and sandstone	+250
C	Leogh	6	Natural	Silty sand abraided till deposit. Dark Iron rich colour (7.5YR 5/8) strong brown with no organics	+100

Table 9, Summary of all natural soils identified in auger surveys and test pits on Fair Isle

2.8 DISCUSSION OF THE SOIL RESULTS FROM FAIR ISLE

Distinctive organic soil horizons were found at each of the sample sites and in each of the landuse areas and these soils are summarised in tables 8 and 9. Overall the soils have similar dark colours, have distinctive silty sand textures and contain larger quantities of organic and anthropogenic inclusions compared to the natural soil horizons. The evidence from the field analyses (sections 2.6 and 2.7) suggests that these soils have been amended by manuring by humans in order to create and maintain soils for arable farming. However, the range of depths of the soils is not as extensive as the deep topsoils and anthropogenic soils found in other areas of Orkney and Shetland and contain considerably less evidence of settlement waste such as ceramics and bone material and therefore should not be classed as 'anthropogenic soils' as described in section 1.4.1. Instead it is suggested that these soils be described as 'amended arable soils'. The distribution of these amended soils is also highly variable across the kaleyard, infield and outfield areas suggesting that each farm on Fair Isle had very individual methods of manuring based upon a limited resource.

The distribution of amended soils at each of the sites is illustrated in figure 31. Surprisingly the deepest horizons are present at Shirva outfield with an average depth of 580mm and this may represent an extensive manuring programme across the entire outfield as a result of settlement and agricultural expansion or more likely because of the movement of soils down slope. The older farms at Busta, Shirva and Leogh have considerably deeper stratigraphies of Ap horizons (490mm – 500mm) compared to less than 100mm at Taing. The same pattern can be seen in the infield and outfields at Shirva and Leogh where a distinctive regularity in soil depth is present and suggests that a very similar manuring strategy was being employed by the oldest farmsteads across the whole site rather than concentrating on a particular landuse area.

At Taing there is considerably less amended soil across the farm reflecting the farms late formation and development during the period when the population reached 360 in 1860. There is however a clear decrease in depth with distance from the settlement centre illustrating a focus of manuring

in the kaleyard area, emphasising the importance of developing a good soil for vegetables. The lack of amended soil in the infield and outfield areas is probably a reflection of the short period of time in which the farm was occupied and also because of a lack of organic material to use as manure.

Of the organic soils identified several localities have a thin Ap-4 horizon which is the oldest enhanced soil in the arable area of the island. Its apparent random occurrence in the infield and outfield areas of Shirva and Leogh and organic nature suggests it was a precursory amended soil developed in small areas available for crop growth.

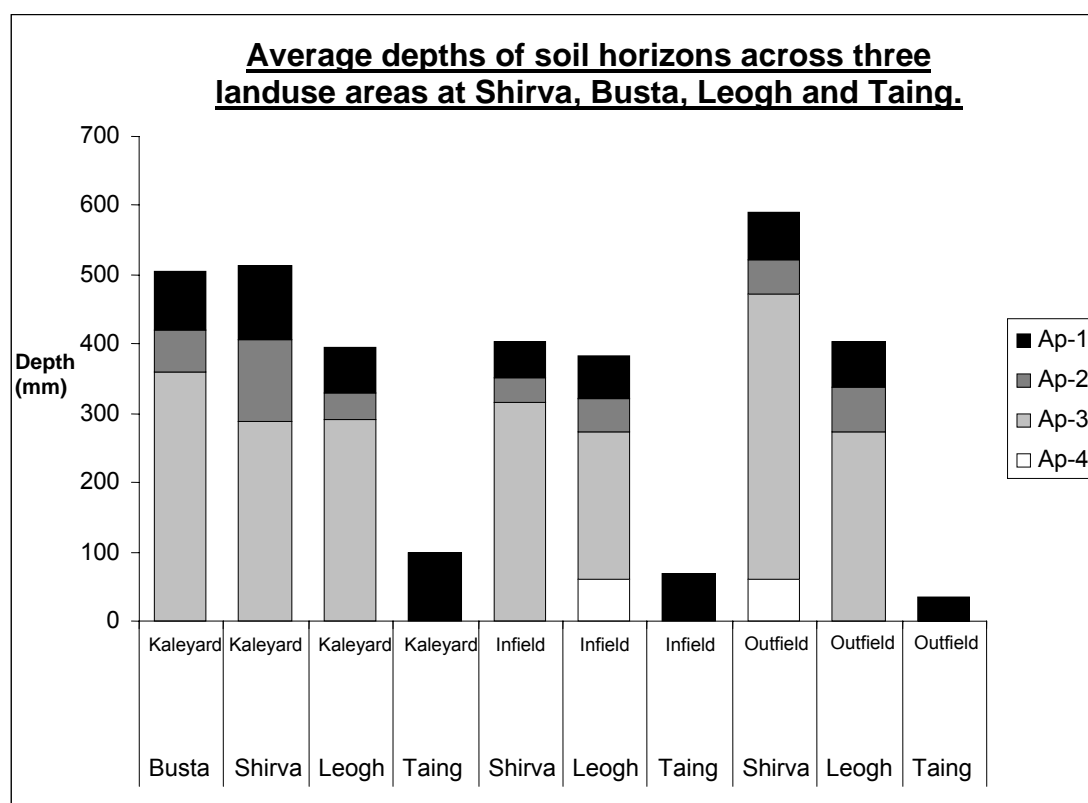


Figure 31, Average depths of arable soil horizons across three landuse areas on Fair Isle

The extent of the Ap-3 horizon across every arable area illustrates a huge development in manuring strategy on the island. Inclusions seen in core and test pit samples show distinctive evidence of the use of peat from upland areas for fuel, bedding for animals and building material before deposition on the land. The Ap-2 and Ap-1 are texturally very similar to Ap-3 suggesting an unchanged manuring process however they are considerably shallower and

may indicate a slower rate of addition since the decline in arable agriculture on the island since the early 20th century.

In several areas of the island distinctive rig features associated with arable farming have been mapped but are within definite upland areas and again illustrate how population and land pressures led the islanders to develop farmland on the poorer soils. It appears that farmers were utilising upland soils for cultivation with either minimal or no anthropogenic enhancement.

2.9 **FAIR ISLE IN CONTEXT**

The amended soils identified in the agricultural area of Fair Isle represent the development of an arable soil since humans moved from occupying the upland to the lowland area and there is a great deal of evidence to suggest that the manuring tradition on Fair Isle was developed from the early days of occupation (Table 10).

	Chrystall, (1994)	Pears (this volume)
Area of study	Burn of Furse (Upland) mid/late Bronze Age settlement	Arable farmland (Lowland) Early Viking to Modern Period
Depth of Anthropogenic soils	Test Pit 1 – 290mm Test Pit 2 – 400mm Test Pit 3 – 670mm	Kaleyard – 400mm to 500mm Infields – 400mm to 420mm Outfields – 420mm to 580mm
Colour	Black	Dark brown, grey, black
Texture	Sandy silt loam	Silty loam to silty sand loam
Inclusions	Fine roots and many sub-angular stones	Charcoal, black amorphous particles, sandstone, peaty organics, lithics.

Table 10, Comparison of the soils identified by work conducted in the upland and lowland areas of Fair Isle

The soils identified in the auger and test pit survey in the arable soils are in many respects similar to the soils identified by Chrystall, (1994). The range of depths identified are very similar between 290mm to 400mm with an

exception of test pit 3 which was interpreted as a midden deposit due to the frequency of burnt bone fragments and carbonised plant material. Both studies highlight the use of peat as the main manuring component creating the dark coloured silty loam texture but the inclusions of calcium carbonate particles in the upland anthropogenic soils suggest that seaweed was also used, however no evidence was found in this analysis for the addition of seaweed or calcareous sand. In the lowland arable soils there were more visible carbonised particles, especially charcoal and peat, in the soils suggesting a greater input from domestic sources than in the upland area where no macro carbonised particles were identified.

The amended soils found on Fair Isle differ considerably from the anthropogenic soils from other Northern Isles (Table 11). On Orkney anthropogenic soils were identified on three islands with the deepest soils well over 1m at Westray and were typically dark brown calcareous sandy loam soils with inclusions of shell material and small charcoal fragments. At Tofts Ness on Sanday the anthropogenic soils occur alongside a number of distinctive farm mound features composed of domestic and organic waste. The soils are typically dark to very dark grey colour with blocky structure and small charcoal particles. At Marwick on West Mainland the soils are typically dark greyish brown to dark brown coloured silty loams with fine charcoal particles.

Authors (Date)	Orkney	
	Site	Depth
Davidson and Simpson, (1984)	West Howe, Marwick	200 – 800mm
	Netherskail, Marwick (West Mainland)	200 – 600mm
Simpson et al., (1998a)	Tofts Ness (Sanday)	275 – 900mm
Simpson et al., (2005)	Quoygrew (Westray)	630 – 1125mm

Table 11, Anthropogenic soils on Orkney

On the Shetland Islands (Table 12) the deepest anthropogenic soils have been identified recently on Unst, however these are isolated horizons associated with anthropogenic dumps and more widespread deeper soils

have been identified at Scatness and directly associated with the multi-period sites at Old Scatness and Jarlshof. These soils are typically dark coloured and highly organic and located in an area with a large resource of organic material. The site of Papa Stour has also been analysed for anthropogenic soils and analysis at a number of the small farmsteads has revealed a range of soils from 200mm to 750mm, especially in the kaleyards.

On St Kilda in the North Atlantic there are over 1.5m of anthropogenic soils in association with addition of peat and turf creating very dark grey, brown/black soils with black carbonised particle inclusions from the input of domestic waste (Meharg et al., 2006). Texturally the anthropogenic soils on Fair Isle are very similar to the Orcadian and Shetland soils and the frequent presence of charcoal and carbonised particles is strong indication of anthropogenic input. In terms of distribution the Fair Isle soils fit very closely with the depth of soils found at Papa Stour which reflects the utilisation of peat, turf and seaweed as manure materials and probably a similar management strategy because of the size of the island and limited resource.

Authors (Date)	Shetland	
	Site	Depth
Bryant and Davidson, (1996)	Olligarth (Papa Stour)	Planticrue: 200mm Kaleyard: 650mm Field: 250mm
Davidson and Carter, (1997)	East Biggins, Gardie, Hamnavoe, North Banks (Papa Stour)	750mm 740mm 300mm 480 – 600mm
Simpson et al., (1998b)	Old Scatness (Scatness)	+600 – 800mm
MacKenzie, (2007)	Underhoull (Unst)	150 – 300mm with areas in excess of 1150mm

Table 12, Anthropogenic soils on Shetland

3 STUDY SITE 2: OLT Hof, THE NETHERLANDS

3.1 INTRODUCTION

The farmstead of Olthof is located in the central-eastern part of the Netherlands in the province of Overijssel (Fig 32). The site is situated 3 miles (5km) south of the city of Deventer and 0.6 miles (1km) east of the town of Epse. The river IJssel runs north-north west, south-south east 0.9 miles (1.5km) to the east and the border between the provinces of Overijssel and Gelderland; the course of the river has varied and now lies to the north of the farmstead.

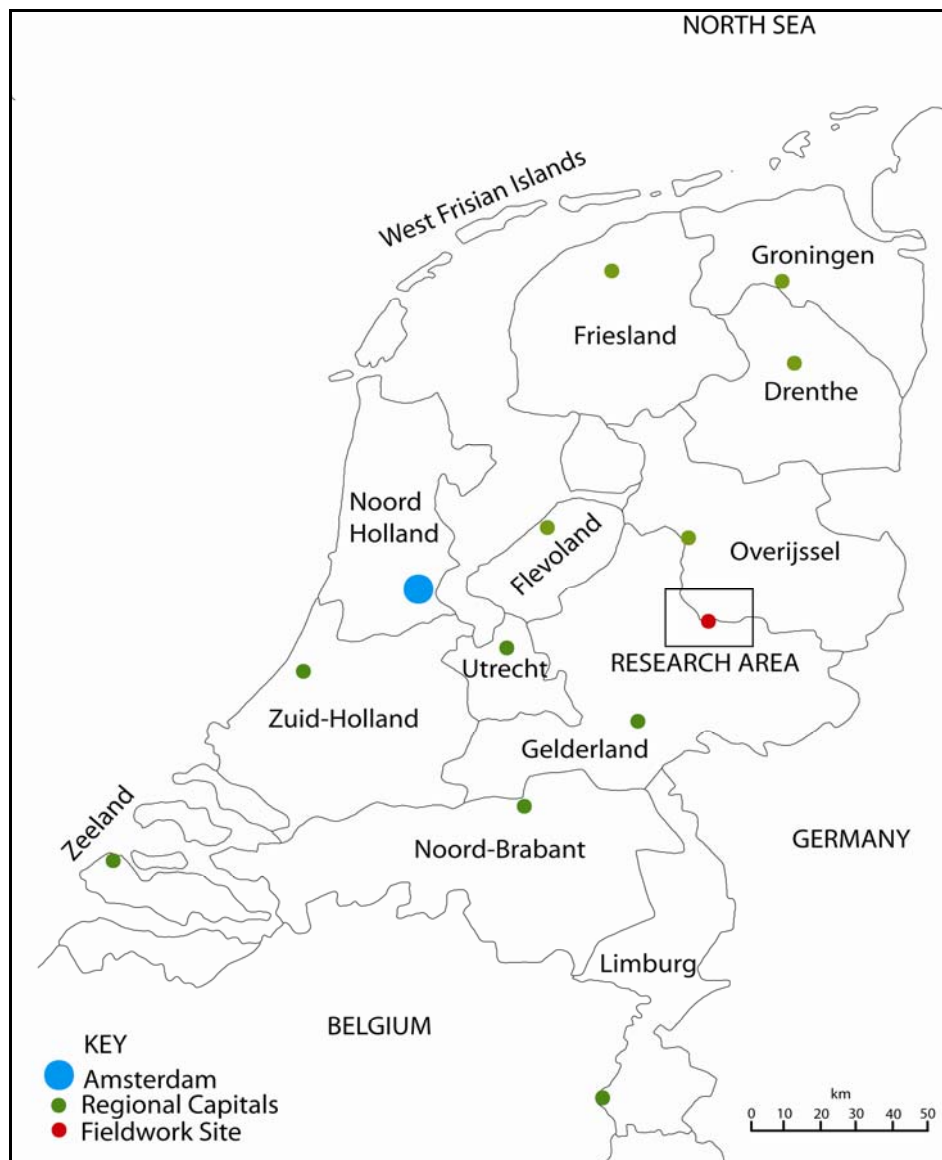


Figure 32, Location map of the Netherlands and the research site at Olthof on the Gelderland-Overijssel border

3.2 GEOLOGY AND SOILS OF THE NETHERLANDS

Compared to other areas of Europe the Netherlands has a relatively short geological history. The oldest rocks originate from the Palaeozoic era and are situated in the very north and south of the country and consist of distinctive Carboniferous limestone (359 – 299Ma) and Permian sandstones (299 – 251Ma).

During the Mesozoic Triassic sands and evaporites were deposited (250 – 200Ma) and rising sea levels in the Anglo-Paris basin, during the Cretaceous, (145 – 65Ma) led to flooding and the deposition of thick chalk layers, common in the north of the country. Most of the deposits present in the Netherlands date from the Cenozoic to the Holocene. Between 40 – 25Ma Oligocene clays were deposited across the east of the country and between 24 – 5Ma distinctive highly organic coal seams around Maastricht in the south east. In the central and southern zones, around Breda, cyclical clay and sand layers are commonplace and these were deposited in the Pliocene (5 – 1.5Ma) from rising and falling sea levels associated with ice movement.

During the late Cenozoic the Netherlands was covered by two large ice sheets. The Elsterian and Saalian Ice Ages had major effects upon the Dutch landscape with the deposition of thick layers of glacial till in the form of large lateral moraines and till plains. This was followed by the deposition of alluvium, peats and loams with the slow withdrawal of the ice. A later ice age, the Weichselian, never reached the Netherlands but very distinctive aeolian sands were deposited which are present in great depths across the central-southern part of the country.

In many respects the Holocene represents the greatest change to the geology of the Netherlands with the ever rising sea level after the last ice age eroding the coastline at a rate of 65cm per century and humans creating extensive arable deposits from organically rich soils and through the process of reclamation. In the last 3000 years large areas of sand were deposited together with peat development in natural lowland areas, especially in the east of the country around Drenthe and Groningen.

Around the site of Epse the geology is characterised by Pleistocene deposits including large areas of aeolian sand in the form of dunes and

plateaus with large areas of coarser river gravel in the form of long thin, elongate strips separating the upland wind-blown sands from lower land which contains the fertile river alluvium deposits which mark the old path of the river Dortherbeek. The small misfit streams to the north of Olthof represent the valleys created by the glacial meltwater at the end of the last ice age. At this time the Dortherbeek and neighbouring Schipbeek drained into the Koerhuisbeek before emptying into the IJssel and these were responsible for the coarse river sands and alluvial deposits (Fig 33).

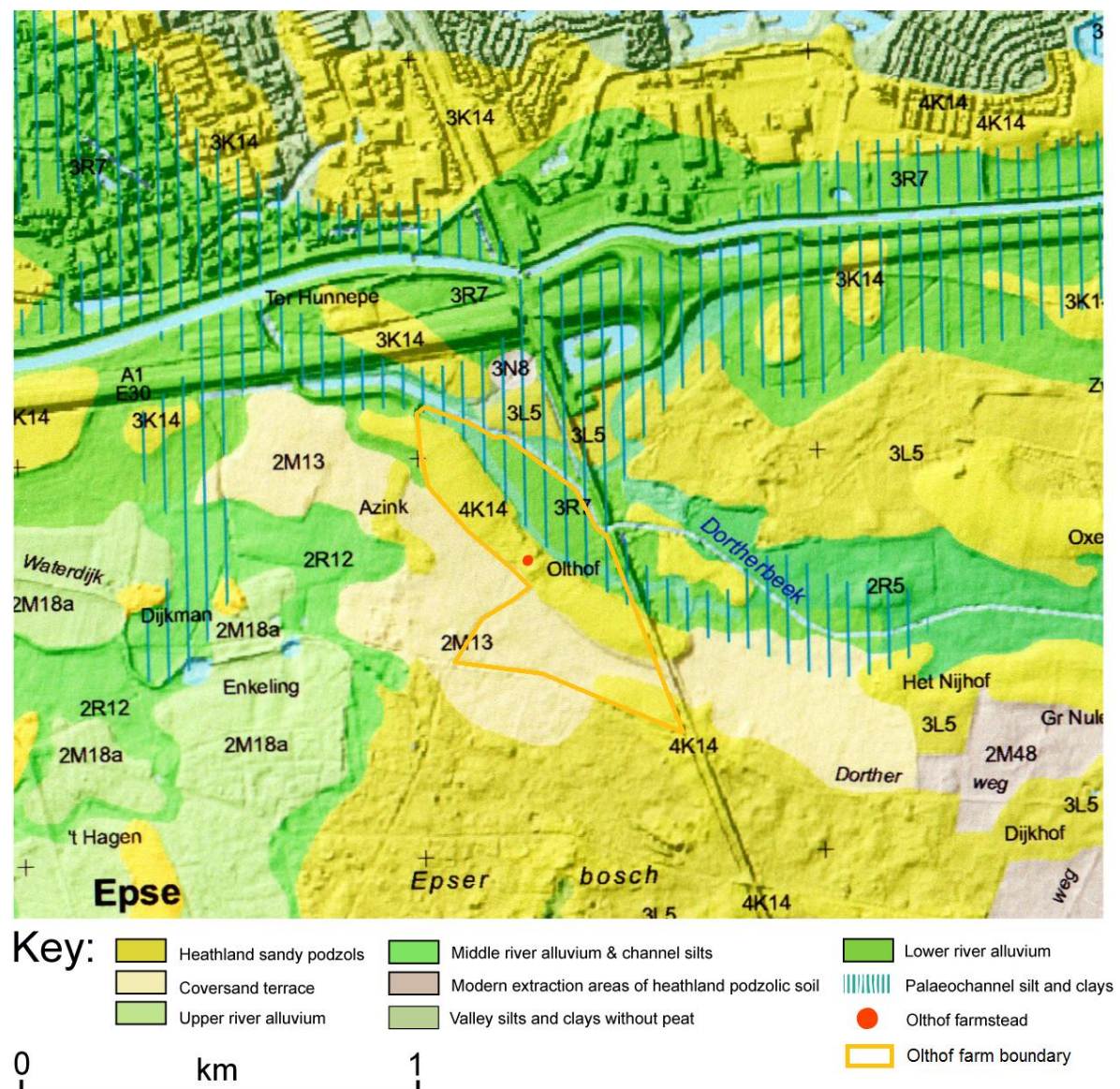


Figure 33, Detailed digital map of the Pleistocene geology around Olthof farm, Epse (Alterra Wageningen, 2006)

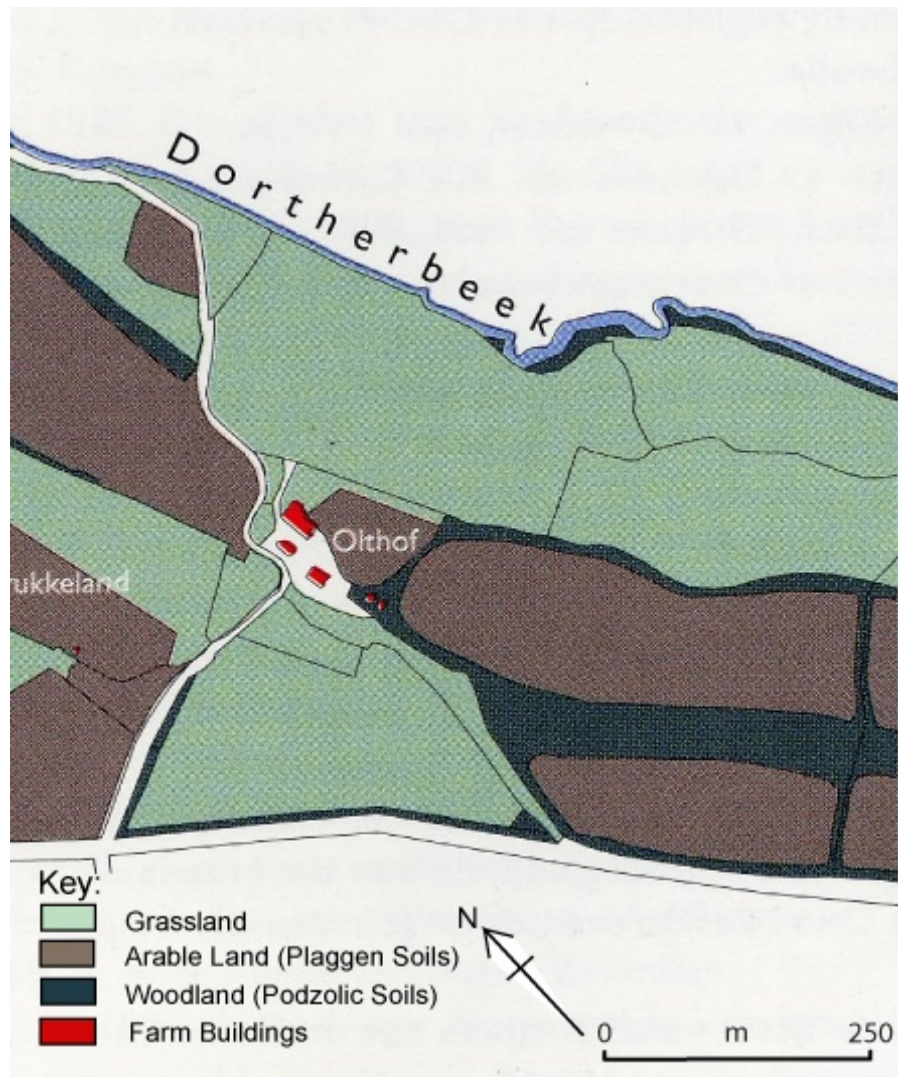


Figure 34, Soil map around Olthof farmstead between the River Dortherbeek and heathland based upon the A.D. 1832 map (Uitsnede Kadastrale Atlas 1832 in Appels, 2003)

Today the Dortherbeek is considerably smaller but historically flooding has still occurred depositing alluvial soils. To the south of the farmstead the land is higher and is covered by thick layers of cover sand and thin podzolic heathland soils. The most distinctive soils typical of this region of the Netherlands are the expansive anthropogenic soils known as “Plaggen” soils, named after the process of formation. These manuring horizons are located on the hinterland between the alluvial and heathland soils and mirror the location of the farmsteads (Fig 34).

3.3 THE HISTORY AND ARCHAEOLOGY OF THE NETHERLANDS

3.3.1 AGRICULTURAL AND LANDSCAPE HISTORY IN EUROPE

Throughout north west Europe the development and organisation of the landscape into farmland and natural areas began with a “slash and burn” culture in the Neolithic period. The increase in population and development of larger farmsteads put huge pressures on the landscape, and as a result communities had to develop more complex methods and laws to keep farming sustainable. This situation was especially common in marginal areas such as the south east of the Netherlands.

Changes in the intensive use of arable agriculture over time led to the development of the classic systems of field rotation, but these occurred at various times across north west Europe depending upon a number of factors. It has been suggested that the agricultural progression in Sweden was almost similar for a thousand years from the end of the Iron Age to the 9th and 10th centuries (Myrdal, 1997) with a transformation into a two field rotation system in the middle to late 10th centuries and this continued until the 13th century when a three field system was developed. Myrdal suggests that a similar system occurred in Denmark, but the three field system is more evident later in the 15th century (Frandsen, 1983). The dating of the field systems in this part of Scandinavia was conducted by an analysis of palaeo-field boundaries and the dating of carbonised particles in buried soils beneath them (Lindquist, 1976).

In Denmark there is both a close agricultural link between mainland Europe and a socio-cultural link with the Scandinavian Peninsula. Arable farming increases with the migration of people from Germany and the development of semi-permanent farms in the 9th to 11th centuries (Poulsen, 1997). Around this time Denmark was split into two distinctive areas between the open field system, classically block shaped (Hoff, 1990) present in the west of Denmark around Jutland and the smaller fields and small holdings in the east of the country. In western Jutland it has been suggested that the sandy soils were manured as early as the 9th century in the rural environment (Poulsen, 1997) and also in the hinterland of the expanding urban areas of Ribe (Madsen, 1980; van Mourik 1990). The expansion of productivity after

the 13th century was in part due to the increase of manure into the small fields in both rural and urban areas (Andrén 1986) but it has also been associated with the increase of cattle numbers and the development of the mouldboard plough (Poulsen, 1997). As with the agricultural landscape of Ireland (chapter 4) the spade was also a key tool in Danish farming, and was most likely the preferred tool for poorer landowners with small fields and no oxen. Poulsen (1997) suggests that later in the 12th and 13th centuries the two technologies were used simultaneously especially in the lowlands of the west to produce and clear dykes.

With the reduction of productivity in the mid 14th century through famines and plagues large farms changed from an arable to pastoral system, trading with mainland Europe for arable products. Smaller farms, however, continued a self-sufficient system until the 16th century and the onset of enclosures (Poulsen, 1997).

The region of Europe known as Flanders (modern Belgium) also has a very detailed, closely linked agrarian history and with Germany and the Netherlands has large areas of heavily manured arable soils. A system of small localised farms was present in the early medieval period with small arable areas intensively manured (Thoen, 1988) as in Scandinavia. But a period of intense urbanisation in the 11th century changed the farming system to a more intensive two field system. Thoen (1997) describes how Flanders could be split into three agricultural areas in the medieval period based upon *“soil and seigneurial management”*

- a) *Coast* – with typically grazed cattle and sheep on upland moorland, saline clay soils and heathland. From 12th century onwards change to peat digging for fuel.
- b) *Southern Flanders* – loamy soils for cereal growth
- c) *Central Flanders* – sandy soils with extensive agriculture from the 12th century onwards

(Adapted from Thoen, 1997)

The 12th century was a period of major change in the area, especially in the southern areas where increased manuring also occurred with farmyard

manure and dung. Debate has continued for a number of years as to whether a three field agricultural system was ever in place in central Flanders (Derville, 1988; Morimoto, 1994) and it has been suggested that the area had a system of large enclosed fields surrounded by smaller fields with non-permanent boundaries and represented both the landscape of the large rich farmsteads and smallholder's land (Thoen 1993 and 1997). The reclamation of marginal land does continue, however, and by the late 14th century there are very large areas of semi and total amendment for arable agriculture.

Even though a localised methodology of arable farming was being utilised, it did not stop the manuring process which continued in the manner of a three field system with infield areas receiving more stable manure (Thoen, 1993). Thoen also suggests that in the later Middle Ages the very large farmsteads start practising a four field system (Thoen, 1995), perhaps because of the limitations on smaller farms in the past and the continued prosperity of the larger, wealthier ones. It is not until the major agricultural increase of the 18th century that the majority of Flemish arable landscape utilises a typical three field system (Thoen, 1997).

3.3.2 AGRICULTURAL AND LANDSCAPE HISTORY IN THE NETHERLANDS

The earliest extensive farming in the Netherlands was the development of Bronze Age field systems preserved today only in the small heathland areas not seriously damaged by later agricultural development (Baher et al., 1968). The majority, however, date to the Iron Age (Bradley, 1978) and show a high level of agricultural understanding. Small intensive Scandinavian field systems dating to the pre-Roman period have been uncovered in southern Denmark which according to Widgren (1988) represent semi-permanent cultivation but anthropogenic soils have also been discovered in the area which suggests a more permanent settled farm landscape (Widgren, 1988; Spek, 1992). It has also been suggested that land reclamation began in 8th to 9th century in southern Sweden (Berglund, 1990), possibly in response to a rising population and the need for agricultural land. However, it has been suggested that farms were fairly fluid until the 11th century when they became

more permanent in the landscape a process termed “*wandering settlements*” (Hoppenbrouwers, 1997).

By the early medieval period the population of north west Europe had increased steadily, especially in Germany and France, but more marginal areas like the Netherlands had a low population density with an agrarian system to match a typical simple infield-outfield system which was fairly intensively cultivated and manured (van Zanden, 1999). The rate of agricultural development, however, depended upon the rural socio-economy and urbanisation and therefore there were distinctive differences between rural areas within the Netherlands (Hoppenbrouwers, 1997).

In the provinces of Gelderland and Overijssel there were numerous small farms and field systems located upon the natural sandy soils and in order for arable farming to be conducted, heavy manuring was required. The raw materials for this process were collected from upland heathland and lowland floodplain areas due to the farmers’ right to use ‘*wasteland*’. But due to over exploitation in the mid 13th century and the lack of common ground for the grazing of cattle and sheep, the process of ‘*marking waste*’ was conducted which created common laws or ‘*markerechten*’ dating back to the early 14th century (Heringa, 1983). This process reduced the cutting down of woodland, destruction of heathland, digging of peat and turf and grazing of animals. This led to a much more organised farming process and a more sustainable landscape. In contrast in the west and north (Drenthe province), the farms were far larger and common land was owned by larger landowners such as the King, Bishop of Utrecht and the Count of Holland, and so the availability of wasteland and manure components was seriously restricted (van Zanden, 1999).

The development of reclamation history has been studied in detail in Drenthe where it has been suggested that permanent settlement occurred later than other regions of the Netherlands (Bardet et al., 1983; Roymans and Kortland, 1993). The settlement of Valthe was analysed and here five stages of reclamation have been uncovered from the small, single field system of the early middle ages situated close to the original foci of the settlement, through to the expansion in the 13th century where the ever enlarging rural population needed to increase yield production. Later during the 15th to 17th centuries the

settlement has a change of landlord and the agricultural landscape enlarges again. But in the post medieval period and proto-modern era the settlement is unable to expand any further due to landscape and urbanisation pressures, therefore the existing land is utilised to its full potential by increased manuring (van Smeerdijk et al., 1994). The infield/outfield system of agriculture was maintained within Dutch farming until well into the 17th century (Bieleman, 1992) with the extraction of organic material from upland/marginal areas. In Anloo around 1700, landowners were able to cut two carts of sods from common land but in 1810 that had increased to 20 cart loads (Bieleman, 1985), a year after the attempted abolition of the 'marks' law in the same province (van Zanden, 1999). The strains on collecting organic manuring components were also being stretched by a cooling of the post medieval climate (1650 – 1850) which affected the growth of woodland and heathland and increased coversand deposition. The 'mark' law, where still enforced, therefore ordered the planting of trees, sowing sandoats and maintenance of heath (van Zanden, 1999).

As well as 'mark' law another process which hindered the collection of organic manuring components was the process of 'specialization' to either pastoral or arable farming. This agricultural split affected smallholders and tennant farms most heavily as a shift from an all round producing farm to either pastoral or arable one altered the ability to maintain a good quality sustainable agricultural landscape. Only the very largest and richest farms would have been able to 'buy' themselves out of this kind of the situation and poorer and medium sized farms would have had to have gone through partial break ups or total desertion.

3.3.3 THE DOCUMENTARY HISTORY OF OLTHOF FARMSTEAD

The earliest record of a settlement at Olthof dates from A.D. 1280 and outlines an ownership issue over a watermill between the monastic site of Ter Hunnepe and an "*Antiquam Curiam*" or Ancient Court which is the literal translation of Olthof and is located in the same place as the farm is today. The link between the two sites is also mentioned in a valuation document dating to A.D. 1494 which shows that the monastic site owns the farmstead which is

named as “Aldenhoff”. Control of the farm and its land continued into the early 19th century even after the dissolution of the monastery after the 80 years war (A.D. 1568 – 1648) due to the stability and wealth of the estate. It was finally given to the Kingdom of the Netherlands after the French occupation in A.D. 1811 and shortly afterwards Olthof was bought as an individual estate in its own right. At the time of purchase in A.D.1813 by Mr Derek Olthof the farmstead had 18 hectares of land with a house, two barns and two haystacks (Appels, 2003).

3.3.4 OTHER FARMSTEADS – AZINK, KLEIN BUSSINK, KRUKKELAND

As well as Olthof, research into three other settlements was conducted by Archaeologie Deventer. Directly west of Olthof along the sandy ridge is the farm of Azink, which is located in a small cluster with Krukkeland and Spijker Azink. Originally the site was called Old Azink which probably originates at the same time as Olthof and indeed also has an extant timber framed aisled hall, however historical documentation suggests the farmstead to have been in existence since the late 15th century. In a document of A.D.1509 the farm is under the ownership of the Duke of Gelre (Appels, 2003) not the monastery of Ter Hunnepe as all the other farms were. The size of the farm is not detailed in the early 19th century but it may be assumed to have been very large as a document of 1881 shows that the farm was undergoing a process of division as the farm was sold with only 11 hectares (27.18 acres) and 16 hectares (39.53 acres) split between other farmers. To the east of Azink is Krukkeland; this farm has a large ‘L’ shaped timber framed building from which the farm takes its name and measures 14 x 12m. Historically the farm dates from around A.D.1628 and was occupied by builders/workmen from Ter Hunnepe monastery. It has been described in early documents as an “undervalued” farm suggesting a relatively small size, however, by the end of the French occupation the prosperity appears to have increased as the farm contains a house, shed, haystack and owns 11 hectares (27.18 acres) of forest and meadow (Appels, 2003). Spijker Azink is considerably smaller than the other two sites and has a late 19th century building on the site. The name “Spijker” indicates nails and therefore the farm could be associated with horse rearing

typical of other farms in the area, especially Klein Bussink. Klein Bussink itself is located further to the west from Olthof on the coversand ridge and is the fourth farmstead with a good historical record. The farm is dominated by a classic timber framed aisled hall building (14m by 14m) which has been dated to the 16th to 17th century by architectural details. However, the oldest documentary evidence is from A.D.1494 where Bussink is mentioned as part of the Ter Hunnepe estate since A.D.1266. The pretext “Klein” (Small or Little) mentioned in A.D.1572 suggests a split and the possibility of a Large Bussink. A “Groot” Bussink is discussed but no further historical or archaeological evidence has been found for the site, possibly because they may have occurred on the same site (Appels, 2003). As with the other farms in the area, Klein Bussink was sold after the French Occupation of the Netherlands and an inventory of A.D.1813 had the farm consisting of a house, a shed, a sheep store, a hay stack, a bakehouse with forest, meadows and agricultural land totalling 20 hectares (49.4 acres) (Appels, 2003). There are a number of other settlements in the area around Olthof mainly to the west of Klein Bussink which all date from the mid 19th century onwards and have developed as individual houses rather than farm complexes. Nieuwenhuis or New House was built in the 1930s as a private house as was the building at Malberg built upon an island of anthropogenic soil. To the east of Olthof is the farmstead of Nijhof which may have been part of the same farm in the past but ever since the building of the railway has been split. No detailed historical work has been conducted on Nijhof but the sites are very similarly sized with equal amounts of arable, woodland and pastoral land.

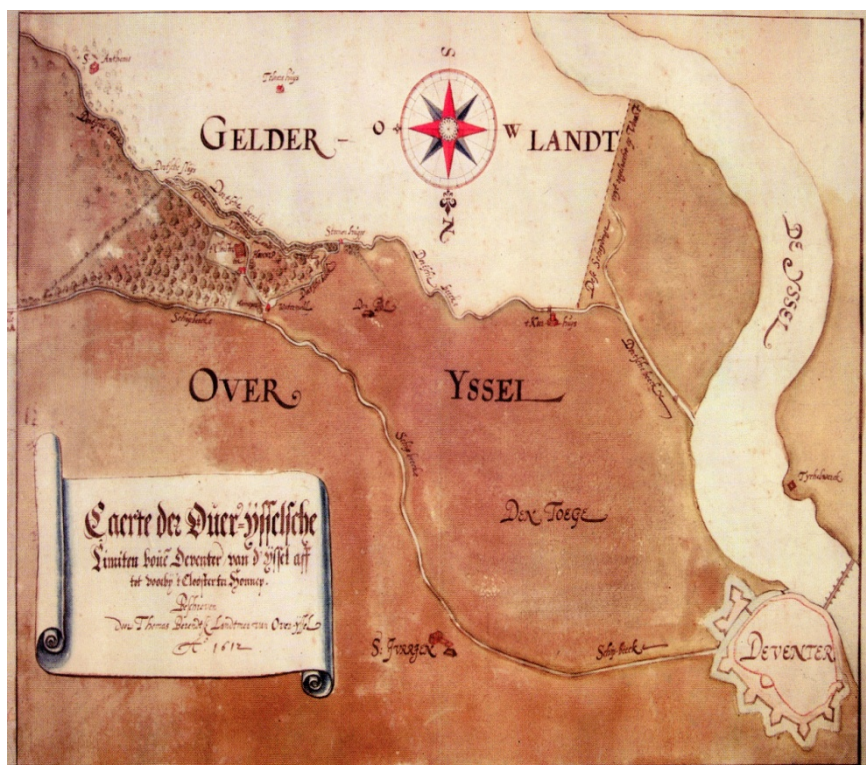
3.3.5 MAP EVIDENCE FOR OLTHOF FARMSTEAD

The earliest map of the area is the A.D.1612 map which shows the landscape around the Gelderland and Overijssel border. Confusingly it is drawn from the south and places the two provinces the wrong way around. The focus of the map is upon the landscape around the land belonging to a monastic building (Plate 35a). The building has a distinctive square cloister shape and has a sub-rectilinear enclosure around it with a gatehouse. The landscape within the church land is composed of a heavily wooded area with small

openings possibly for arable fields. There are no other buildings in the area except a watermill and the chapel of St Anthonis is shown along with several villages (Fig 35b).

The map evidence of the site in A.D.1668 (Plate 36) shows a more detailed landscape of the monastic lands in a correctly orientated map, and Olthof appears for the first time across the border in Gelderland. Both the A.D.1612 and A.D.1688 maps show very specific areas of the Dutch landscape associated with the monastic lands with much of the surrounding landscape missed out. This illustrates the complexity and social standing of boundaries in the Dutch landscape but Olthof obviously has important links with the religious complex as it is shown on the map in an area of no other detail. The landscape in the late 17th century is a particularly rural one with very few urban areas except the monastic complex in the north west of the map which appears as a large enclosed building in ruins. There are several large buildings also within the complex which are not in the A.D.1612 map and these may represent the reoccupation of the site after the abandonment of the monastery. Today the new A1 motorway runs almost directly over the top of the complex and although it is not recorded on any other maps it does show that the landscape is a mixture of irregularly sized fields with both arable and pastoral agriculture with large areas of woodland together with an excellent system of mills and drainage dykes, especially towards the east of the map between the Schipbeek and the Oosterbeek.

A more generalised map of the area was produced in the early years of the 18th century (Plate 37). The map is orientated with west at the top of the page but clearly shows the city of Deventer with the characteristic gridded internal urban structure within an internal boundary wall and a larger external defensive wall with distinctive triangular towers. Overall the scale of the map is too large to show Olthof, however the nearby settlements of Epse and Tolhuys are shown as small symbols alongside the main north-south road between Deventer and Zutphen. The dotted line following the Dorterbeek is the boundary between Gelderland and Overijssel and it runs parallel with its floodplain, clearly marked as the grey strip. This area would have been utilised by settlements alongside the Dorterbeek as grazing and meadowland for cattle and sheep.



(a)



(b)

Figure 35a+b, Map of A.D. 1612 showing the Gelderland and Overijssel border (a) and detailed map of the monastic complex and lands of Ter Hunnepe to the north of Olthof (b) (Berendtsz, 1612; in Appels, 2003)

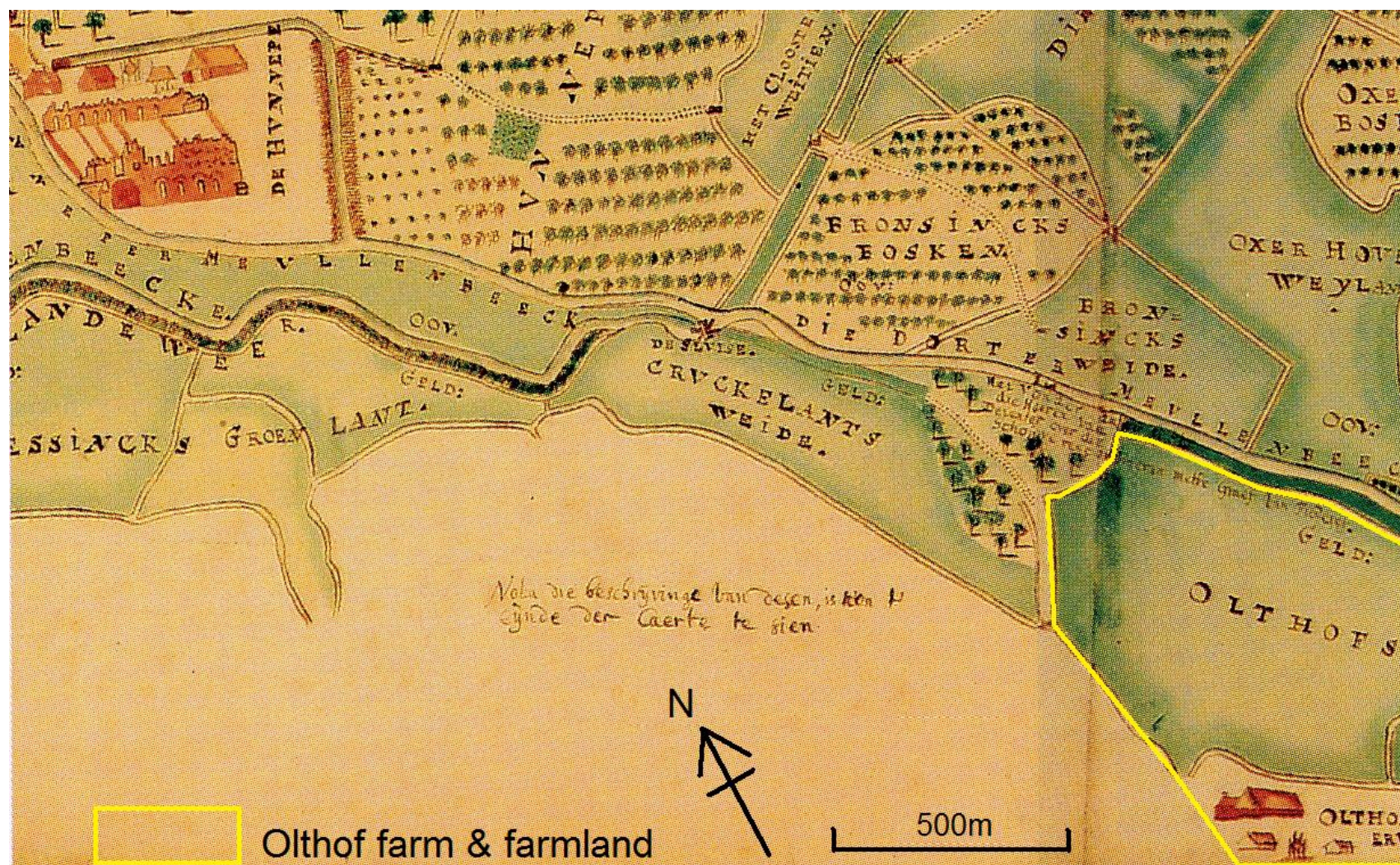


Figure 36, Map showing the landscape around Olthof farm circa A.D. 1668 (van Wijk, 1668; in Appels, 2003)

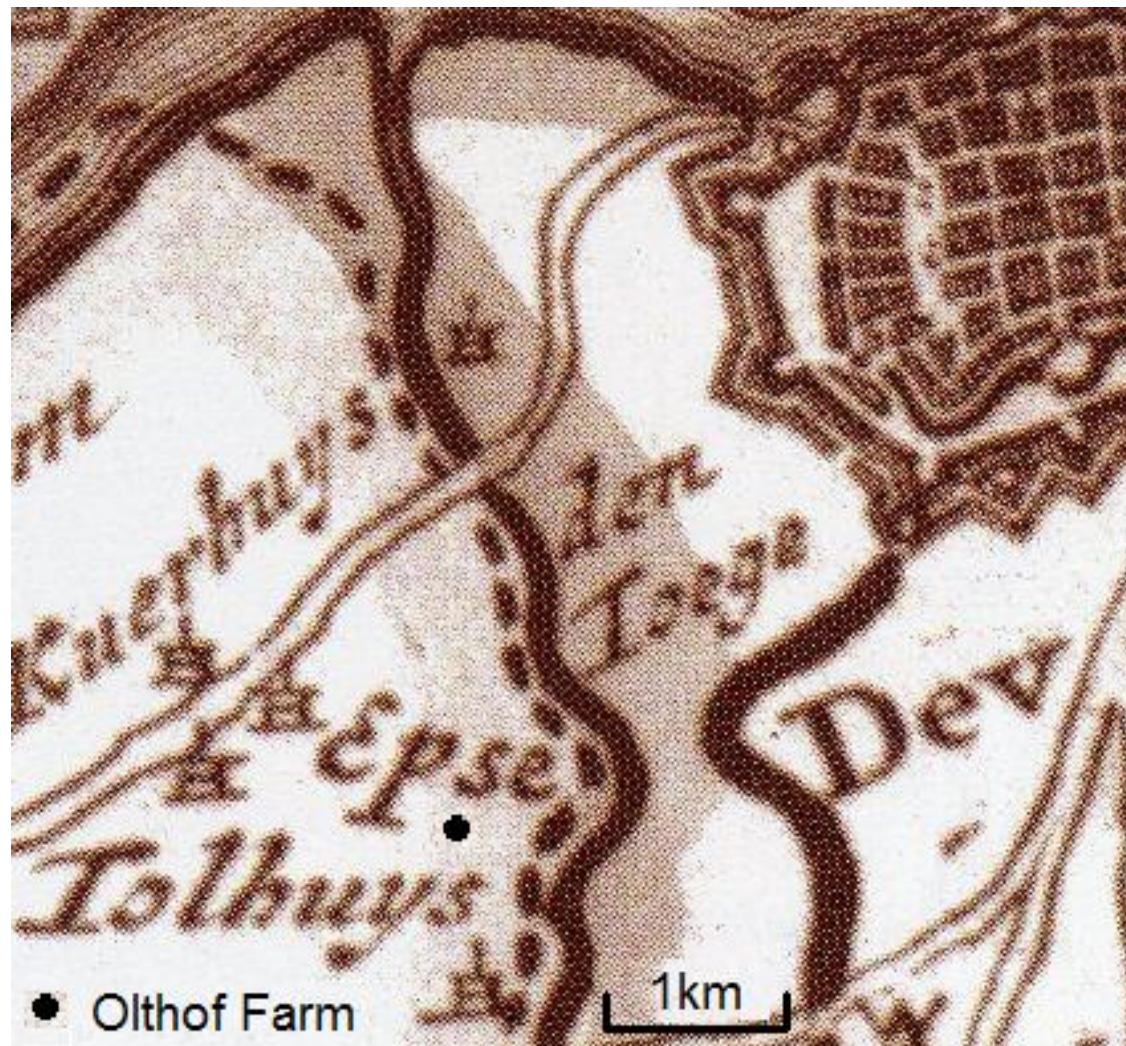


Figure 37, Map showing the landscape around Epse and Deventer circa A.D. 1710 (Appels, 2003)

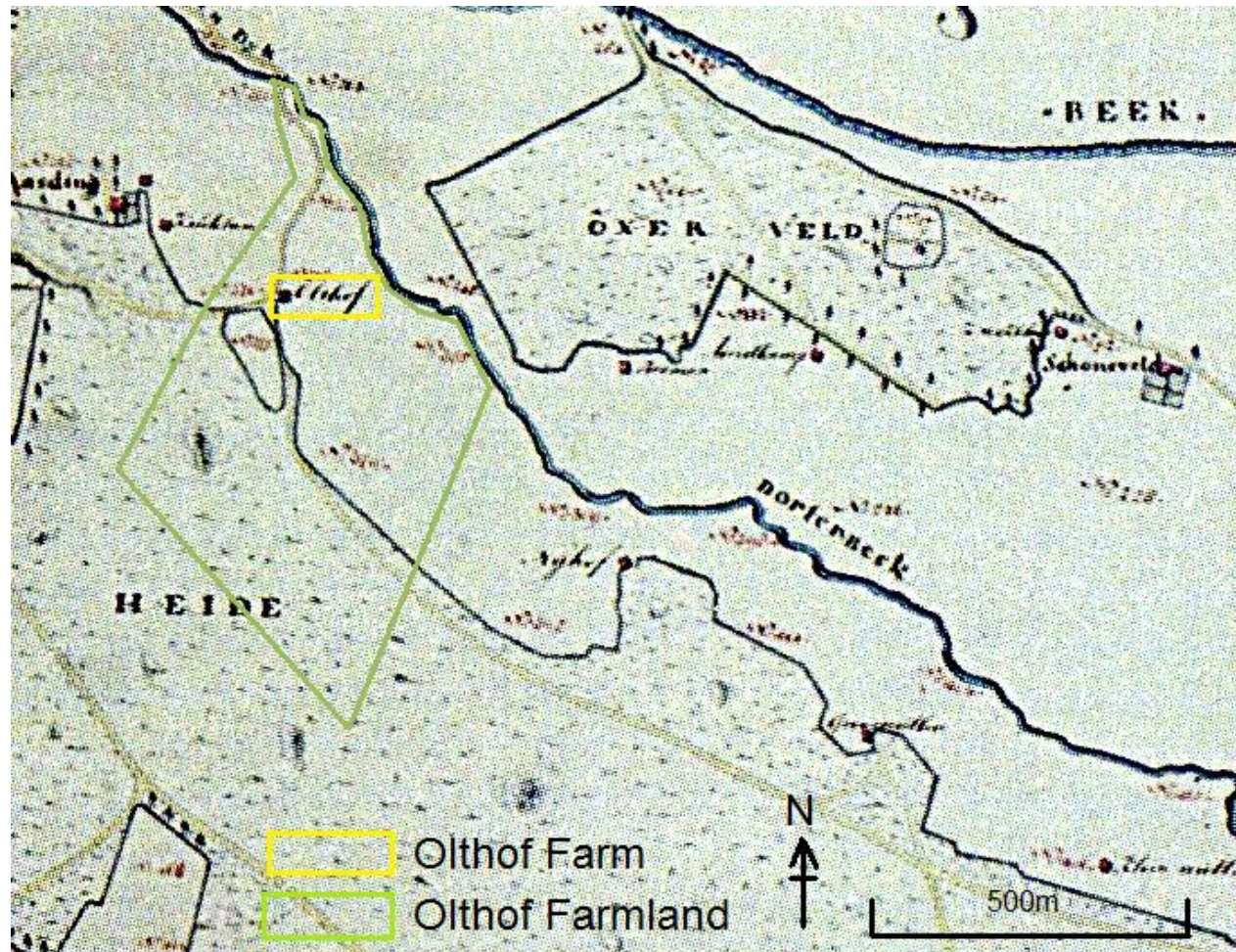


Figure 38, Map showing the landscape around Olthof farmstead A.D. 1807 (Appels, 2003)

The map of 1807 (Fig 38) clearly shows the clustering of small farmsteads in and around small clearings of heathland in the upland areas. There is a distinctive regular series of small roads linking the farms with villages and towns of Epse and the city of Deventer and in places individual houses have also begun to appear in an irregular row style. Olthof is located on the border between a large area of heathland and open land possibly an area of lowland reclamation, which today is beneath the new A1 road and the Deventer junction. Olthof is depicted as a single small building with a small road running through to the north continuing to the old site of the monastic range of buildings shown in earlier maps.

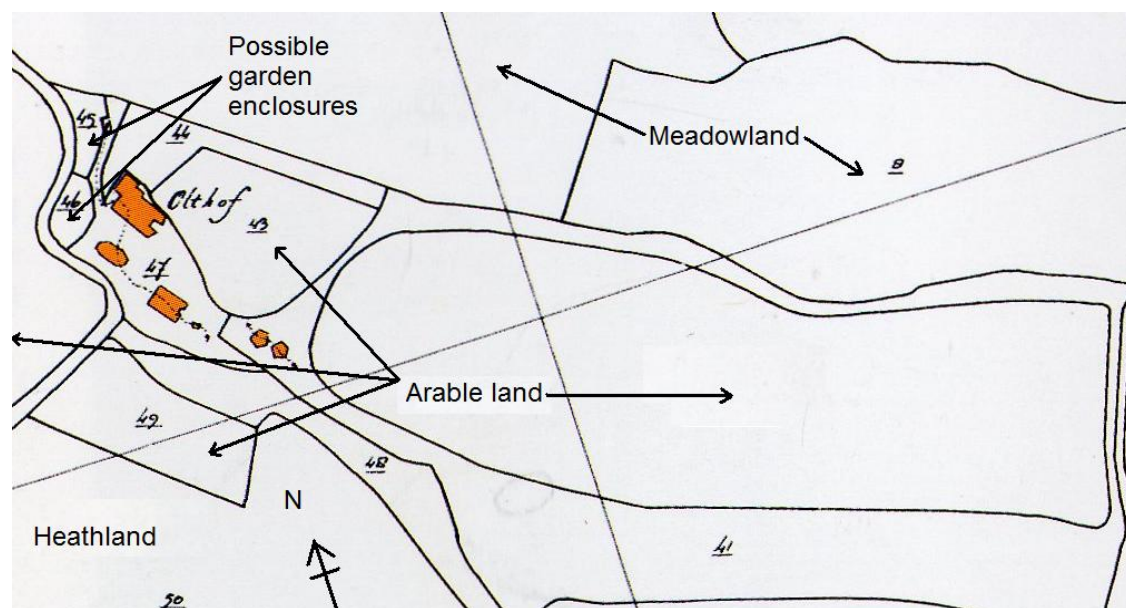


Figure 39, Map of the landscape around Olthof farmstead dated A.D. 1832 (Uitnede Kadastrale Atlas 1832 in Appels, 2003)

In 1832 the first very detailed maps of the Dutch landscape were produced (Fig 39). They were similar to the British Tithe and First Edition Ordnance Survey maps and utilised a number system which gave the landuse at the time reproduced in the soil and landuse map (Fig 34, section 3.2). This is the first detailed survey of the individual buildings in the areas and Olthof at the time consists of the main farm building which has clearly developed over time but changed very little to the present day.



Figure 40, Map of the landscape around Olthof farm dated A.D. 1846-48 (Topographical and Military Map of the Netherlands 1850)

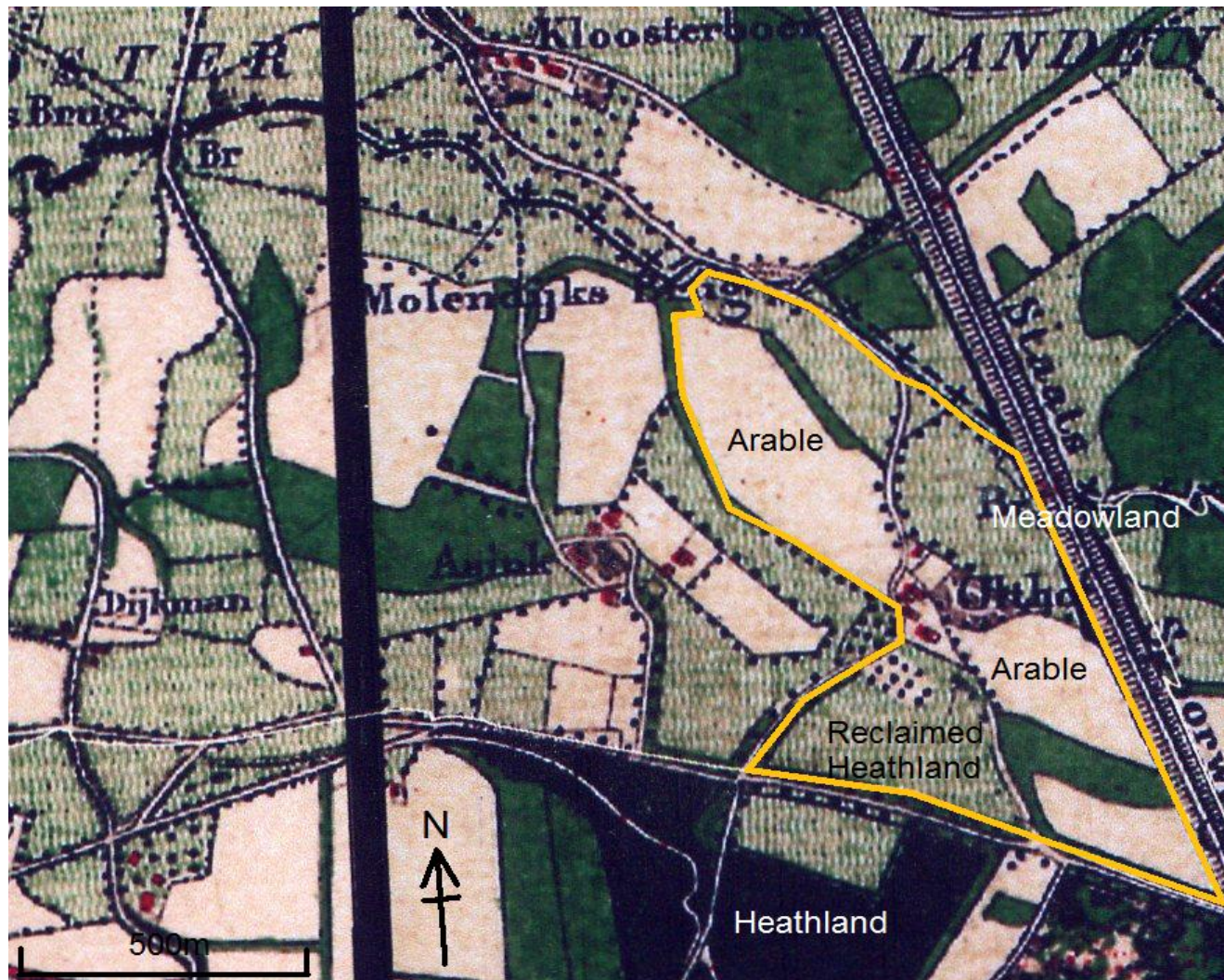


Figure 41, Map of the landscape around Olthof farm dated A.D. 1866-67 (Chromotopographical map of the Netherlands, 1867)

With it are two smaller out buildings to the south and two smaller round structures present within a distinct area of woodland surrounding a large field. A photo taken in 1950 of the farm shows two large grain storage buildings in a slightly different position and archaeological evidence from the area has shown that the design of the structures has varied very little since the early medieval period.

The landscape of the area in the early to mid 19th century (Figs 40 and 41) shows a distinctive split between the reclaimed land to the west of the river IJssel with large rectilinear fields created by increased drainage of lowland marsh. To the east of the river in the old landscape area there is a palimpsest of old and new reclaimed land in the low meadowland and also in the heathland. The fields are very dense suggesting pressure on the landscape and the number of settlements and farmsteads on the upper sand bars has increased from the map of 1807.

Around Olthof there has been little change in the field arrangement especially with Nijhof and overall the fields are considerably larger than fields of newly developed farms and most of the farmland is bounded by woodland strips or lines of individual trees. The anthropogenic development of the landscape between the late 1840s and the 1860s is very evident across the whole eastern Netherlands and this is exemplified in figures (40) and (41). The farms of Olthof and Nijhof have been split by the building of the railway between Deventer and Zutphen which would have meant a loss of land to both farms but overall there has been an increase in the size of the arable fields. The changes in land use are more clearly defined on the 1860s map which shows clear differences between the arable farm land (white/beige), pasture (light green), woodland (green) and heathland (dark green).

3.4 ARCHAEOLOGICAL RESEARCH AROUND OLT Hof FARMSTEAD

A key reason for selecting Olthof farm for further investigation was due to the extensive geoarchaeological work conducted on the farm and surrounding landscape over the last 10 years. The work was conducted by Archaeologie Deventer, a commercial archaeological group and was carried out in response to the development of the new A1 motorway running west to east across the Netherlands and the proposed development of a 120 hectare area called North Epse (Eps e-Noord). In all four major excavations have been conducted around the farm and therefore a very clear settlement history can be determined. The following text is a précis of the detailed archaeological, historical and cartographical material from the archaeological report “*Between Deventer and Epse: 10,000 years of habitation history in the area of North Epse*” (Appels, 2003).

The oldest archaeological artefacts found in the vicinity of Olthof are a large number of worked flints dating from the middle to late Neolithic (approx 6000 to 4500 BP). The flints have been found in the form of rough scrapers and extremely ornate arrow heads with distinctive barbs. Most of the important Neolithic finds were located on the sandy ridge where Olthof farm is now located as well as sandy bars close to the River IJssel indicating possible hunting areas or seasonal occupation areas close to water sources. The earliest archaeological features were located beneath a thick cover of aeolian sand and consisted of several subtle stake holes and small pits which were dated to the early Bronze Age (approx 4500 – 3700 BP) from small sherds of pottery produced in the local vicinity. Middle to late Bronze Age features were also located on the edge of the upland and alluvial areas and consisted of a series of small pits containing settlement waste however no evidence of occupation was uncovered. Like the Neolithic evidence Iron Age features were found in a distinctive pattern on the sandy ridges towards the south west of the assessment area towards the east bank of the River IJssel. The excavations by Archaeologie Deventer uncovered a complete building plan buried beneath deep anthropogenic soils. The house had a distinctive rectilinear shape (17m by 9m) and was surrounded by 36 small 500mm post

holes which are typical of buildings of this age in the Netherlands (Appels, 2003). Along with the farm building other Iron Age features in the area include a number of large storage pits used for storing excess grain. These were found in the high sandy areas and dated by C14 methods on ceramics to approx 2700 – 2600 BP. In other wetter areas of the landscape grain was stored in above ground stores and evidence for these has been found as discrete postholes 200 – 300mm in size and between 1.5m² and 2m². Archaeological evidence between the end of the Iron Age and beginning of the early medieval period is scarce and has led to interpretations that rural activity decreased and did not increase again until the early 12th century A.D. as a direct response to the increase of urban centres and the demand for agricultural produce.

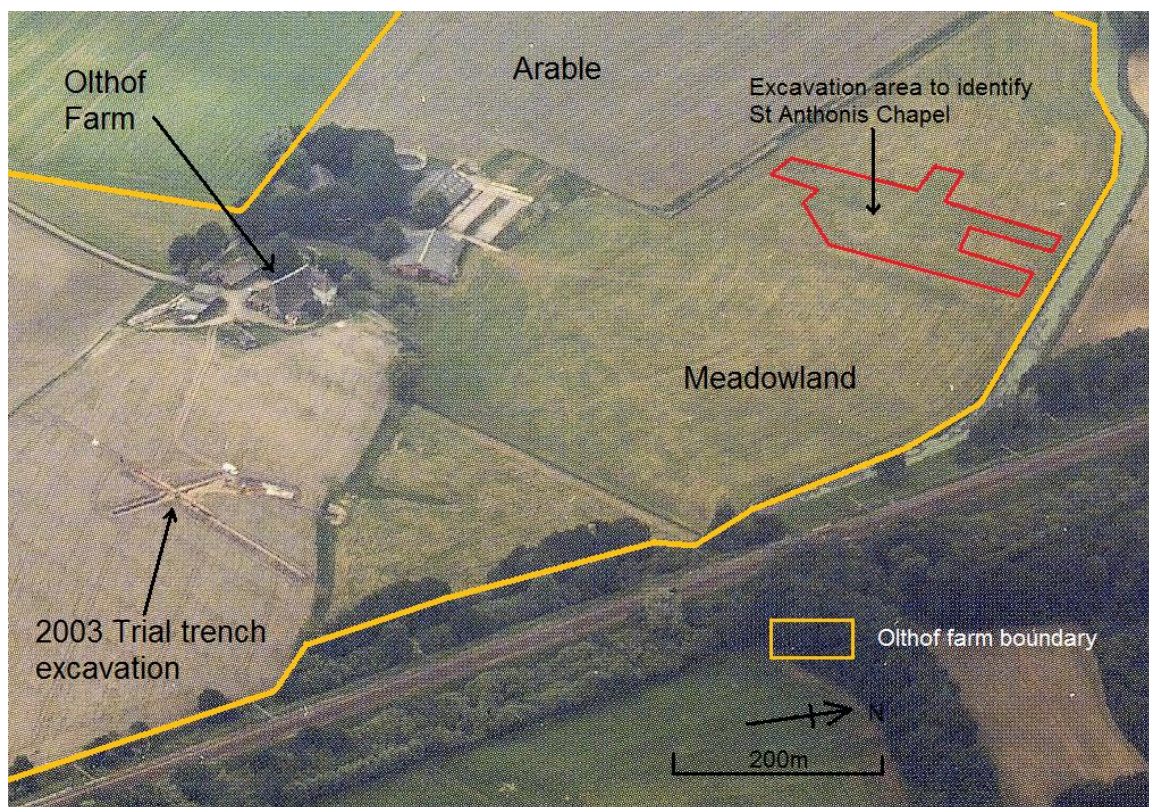


Figure 42, Aerial photograph of the 2003 archaeological excavation to the east of Olthof (Appels, 2003)

In the Epse-Noord area the onset of the 12th century population boom was mirrored in the archaeological evidence. Excavations (Figures 42 and 43)

revealed two farms which may have been precursors to the existing farms at Azink and Olthof and the evidence found suggested that the building form had changed from the prehistoric bi-partite one to an aisled hall design. The building at Olthof was 23m long and 11.5m wide with an 8m wide central area and smaller 1.75m wide aisles for the use of farm animals (Appels, 2003). The building must have been a very similar size to the existing Olthof farm as in places the internal postholes were over 1m diameter indicating a sizeable structure. The importance and status of the site is reinforced by the presence of an outbuilding measuring 12m by 5m and in the same orientation. To the west of Olthof and the north of Azink a second large building dating to the early medieval period was excavated. This building had a similar aisled hall structure and measured 17.5m by 3.5 to 5.5m (Appels, 2003). It was dated to the 11th/12th century A.D. using pottery found in the post holes and by its plan which resembled other farm buildings in Zutphen (Groothedde, 1996).

Both the excavations at Olthof revealed that the early farmsteads had numerous phases suggesting a long period of occupation and time to develop large boundary ditches, possibly created as a defensive structure due to an instable socio-political landscape or merely as a clear boundary feature between occupation areas and farmland. At Olthof the ditch found was 4m wide and contained early medieval pottery and at the Dortherbeek site the two-phase boundary feature was between 1.25 to 3.5m wide and dated from A.D. 1100 to A.D. 1540 suggesting over 400 years of occupation. Figure 42 also shows the outline of the old excavation which investigated the supposed site of St Anthonis's chapel. The excavations did not reveal any occupation evidence but did uncover a very large 3m wide moat, dated with pottery to the 13th century A.D., encircling an area 33m in diameter (Appels, 2003). The negative evidence for the chapel has been interpreted as levelling in the 1980s by deep ploughing, but the archaeologists are certain that it is the location as the limited archaeology is complemented by historical documentation and old maps of the area, discussed in sections 3.3.3 to 3.3.5. Archaeological work conducted on the site was to the north west of Olthof (Fig 44).

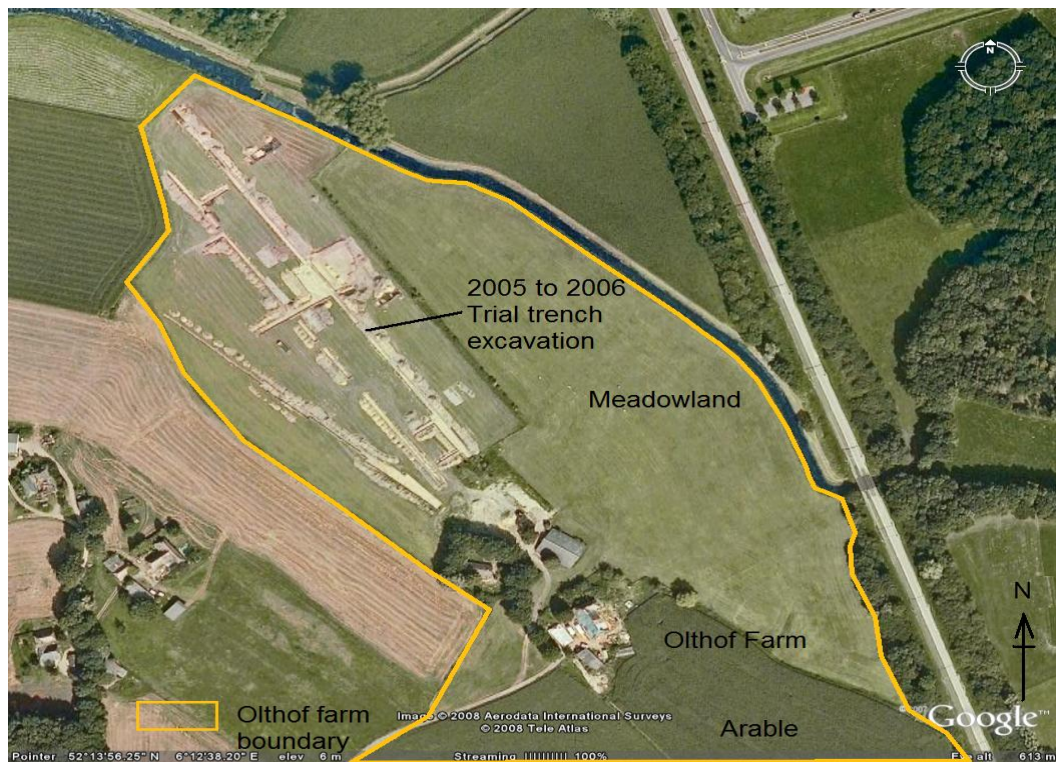


Figure 43, Aerial photograph of the 2005/2006 trial trench excavations to the north west of Olthof farm (Google Earth, 2008)



Figure 44, Photograph of the 2007 archaeological excavation of the 12th century farm building and well to the north east of Olthof farm (Archaeological Deventer, 2007)

Preliminary results of the work have shown a number of subtle prehistoric features preserved beneath the anthropogenic soils, including grain storage pits but no direct evidence of settlement. Most recently in July 2007 the area directly to the north east of the farm was excavated (Fig 44) and another large timber framed aisled farm building was found with internal postholes measuring in excess of 750mm together with two outer ranges with smaller postholes. Along with the building a very large well was excavated which measured +7m in diameter and over 1.5m deep, and as with the previous farms found in the immediate area was associated with a large, possibly defensive, boundary ditch. The features were all contemporary and pottery fragments indicated a date of around the early 12th century A.D.

3.5 THE SPATIAL DISTRIBUTION OF SOILS IDENTIFIED IN THE AUGER SURVEY ACROSS OLTHOF

Sections 3.5 and 3.6 illustrate the results of the fieldwork analysis conducted in an attempt to answer the key questions outlined in section 1.11, and this was done by utilising the methodologies detailed in section (1.12). The results of the auger survey and test pit excavation revealed a number of soils which have been affected by humans in various quantities. This section discusses the variety and distribution of anthropogenic soils found across the settlement by interpreting the transect diagrams and comparing the diversity and range with the natural geographical landscape. Four transects composed of 23 cores illustrate the varying distributions of the soils across the site (sections 3.5.1 to 3.5.4). Transects 1, 2 and 3 illustrate the soil sequence between the old heathland area and the floodplain of the Dortherbeek and transect 4 illustrates the soil sequence along the axis of the Pleistocene sandy ridge (Fig 45). The soils are then analysed across four landuse areas; the garden (section 3.6.1), the inner and outer arable landscape (sections 3.6.2 and 3.6.3) and the reclaimed heathland and meadowland soils (section 3.6.4). The overall fieldwork results from Olthof are discussed in section 3.7 where comparisons with previous work are made. (Raw data in appendices 3 and 4).

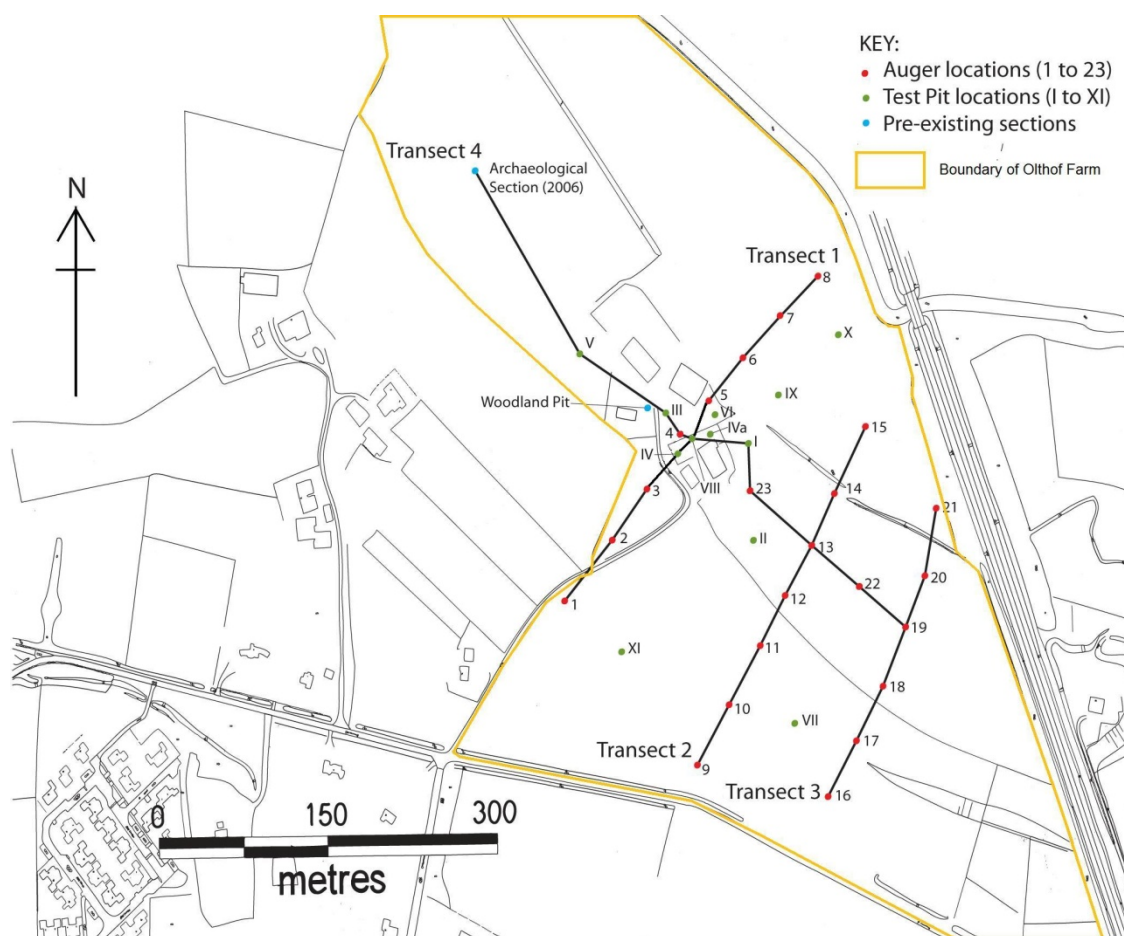


Figure 45, Location map of auger points and test pit excavations around Olthof farm

3.5.1 TRANSECT ONE

Transect one consists of 8 cores (1 to 8) and is orientated south to north and incorporates a range of land uses (Fig 46). The anthropogenic soils (Ap-1 and Ap-2) increase in depth towards the farmstead from 200mm to 420mm before increasing to 700mm directly adjacent to the garden area, and decreasing slightly to 630mm to the north of the sandy ridge. The soils range from very dark grey to black (10YR 3/1 to 2/1) and have a distinctive sandy loam texture with inclusions of small sub-rounded quartz fragments and very small organic fragments and charcoal particles.

In the cores around the farmstead there are slightly more organic and charcoal particles as well as ceramic and some degraded brick fragments. In cores 6 to 8 the anthropogenic soils are completely absent and replaced by a sandy silt alluvial deposit (A1 and A2) ranging from 650mm to 780mm. The

alluvial soils have a typically dark yellowish brown to light brown colour (10YR 4/4 to 3/4) with sandy silt textures and inclusions of small, rounded lithic fragments, some degraded organics and iron and manganese staining and concretions. Below the anthropogenic soils, in cores 2 and 3, a thin (100mm) remnant soil (Ah) is present with a yellowish brown colour (10YR 3/4 to 3/6), a silty sand texture and organic and quartz fragments. At the base of the sequence is a light grey to grey (10YR 7/1 to 6/1) with silty sand texture which derives from the natural coversands.

3.5.2 TRANSECT TWO

Transect two consists of seven cores (9 to 15) and is orientated south to north from the old heathland across the inner arable area and into the lowland, floodplain pasture area (Fig 47). The anthropogenic soils (Ap-1 to Ap-2) range from 225mm in cores 9 to 11 to between 525mm and 975mm in the central area. Core 15 is located in the floodplain of the Dortherbeek and no anthropogenic soils are present in this area. In the heathland area the plaggen soils are typically greyish brown to dark greyish brown (10YR 5/2) indicating partial leaching. The soils are sandy loams with few organic inclusions and almost no black charcoal or carbonised fragments. In the central infield area the soils change to a much darker grey to black colour (10YR 3/1 to 2/1) with a typical sandy loam texture and an increase in the amount of organic and black carbonised particles (Ap-1). Beneath the upper plaggen soil is a very dark greyish brown buried soil with a sandy silt loam texture and organic inclusions and some charcoal particles. In three of the cores a dark yellowish brown (10YR 3/4 to 3/6) silty sand buried podzol (Ah) is present with fine grained mineral fragments and heavily decomposed organics. The remnant soil appears to fill small hollows in the natural sediments where agricultural activity has been unable to incorporate it into the existing soil stratigraphy. The sequence in the lowland area consists of a 300mm deep A1 clay sandy silt with quartz inclusions and roots. Beneath the anthropogenic and the buried soils are a series of 150mm to 350mm silty sand horizons (B1 and B2) with no organic material.

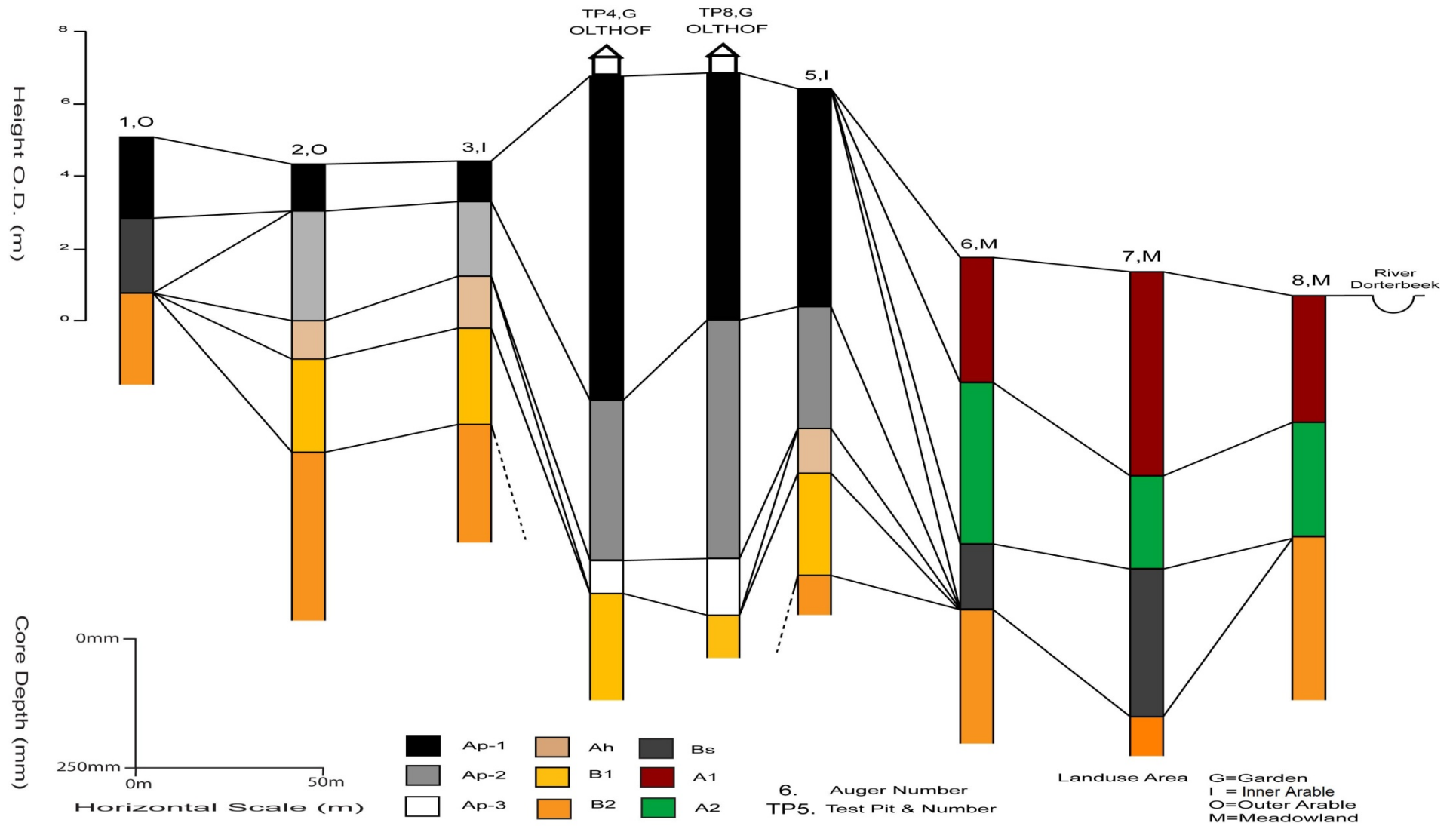


Figure 46, The distribution of anthropogenic and natural soils across Olthof farmstead in transect 1

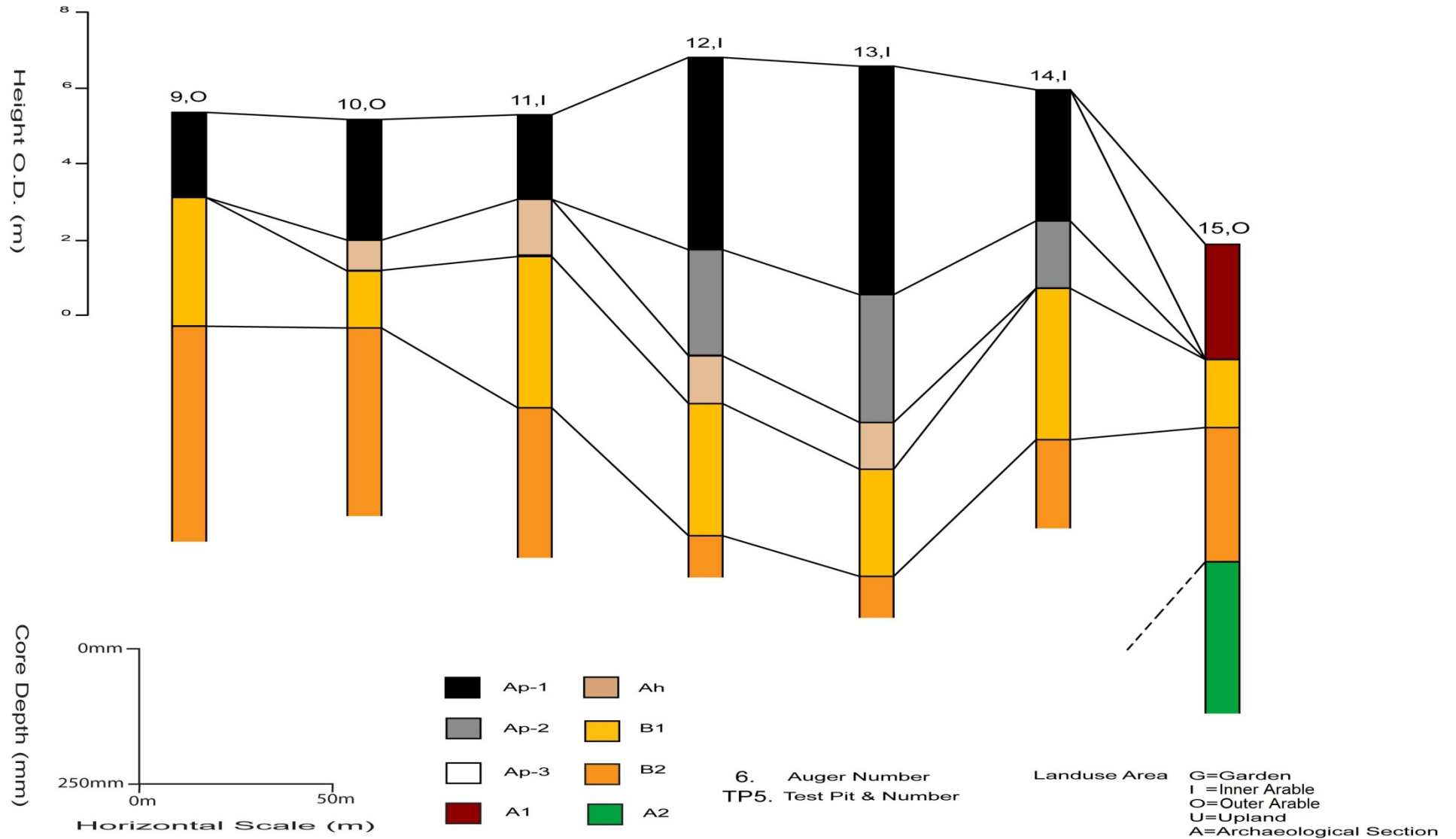


Figure 47, The distribution of anthropogenic and natural soils across Olthof farmstead in transect 2

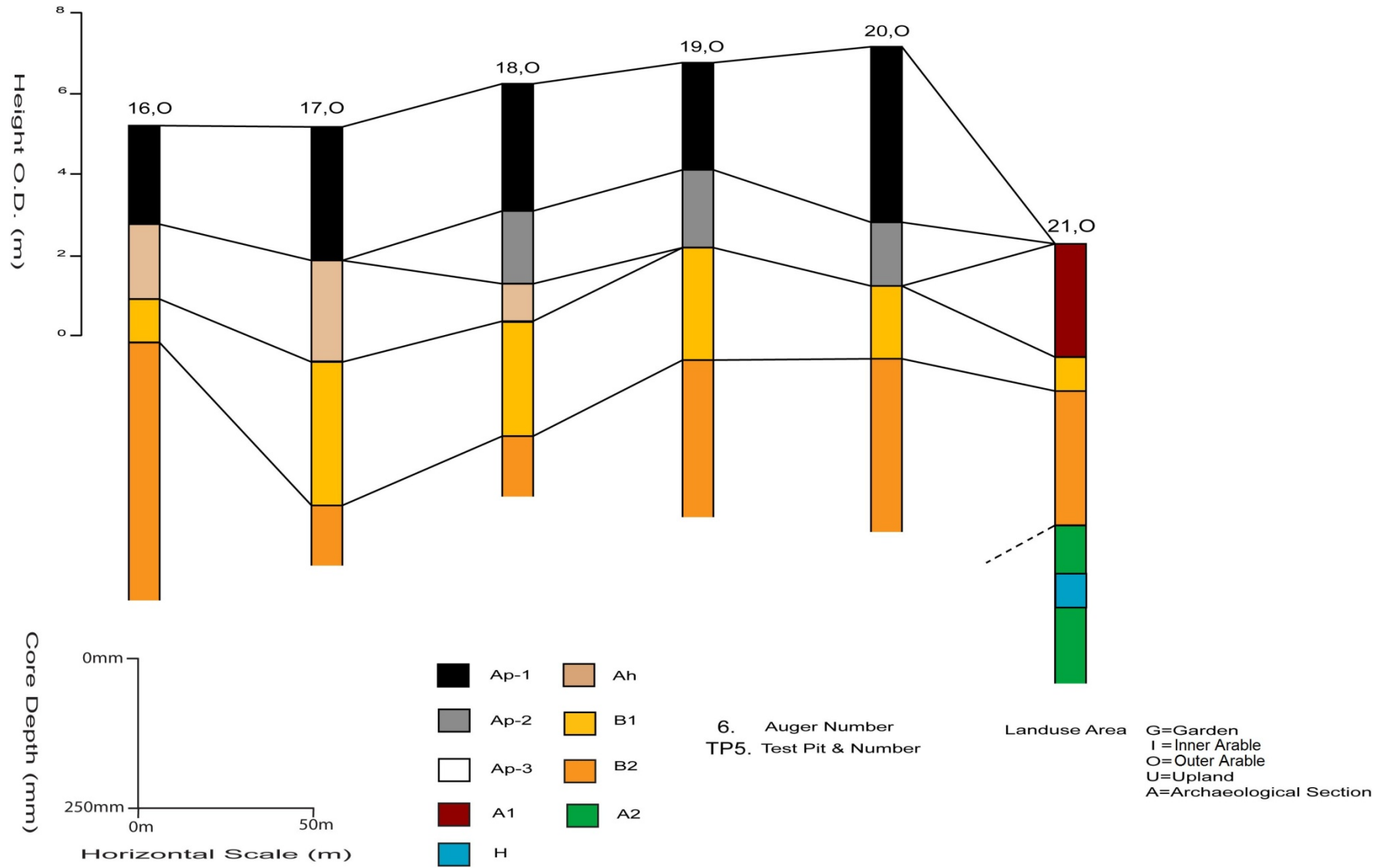


Figure 48, The distribution of anthropogenic and natural soils across Olthof farmstead in transect 3

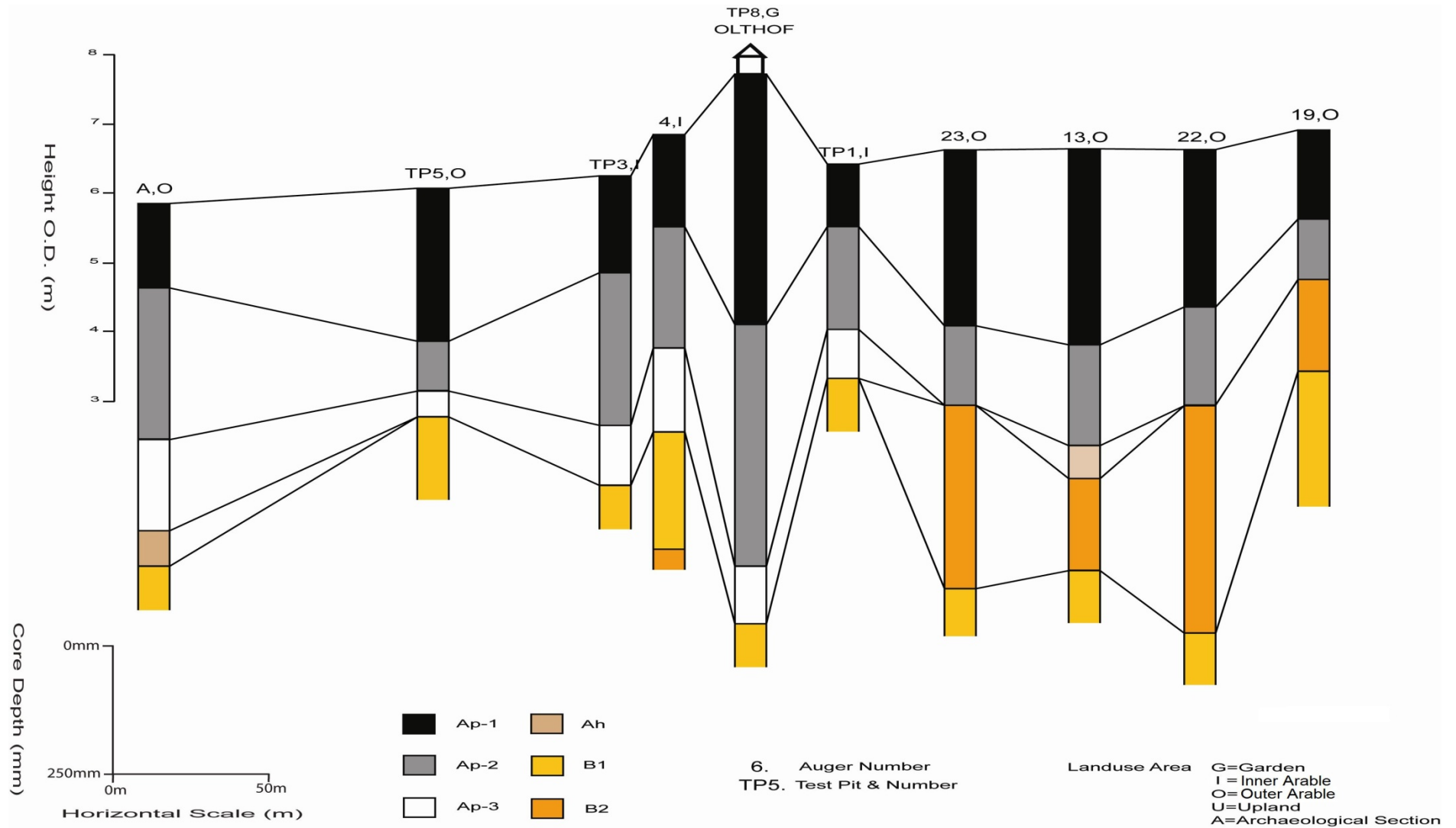


Figure 49, The distribution of anthropogenic and natural soils across Olthof farmstead in transect 4

3.5.3 TRANSECT THREE

Transect 3 is located to the very east of Olthof's farmland and consists of six cores (16 to 21) from the old heathland to the pasture in the floodplain area (Fig 48). Interestingly this transect reveals a remarkably uniform depth of upper anthropogenic soil (Ap-1) ranging from 275mm to 350mm across the old heathland area and this increases to 480mm on the northern side of the coversand ridge. The plaggen soil ranges from a dark greyish brown to black colour (10YR 3/1 to 2/1) with a sandy loam texture and quartz inclusions plus small infrequent charcoal fragments with some coarse organic fragments.

A dark greyish brown to brownish yellow coloured (10YR 3/1 to 2/1) buried anthropogenic soil was identified beneath the plaggen soil on the coversand ridge (Ap-2) and this has a sandy silt loam texture with very few organic fragments and black carbonised particles. The soil ranges in depth from 170mm to 200mm. In the old heathland area is a buried podzolic soil (Ah) which ranges from 100mm to 300mm and consists of a dark reddish grey to dark grey brown (2.5YR 3/3) organic silty sand with large areas of leaching and iron and sesquioxide concentrations. In the floodplain area the upper soil is identical to the organic clay sandy silt soils (A1) seen in transects 1 and 2, and ranges from 300mm. Below the A horizon are a series of white to yellowish brown (10YR 6/4 to 7/3) silty sands (B1 and B2) with very fine grained quartz grains. Beneath the B horizon is a very light grey to grey coloured (10YR 6/4 to 7/6) silty sand clay horizon (A2) with few coarse plant fragments and contains a thin dark grey to black coloured silty clay loam buried peaty soil (H) with large plant and woody fragments with fine grained lithic fragments.

3.5.4 TRANSECT FOUR

Transect 4 analyses the range in depth across the coversand ridge where the majority of the anthropogenic soils are located (Fig 49). The transect is 6 cores (3,4,13,19,22 and 23) as well as data from 3 test pits and an archaeological section. The most striking observation is the marked

increase in depth of anthropogenic soils from the arable land to the garden area (400mm to 700mm). There also appears to be a thickening of the anthropogenic soils around the east of the farm exactly where archaeological evidence of an older settlement was found and these horizons may represent degraded soils from that period of settlement. The plaggen soil (Ap-1) is typically a very dark greyish brown to black (10YR 3/1 to 2/1) and becomes almost exclusively black closer to the farmstead, between core number 4 and test pit 8.

The level of organic and anthropogenic inclusions also increases towards the farm, especially plant and turf fragments, and the size and number of black carbonised particles. The depth of the plaggen soil ranges from 150mm at the outer extremities on the border with the natural soils, 400mm to 600mm in the arable land and 750mm to 900mm in the garden. To the west of the farm the Ap-1 horizon steadily decreases in depth, possibly because of an increase in the slope angle and subsequent surface erosion. Beneath the Ap-1 horizon is a dark grey to black Ap-2 horizon which is located in most of the cores taken and is composed of an organic sandy loam with inclusions of plant fragments and very small carbonised particles. This ranges in depth from 200mm to 600mm and mirrors very closely the Ap-1 horizon and may represent a leached plaggen soil. The least distinctive anthropogenic soil is the Ap-3 horizon. This horizon ranges from 150mm to 350mm and has a very subtle grey to light brown colour (10YR 3/1 to 2/1) with a silty sand loam texture and almost no organic inclusions and a very small number of black particles, possibly carbonised particles or iron concretions.

In several cores a buried podzolic soil (Ah) was found and at each location (13 and the archaeological section) the horizon is very thin, around 100mm, and consists of a dark yellowish brown (10YR 3/4 to 3/6) silty sand with a fine grained structure. These thin lenses probably correspond with the remnant of considerably deeper soils truncated by plough or spade activity at the beginning of arable activity on the site. Beneath the anthropogenic soils a distinctive series of silty sands was identified (B1 and B2) of light yellow to white colour (10YR 6/4 to 7/3) ranging from 200 – 400mm in depth with fine grained quartz and high iron content.

3.6 THE SPATIAL DISTRIBUTION OF SOIL HORIZONS ACROSS DIFFERENT LANDUSE AREAS

3.6.1 GARDEN SOILS

Olthof's garden enclosure (Plate 14) measures 15m by 7m and is situated to the north west of the main farm building. The area was used to grow vegetables and fruit for the farm but more recently, was changed into a small garden area with a centrally grassed area, plant beds along with small trees and shrubs.



Plate 14, Photograph of Olthof garden looking north (B. Pears)

Two test pits were excavated in the garden area (test pits 4 and 8) and in both deep anthropogenic soils are present ranging from 1.4 to 1.6m deep (Figs 50 and 51). In both test pits 4 and 8 is a very deep Ap-1 horizon which ranges in depth from 720 – 900mm and has a distinctive dark grey to black colour (10YR 3/1 to 2/1) and a sandy loam texture.

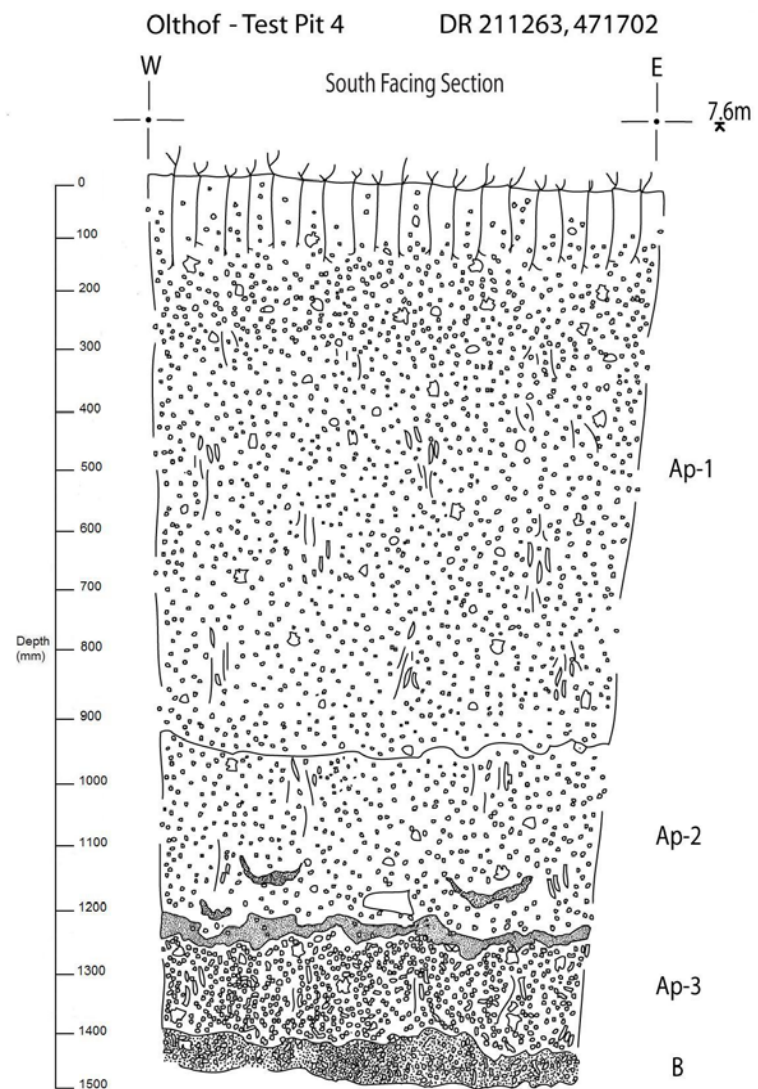


Figure 50, Section drawing and photograph of Olthof garden soil horizons in test pit 4

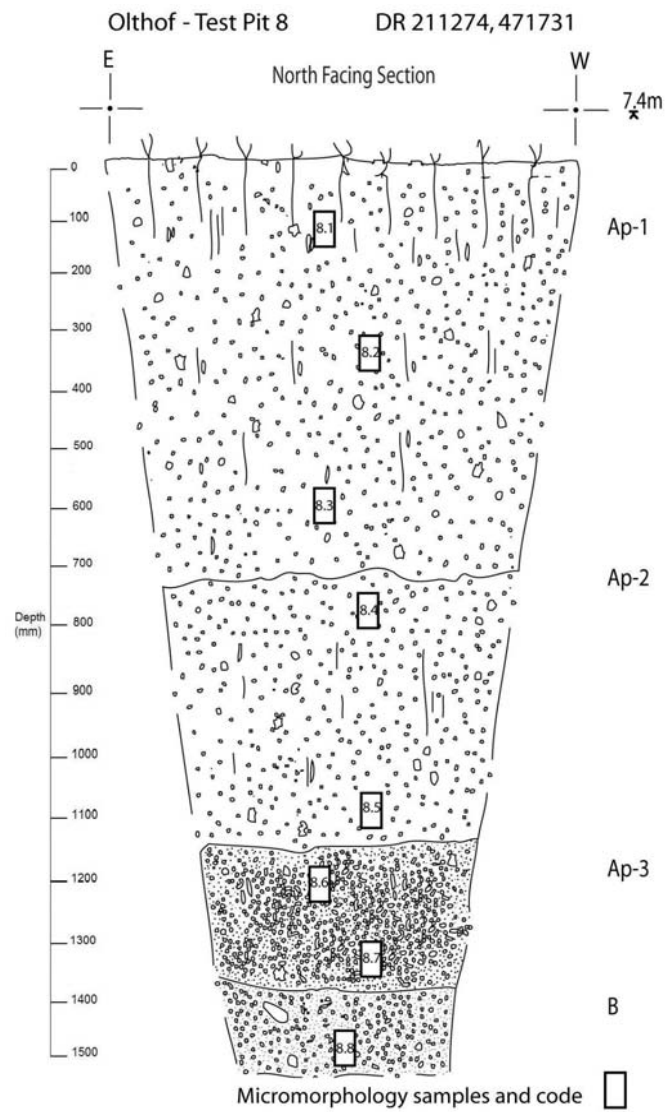


Figure 51, Section drawing and photograph of Olthof garden soil horizons in test pit 8

Within the soils are inclusions of small organics and charcoal fragments as well as post-medieval to modern pottery and building debris in the form of brick and tile. Below the Ap-1 horizon is a slightly lighter coloured dark grey to grey/black (10YR 3/1 to 2/1) sandy loam soil (Ap-2) which ranges from 380mm to 500mm deep. The plaggen horizon appears to have been moderately leached of nutrients and indeed the organic inclusion and carbonised particles were fewer in number and smaller in size. In test pit four is a thin, heavily disturbed E horizon with a very coarse, angular boundary with the Ap-2 boundary. The dark yellowish orange (10YR 5/6) sand appears to have undergone considerable leaching and contains almost no organic fragments and no carbonised or anthropogenic inclusions. The horizon occurs sporadically across the garden as it is not present in test pit 8. A third more discrete anthropogenic soil (Ap-3) is present in both test pits and ranges from 150mm to 250mm thick and has a much lighter grey to light brown colour (10YR 5/2) with patches of brownish grey. The sandy loam has very small remnants of organic inclusions but contains very few macro size black carbonised particles. Beneath the anthropogenic soils is a light grey to white coloured (10YR 6/4 to 7/3) silty sand which has interpreted as a B horizon. The boundaries between the Ap-3 and B horizons in both test pits are fairly smooth and undisturbed, suggesting that during the initial manuring of the garden there was minimal disturbance with spades and an emphasis on increasing the depth of the soil.

3.6.2 INNER ARABLE SOILS

Outside the garden, the inner arable area at Olthof was assessed using a number of cores and test pits, however identifying this area was extremely difficult because of the expansion of fields and removal of boundaries in the early 20th century. Three test pits were located within 100m of the farm and at each, three distinctive anthropogenic soils are present (Figs 52 to 54). The Ap-1 horizon is a light grey to black, (10YR 3/1 to 2/1) silty sand loam with a fine mineral content and inclusions of organic fragments and charcoal. The soil ranges from 130mm to 320mm with a clear deepening towards the garden.

Olthof - Test Pit 1 DR 211347,471709

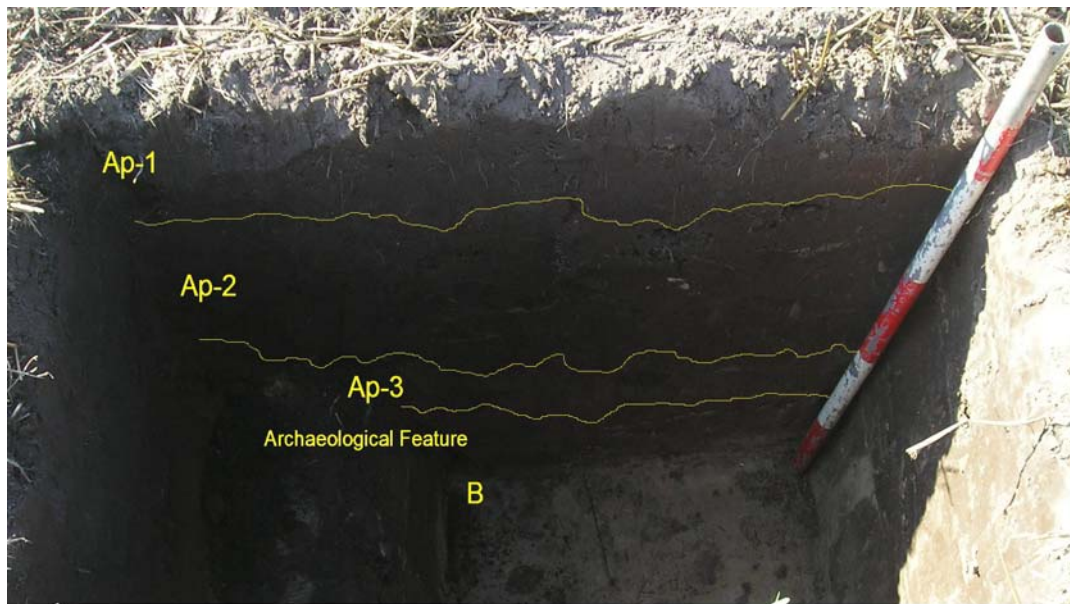
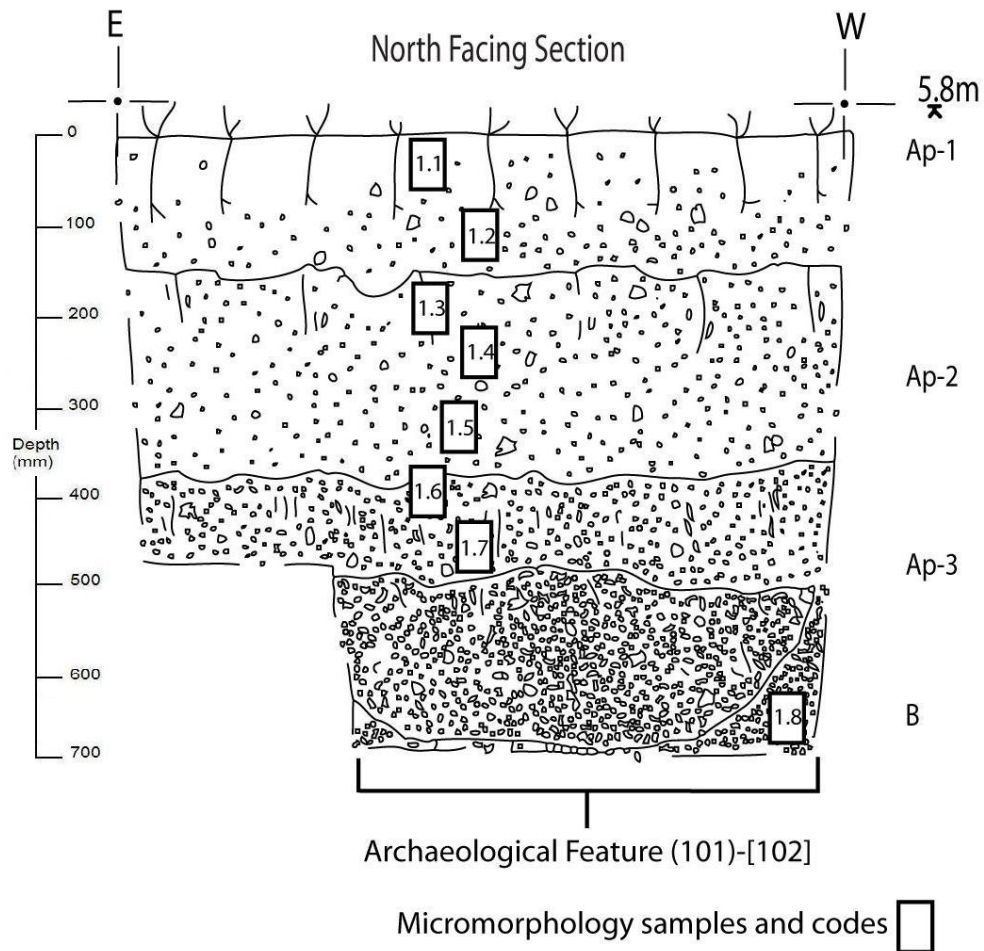


Figure 52, Section drawing and photograph of soil horizons in the Olthof inner arable area in test pit 1

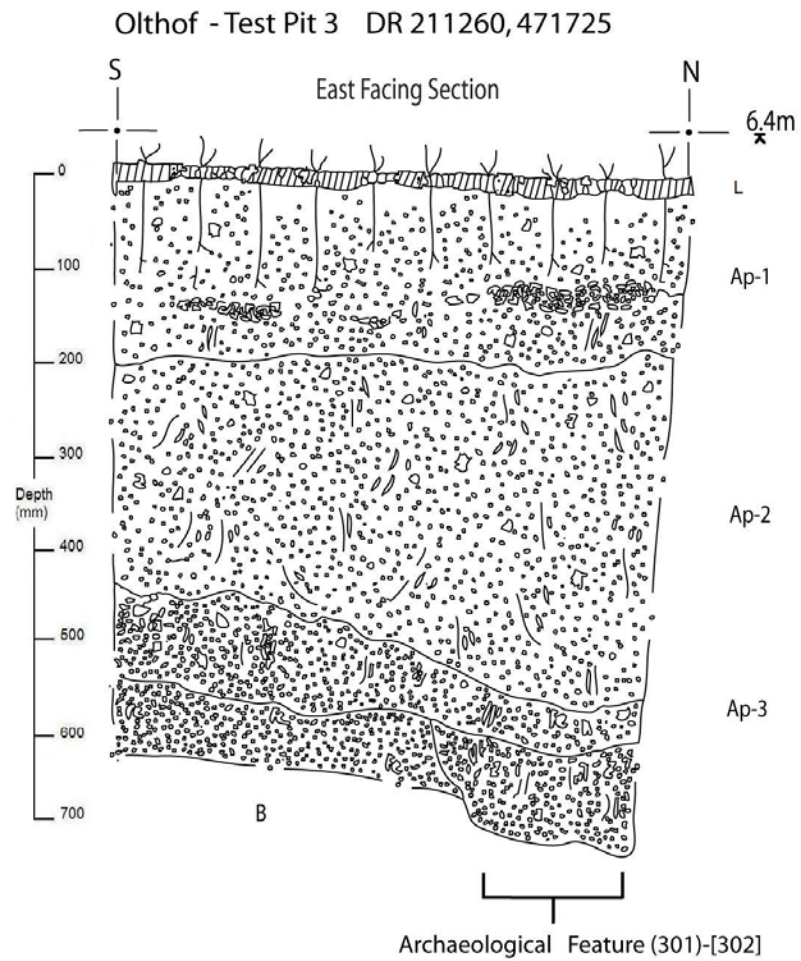


Figure 53, Section drawing and photograph of soil horizons in the Olthof inner arable area in test pit 3

Olthof - Test Pit 6 DR 211299, 471743

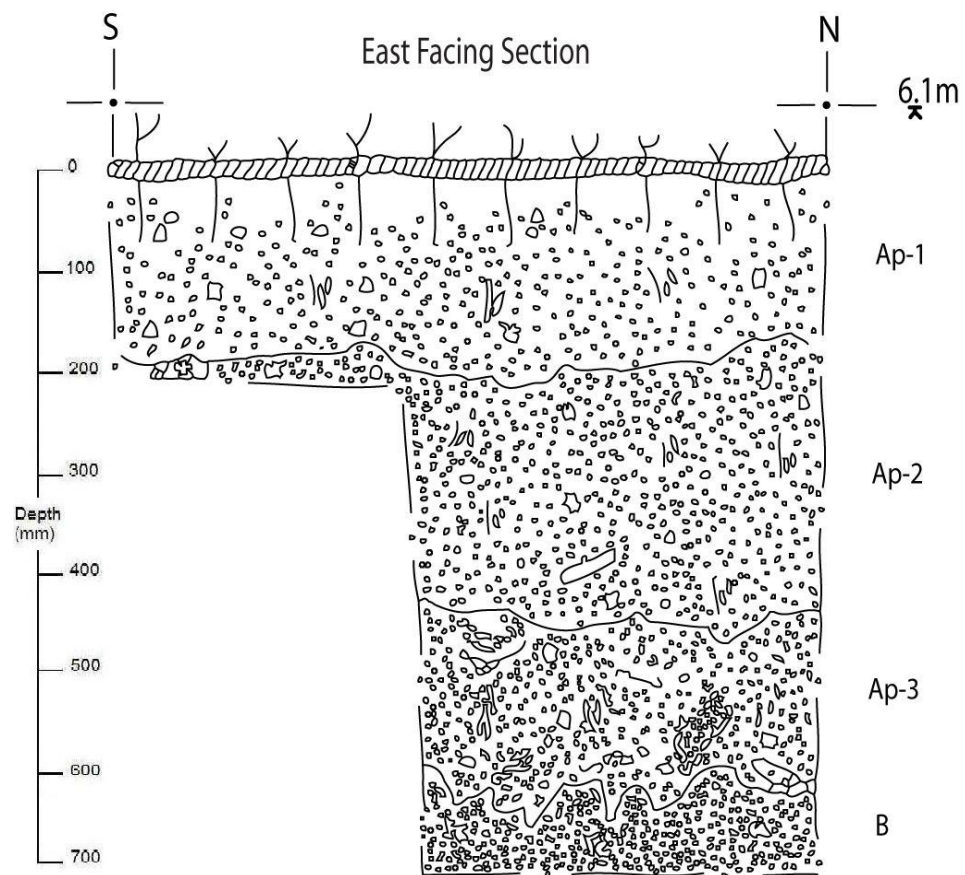


Figure 54, Section drawing and photograph of soil horizons in the Olthof inner arable area in test pit 6

The second anthropogenic soil (Ap-2) is also present in each of the test pit and ranges from 320mm to 340mm, at the north east extremity, but increases to 420mm to 630mm close to the centre of the farm. The soil is a dark brown to black coloured (10YR 3/1 to 2/1) silty sand loam with inclusions of organic fragments, small degraded pottery and small carbonised particles. The Ap-3 horizon is a considerably lighter coloured sandy loam with considerably less organic and carbonised inclusions. The depth of the soil ranges from 110mm to 250mm and is typically a light brown to grey coloured (10YR 5/2) silty sand loam with medium to fine grained mineral inclusions, predominantly quartz fragments, as well as very small, degraded organic fragments and rare charcoal particles. In all three sections the boundaries between the Ap-2 horizon and natural sandy B soils is irregular with frequent evidence of post burial mixing from biological activity.

Test pits 1 and 3 (Figs 52 and 53) reveal two distinctive archaeological features, which due to the limitations in the size of the excavations and the time constraints could not be investigated fully. The feature in test pit one [102] is a small gully or pit orientated north, north east to south, south west with steep rounded edges and a semi flat base. Within the feature is a single light brown (10YR 4/2) silty sand loam (101) with a high mineral content, possibly from running water, particularly towards the base and inclusions of degraded organics, similar to the Ap-3 horizon.

No dating evidence was found in the feature, however the remarkable similarity of the Ap-3 horizon and the fill (101) may indicate deliberate infilling when manuring began. The feature in test pit 3 [301] is located in the northern corner of the test pit, measures 450mm by 350mm with a sub-rounded shape with steep edges, sharp breaks of slope and a highly irregular base. Within the cut of the feature is a highly mixed dark brown (10YR 3/4) sandy silty loam (301) with large rooty fragments, a range of mineral and lithic fragments and laminations of dark brown, red (10YR 2/3) iron staining. The date of the feature could not be ascertained as no artefacts were found within the fill and therefore was interpreted as a tree-bowl, possibly cleared as a result of the need for an increase in arable farmland.

3.6.3 OUTER ARABLE SOILS

Two test pits were excavated in the outfield areas of Olthof farm, one to the south east and one to the north west along with a third pre-existing archaeological profile (Figs 55 to 57). The stratigraphy in the test pits includes three distinctive anthropogenic soils (Ap-1 to 3), the remnants of a podzolic soil (Ah), eluviated horizon (E), natural sandy soils (B) and upper Pleistocene sand (C). Test pit 2 contains the deepest sequence of anthropogenic soils found in the outfield which mirrors an anomaly seen in the auger transects. The upper Ap-1 horizon is composed of a light grey to black coloured (10YR 3/1 to 2/1) organic rich silty sand loam with frequent, small charcoal fragments less than 2mm and some post-medieval pottery fragments. The horizon ranges from 140mm to 160mm in test pit 2, to over 500mm in test 5 and is most likely a direct result of intensive ploughing and surface soil movement. Horizon Ap-2 is very similar horizon Ap-1 but shows considerably less mixing and has a black silty sandy loam with a high numbers of organic inclusions but smaller, rarer black carbonised particles. Test pit 5 and the archaeological section have between 180 to 220mm of the Ap-2 horizon but on the south east side of the farm in test pit 2 the horizon is 700mm deep and contains small, degraded ceramic fragments and a higher proportion of organic and black carbon particles which suggests input was occurring at different rates.

The third anthropogenic soil (Ap-3) is a very distinctive dark brown to grey colour (10YR 5/2) with a distinctive organic content and partially leached in places. The sandy loam horizon has a highly mixed boundary with the plaggen soil (Ap-2) and much lower quantities of organic fragments and black carbonised particles. Across the three sections, and the augers, the Ap-3 horizon is very consistent ranging from 120mm to 170mm suggesting relative uniformity in the addition of manure in the outfield area. In test pit 5 and the archaeological section is a very distinctive dark brown to grey coloured remnant of a podzolic soil (Ah). The horizon contains some organics but no anthropogenic inclusions. In both places the boundary between the old soil and the anthropogenic horizons was very irregular and angular which suggests truncation by ploughing.

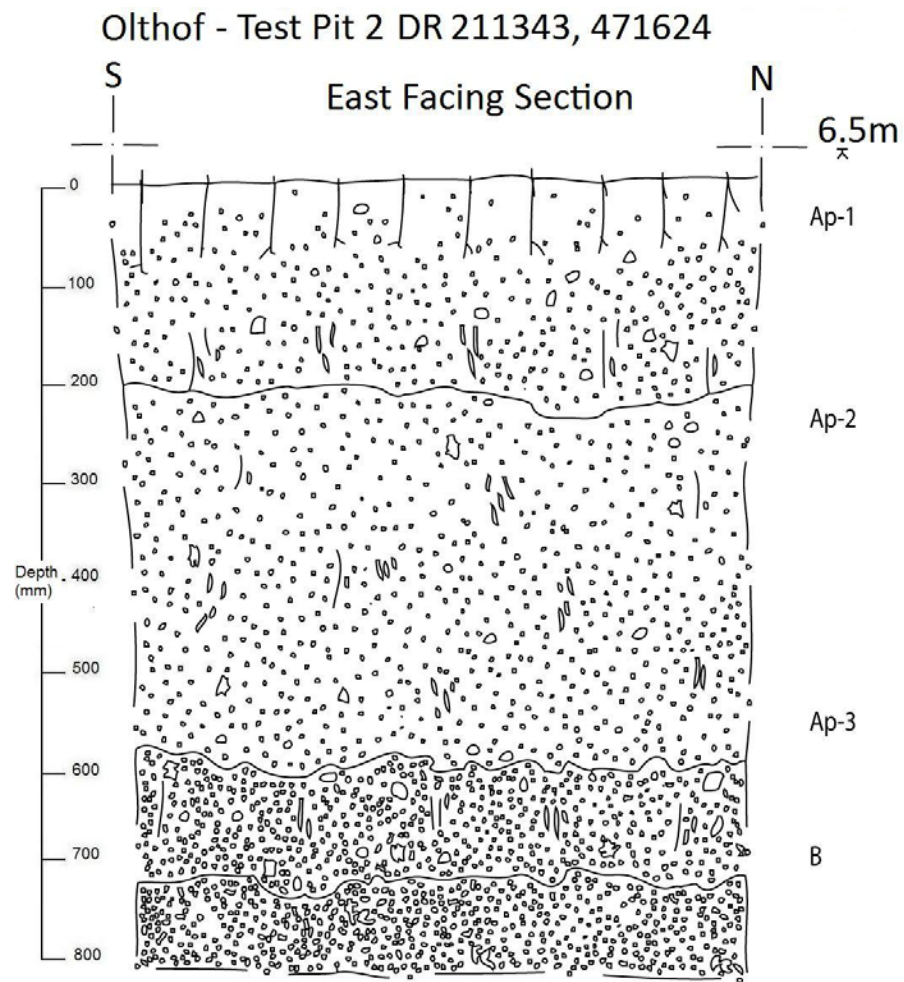


Figure 55, Section drawing and photograph of soil horizons in the Olthof outer arable area in test pit 2

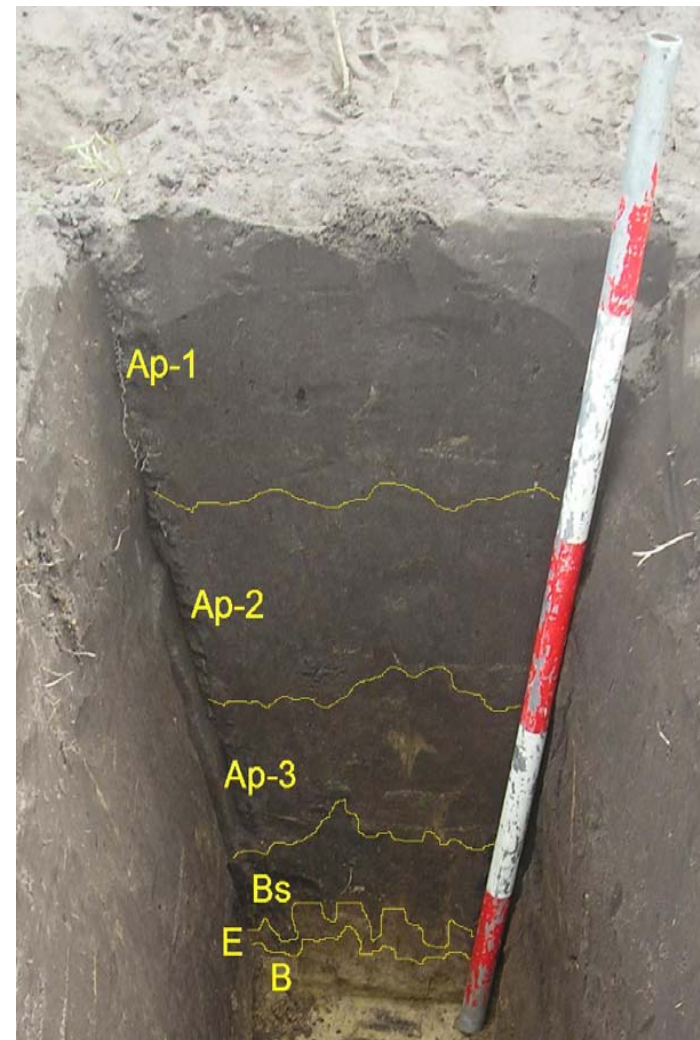
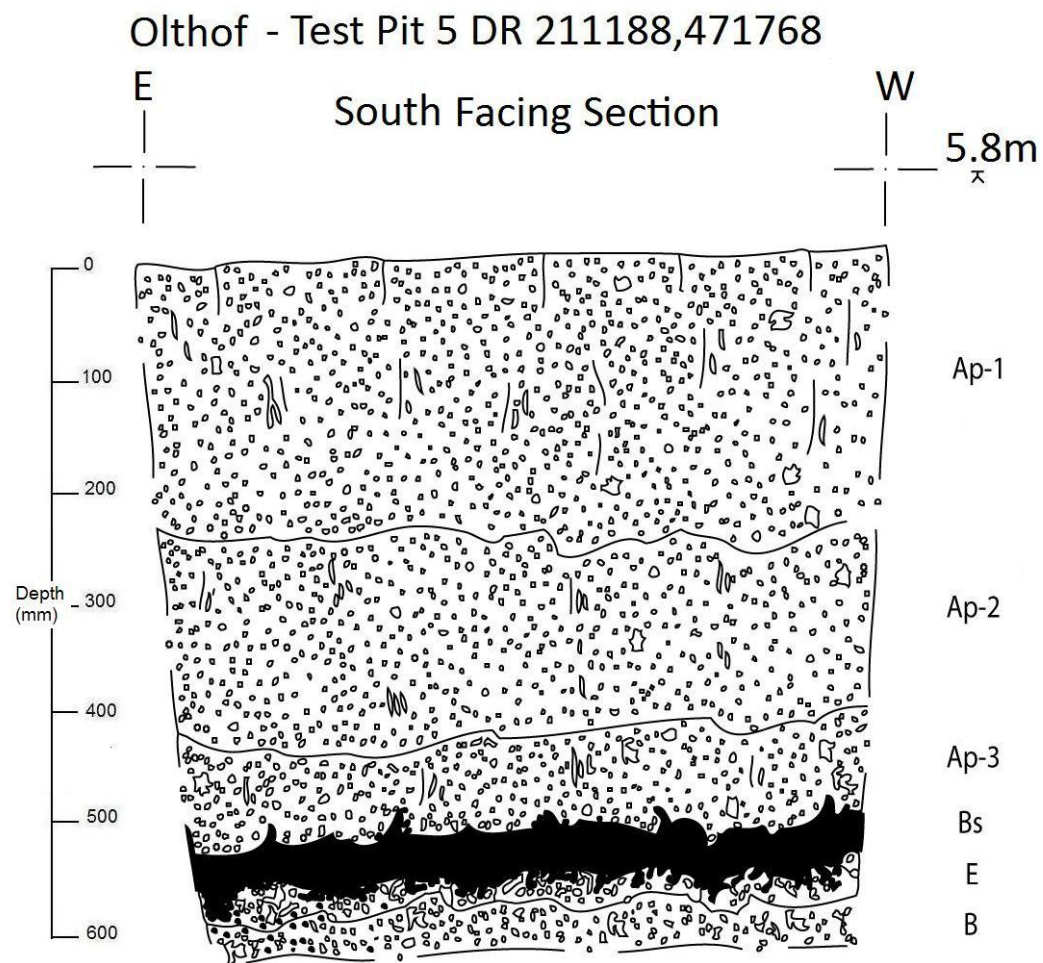


Figure 56, Section drawing and photograph of soil horizons in the Olthof outer arable area in test pit 5

Olthof - Archaeological Section DR 211146,471883

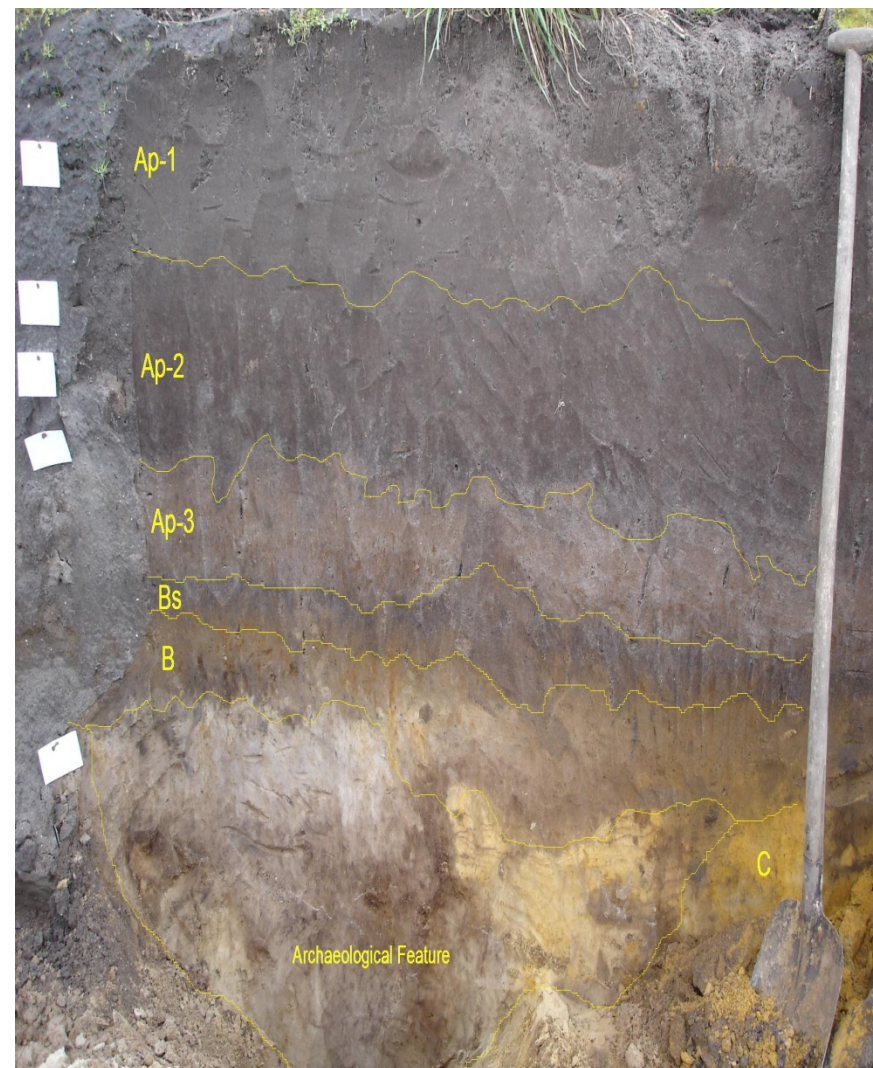
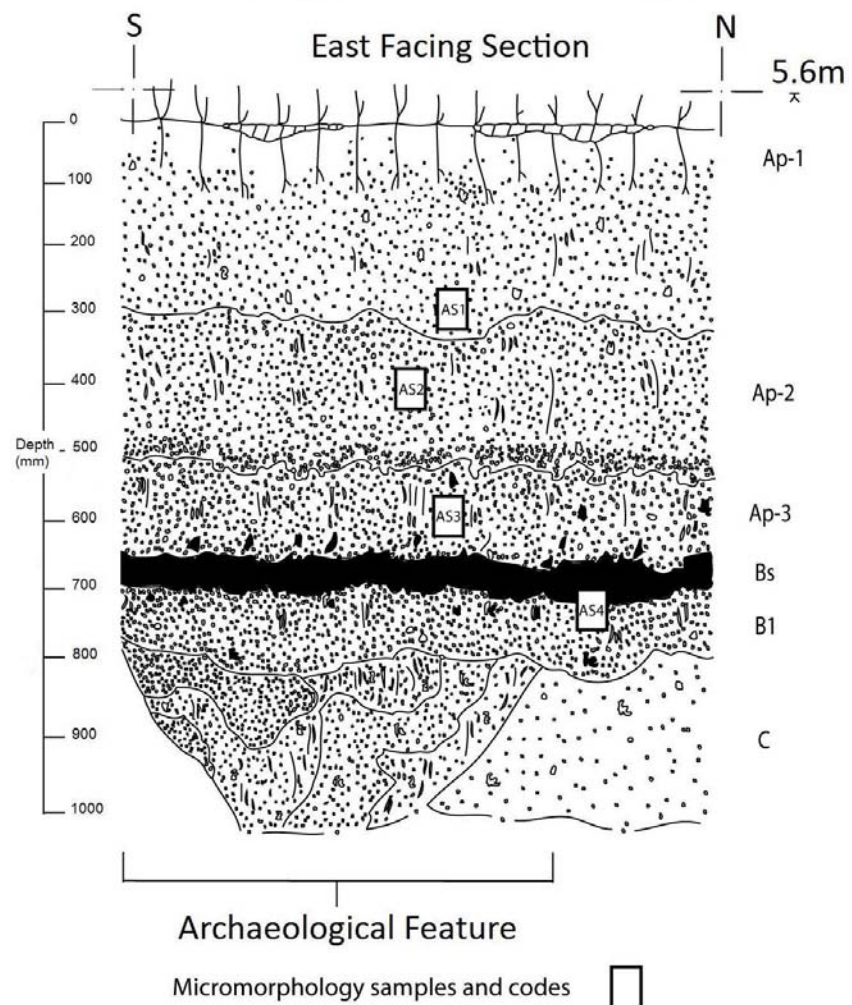


Figure 57, Section drawing and photograph of soil horizons in the Olthof outer arable area in an archaeological section

Below the podzol a leached light yellow to white (10YR 7/3) silty sand (E) was identified with no organic or anthropogenic inclusions and beneath that a light yellow (10YR 6/4) loamy silt sand (B) with very small organic fragments originating from post burial mixing.

In the archaeological section part of a steep sided feature was uncovered which might be part of a pit or ditch with a rounded base and measuring 740mm wide by 130mm deep and containing four distinctive fills. Each of the fills were dark yellow, grey to brown coloured silty sands with minimal organics and red, orange iron mottling and staining. The four fills (75mm to 95mm) were not horizontally deposited and heavily mixed and had no anthropogenic inclusions which suggested that the feature was a tree-bowl similar to the one found in test pit 3.

3.6.4 UPLAND AREAS AND NATURAL SOILS

As well as the test pits excavated on the farmland on the Pleistocene ridge a range of test pits were also excavated in natural environments in order to record the natural soil stratigraphy. Four test pits were excavated in total with two in the old heathland (7 & 11) (Figs 58 and 59), and two in the alluvial meadowland of the Dortherbeek (9 & 10) (Figs 60 and 61). Historically the area to the south of the farm had been heathland before alteration to farmland and it was assumed, before the fieldwork began, that a distinctive podzolic profile would be found as seen in the modern heathland.

Both the auger survey and test pits reveal a distinctive anthropogenic soil (Ap-1) with a distinctive dark grey to black (10YR 3/1 to 2/1) silty loam with some organic fragments and very few charcoal fragments. It is very extensively mixed through ploughing action and ranges from 300mm to 400mm in both test pits and the auger survey. In test pit 7 is a thin 100mm to 120mm thick Ap-2 horizon which is identical to the Ap-1 but may have been situated beneath the plough and avoided mixing. The boundary between the Ap-1 and Ap-2 soils is very gradual and indistinct in places and it has been assumed that the two are actually the same soil and represent the total effect of manuring since heathland clearance.

Olthof Old Heathland - Test Pit 7 DR 211371, 471530

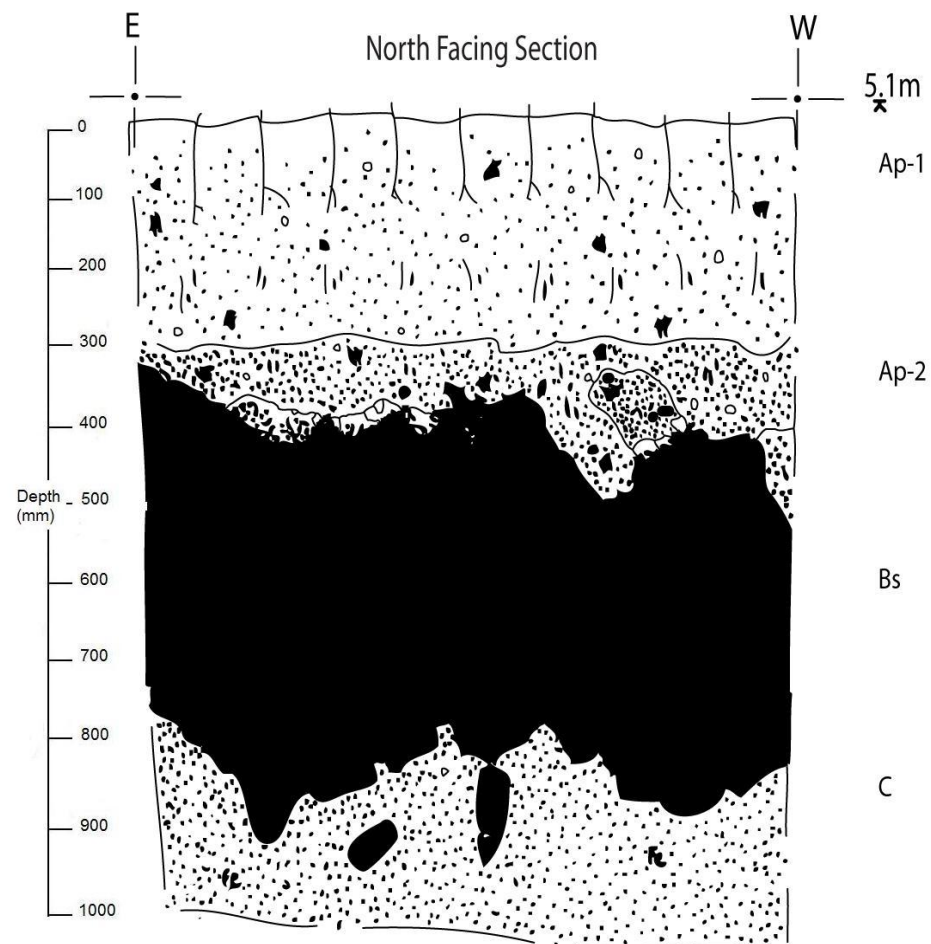


Figure 58, Section drawing and photograph of Olthof old heathland soil horizons in test pit 5

Olthof Old Heathland - Test Pit 11 DR 211213,471554

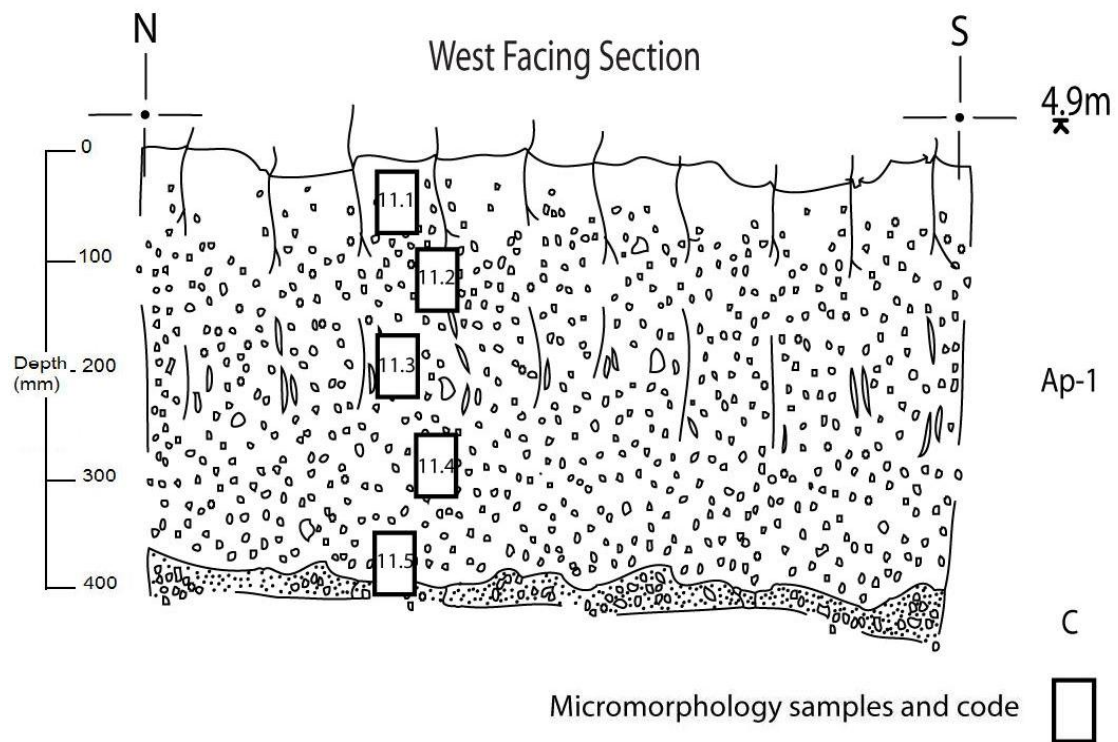


Figure 59, Section drawing and photograph of old heathland soil horizons in test pit 11

Test pit 7 also shows very distinct evidence of an extensive podzolic soil (Ah). Ranging from 450mm to 490mm the old heath soil is a dark yellowish brown with dark reddish grey areas (10YR 3/4 to 2.5YR 3/3) with a silty sand loam texture and few organic inclusions. The horizon appears in the majority of the cores taken across the area mainly as thin remnants (130mm to 150mm) and heavily truncated by ploughing, but in test pit 7 the layer is unusually thick and appears to be filling a small hollow 7 to 10m across. In places the horizon has been very heavily disturbed and mixed by animal burrowing and large fragments of podzolic soil had been mixed into the natural coversand horizon (C) below.

In the floodplain of the Dorterbeek the soil sequence is very different (Figs 60 and 61). In both the auger survey and the test pits the upper soil is typically a thin 90mm to 130mm, dark greyish, brown coloured (10YR 4/4) clay sandy silt with fine grained mineral inclusions coarsening down profile (A1). Beneath is a light brown, light grey (10YR 6/4 to 7/6) clay sand silt (A2) with fine quartz fragments, which varies from 300mm to 400mm. Both the A horizons have high organic levels but no anthropogenic inclusions and there is no mixing through agricultural activity. In test pit 9 (Fig 60) is a third alluvial horizon, ranging between 375mm to 390mm, and has a distinctive light brown (10YR 7/6) clay silt with very little coarse lithic or organic inclusions, but does have areas of darker orange, red (7.5YR 6/8) iron and manganese staining from repeated waterlogging (A3). Test pit 9 also contains evidence of a blue, grey sandy clay palaeochannel soil similar to the horizon seen in core 21 (Transect 3, Fig 48). This horizon has a large quantity of iron and manganese translocation. In test pit 10 (Fig 61) the A1 and A2 horizons are located above two very dark red, orange coloured (10YR 6/6 to 7.5YR 6/8) iron rich soils with large mineral nodules throughout (Bs1 and Bs2).

Olthof Meadowland - Test Pit 9 DR 211336, 471773

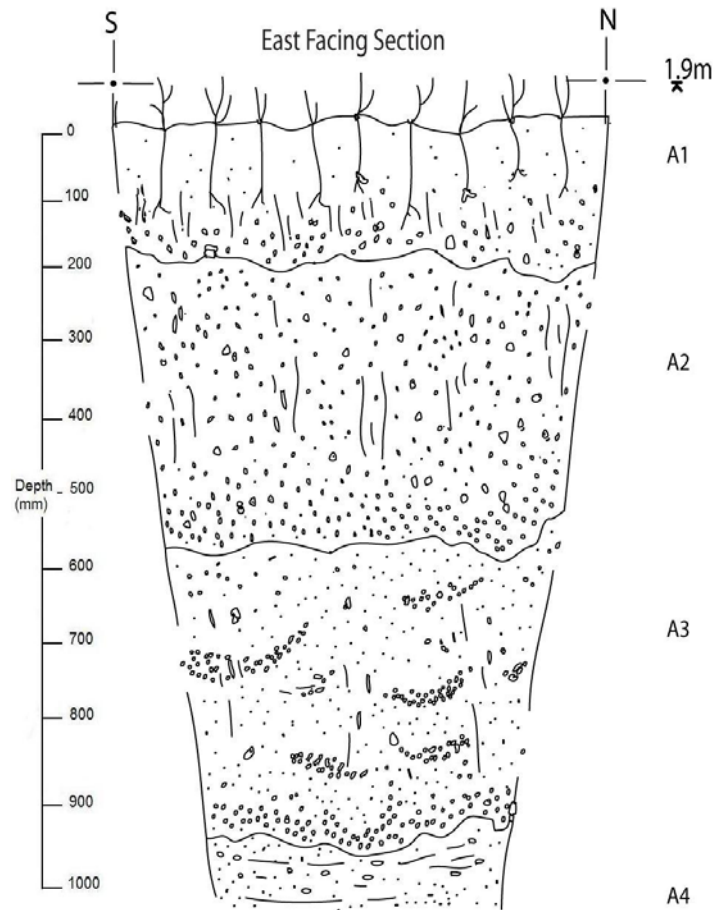


Figure 60, Section drawing and photograph of soil horizons in Olthof meadowland test pit 9

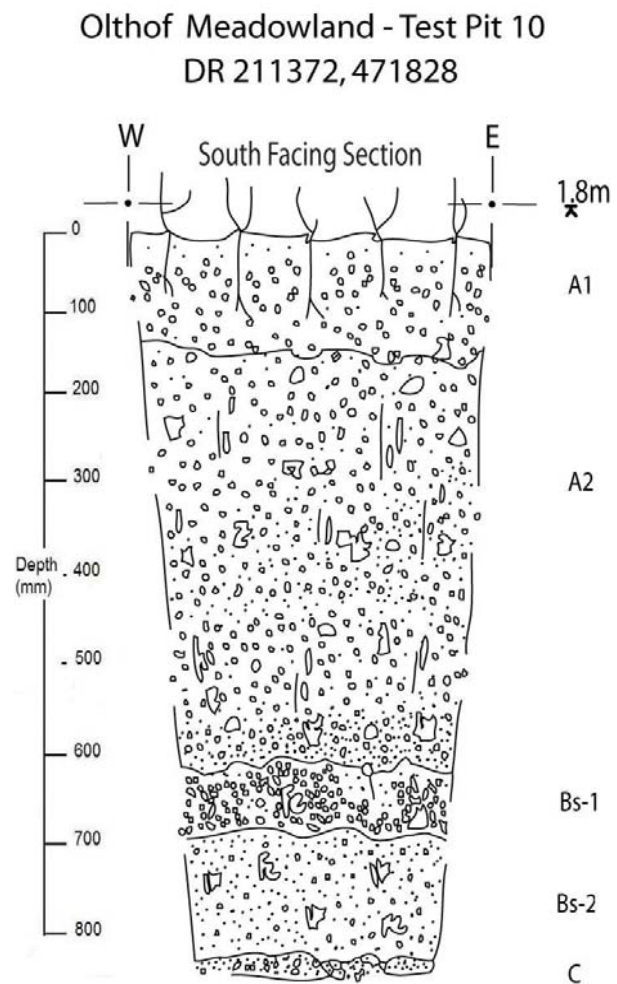


Figure 61, Section drawing and photograph of soil horizons in Olthof meadowland in test pit 10

Context	Location		Description	Range of Depths (mm)
	Transects	Test Pits		
Ap-1 (Black)	All	1,2,3,4,5, 6,7,11, Arch. Section	Light grey to black (10YR 3/1 to 2/1) coloured silty sand loam with inclusions of fine to medium grained quartz sand fragments 250 – 500µm sub rounded shape, with medium sphericity. Charcoal, 10 – 15% occurrence between 500um to 1mm. Considerably less ceramics than other areas. Sandy laminations throughout, yellow/grey colours with a coarser quartz texture.	150 – 900
Ap-2 (Black)	All	1,2,3,4,5, 6,7,8,11, Arch. Section	Dark grey and black (10YR 3/1 to 2/1) sandy loam (40%, 60%) inclusions of fine to medium grained quartz sand fragments 250 – 500µm sub rounded shape, Increased amount of organic material +60% and charcoal 20 – 25%.	400 – 600
Ap-3 (Brown)	1 and 4	1,2,3,4,5, 6,7,8, Arch Section	Grey to light brownish grey colour (10YR 5/2) silty sand loam (20%, 40%, 40%) quartz sand inclusions sub-rounded and well sorted throughout the horizon. Some charcoal present 10 – 15% mostly degraded to <250µm, no ceramic fragments, organic material has no defining structure.	200 – 450

Table 13, Summary of all anthropogenic soils identified during fieldwork at Olthof farm, the Netherlands

Context	Location		Description	Range of Depths (mm)
	Transects	Test Pits		
A1	1,2,3	9,10	Dark yellowish, brown (10YR 4/4 to 3/4), Sandy silt (40%, 60%) with inclusions of quartz fragments <125µm well rounded and well sorted slight coarsening down profile. High organic content +60% mainly rootlets.	350 – 420
A2	1,2	9,10	Yellow to Light brown coloured (10YR 6/4 to 7/6) Sandy, silt (40%, 60%) with inclusions of quartz fragments 125 – 250µm well sorted, fine grained sub-rounded shape 20 – 30%. Fe increase seen through darker orange staining	210 – 400
Ah	All	/	Very distinctive dark reddish grey (2.5YR 3/3) to dark yellowish brown (10YR 3/4 to 3/6) coloured silty sand (20% to 80%) with inclusions of fine quartz fragments less than 125µm few organics and heavily leached in places. Typical remnant podzolic soil. Present in test pit 7 as a fill of a treebowl.	100 – 200
H	2	/	Very dark grey to black (10YR 3/1 to 2/1) Silty clay loam (40%, 20%, 40%) Very high organic content +85% with large woody fragments and peaty inclusions. Quartz sand <125mm at <10%.	200
Bs-1 & 2	1	10	7.5YR 6/8 Reddish yellow colour Silty clay (30%, 70%) with Very heavily iron rich silty clay deposit with inclusions of Fe lumps 5 – 10mm at 10% occurrence.	200 – 250
B1	1,2,3,4	All	Varies in colour from light grey (10YR 7/1 to 6/1) to yellow and yellowish brown (2.5YR 7/8 and 10YR 6/4 Silty sand (30%, 70%) with a high mineral content especially fine grained quartz (possibly from aeolian origin) between 250 – 500µm with patches of darker yellow/orange coloured iron sand +500um. Quartz sub rounded shape with medium sphericity.	200 – 400+
B2	1,3	/	Colour from light grey and grey (10YR 7/1 to 6/1) to light brownish grey (10YR 6/2) and areas of white (10YR 8/1) with a Silt sand (20%, 80%) texture and very small clay quantities. Quartz fragments +60% , well sorted and size range 250 – 500um. With sub-rounded to sub-angular shape.	200 – 400+
C	/	7,10,11 Arch Section	Light grey to light yellowish brown (10YR 7/1) to (10YR 6/4) medium to fine sandy gravel (70%-30%). Medium to well sorted with sub-rounded to rounded quartz fragments. No distinguishable organic inclusions. Natural Coversand horizon with fine terrace gravels.	250+

Table 14, Summary of all natural soils identified during the fieldwork at Olthof farm, the Netherlands

3.7 DISCUSSION OF ANTHROPOGENIC SOILS AT OLT Hof

A summary of the soils at Olthof shows that there are distinct textural differences between the natural and anthropogenic horizons (Tables 13 and 14). There is also a distinct variation in the distribution of anthropogenic soils at each of the four landuse areas is summarized in figure 62. The deepest anthropogenic soils are in the garden area with a sequence of over 1.5m. In the arable areas the depths of soils are much shallower and less distinctive with the sequence ranging from 600mm to 1000mm and a progressive shallowing away from the garden area.

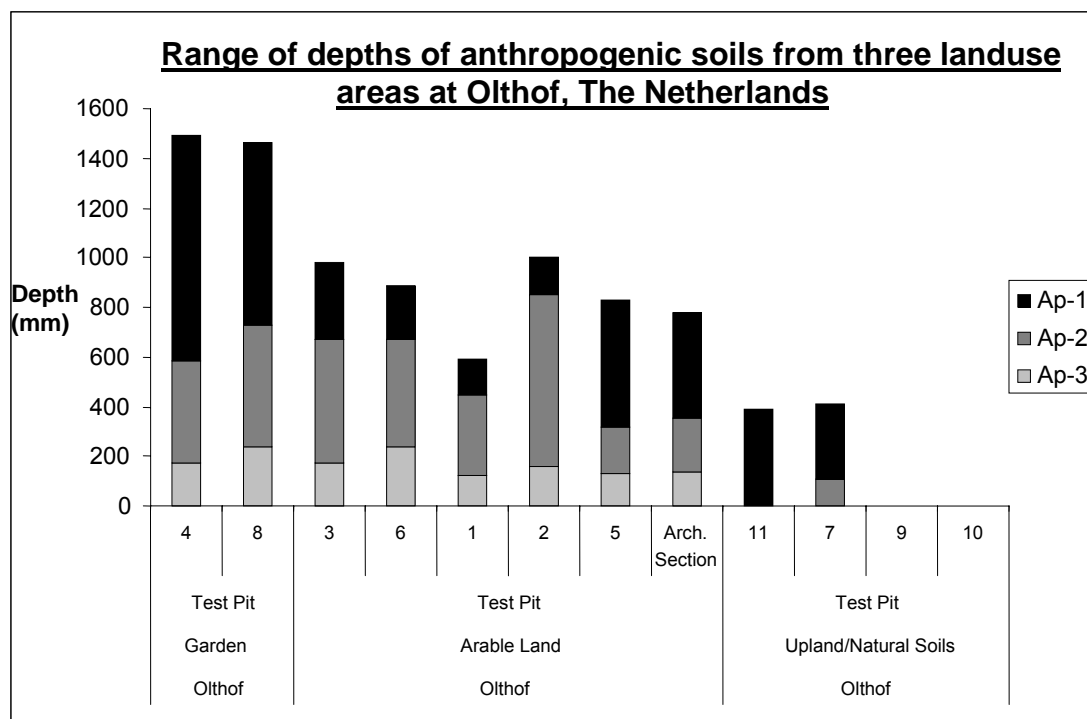


Figure 62, Range of depths of anthropogenic soils from different landuse areas at Olthof

The shallowest soil sequence is in the old heathland area with a distinctive heavily disturbed plaggen soil developed since the reclamation of the heath into farmland. In each of the areas the Ap-1 horizon ranges the most from 730mm to 910mm in the garden, to 150mm in the arable areas. In test pit 5 and the archaeological section the Ap-1 horizon is unusually deep from 430mm to 510mm and this may be due to the movement of soil down the slope to the north west of the farmstead or perhaps as a direct result of an

increase in manuring in this particular arable area, but the auger survey shows a general shallowing of anthropogenic soils away from the farm centre.

The depth of the Ap-2 horizon is far more uniform across the different landuse areas ranging from 410mm to 490mm in the garden and 435mm to 500mm in the close arable areas. Further away from the farm the arable area has a considerably shallower Ap-2 horizon ranging from 190mm to 210mm and a remnant horizon (110mm) in test pit 7. An unusually deep layer of Ap-2 is present in test pit 2 and this may represent an area of increased manuring just outside the central area of the farm. The Ap-2 horizon in the cores taken around the test pit (12, 13 and 23) has a considerably shallower depth from 260mm to 325mm suggesting that the sequence in test pit 2 is abnormal. The shallowest of the anthropogenic soils found is the Ap-3 horizon and it ranges from 130mm to 240mm across all the landuse areas with the deepest horizons in the garden and inner arable area and 130mm to 160mm in the outer arable area.

	Dercon et al., (2005)	Pears (this volume)
Area of study	Olthof farmstead, the Netherlands	Olthof farmstead, the Netherlands
Depth of Anthropogenic soils	Present Landcover Pasture – 1350mm Arable – 860mm Woodland – 760mm	Landuse Areas Garden – 1477mm Inner Arable land– 815mm Outer Arable land – 775mm Natural soils – 400mm
Colour	Dark brown, dark grey brown to black	Dark brown, grey, black
Texture	Silty sand loam	Sand loam to silty sand loam
Inclusions	Large quantity of quartz mineral with some organic and carbonised particles	Charcoal, black amorphous particles, sandstone, peaty organics and some ceramics

Table 15, Range of anthropogenic soils found from two studies at Olthof farmstead

The analysis of the anthropogenic soils at Olthof was initially conducted as part of a larger pan-European analysis of anthropogenic soils (Dercon et al., 2005) it allows direct comparison of the distribution of the soils in the two studies, summarized in Table 15.

Both studies at Olthof reveal enhanced depths of anthropogenic soils. Dercon et al., (2005) focussed upon three different existing landuse areas and the deepest plaggen horizon was located in the pasture area which correlates most closely to the depth of soils found in the garden. The similarity in the range of depths from the garden outwards suggests that the area used for arable farming was much larger and was extensively manured. The evidence from the current work suggests that even marginal upland areas were stripped of their natural heathland soil, probably for organic manure components, and arable areas developed in their place, some of which are still utilised to this day.

Authors (Date)	Anthropogenic soils	
	Site	Depth
Pape (1970)	Eibergen, Gelderland, Netherlands	Black plaggen – 1350mm Brown plaggen – 750mm
Eckelmann (1980)	Osnabruck, Germany Vorden, Quackenbruck, Osnabruck	plaggen soil – 650mm plaggen soil – 500mm plaggen soil – 1000mm
Blume and Kalk (1986)	Sylt, Denmark	Black plaggen – 580mm
Elwert and Finnern (1993)	Seeth, Schleswig-Holstein, Germany	Black plaggen – 660mm
van Smeerdijk et al (1995)	Valthe, Drenthe, Netherlands	Test Pit 1 – 380mm Test Pit 2 – 480mm Test Pit 3 – 600mm
van Mourik (1997)	Weert, Limburg, Netherlands	Black Plaggen – 750mm

Table 16, Anthropogenic soils in mainland Europe

Distinct similarities are also seen between the colour, texture and inclusions found in the two projects, showing overall consistency in the range of anthropogenic horizons found across the farm. On a larger scale the anthropogenic soils identified at Olthof fit into an ever increasing database of sites analysed for the range and distribution of anthropogenic soils (Table 16).

The extensive occurrence of plaggen soils across north west Europe shows that anthropogenic enhancement led to deepened soil horizons. In Flanders and North Brabant mean plaggen depth was between 700mm to 1000mm (Pape, 1970), but more detailed field sampling of the plaggen soils in Eibergen found distinctive areas of very deep black plaggen soils of over 1350mm close to the settlement centre and very similar depth to the garden soils found at Olthof. Pape (1970) also identified a brown plaggen soil which was shallower than the black plaggen soil, but thicker than the brown coloured anthropogenic soil found at Olthof, possibly because of a different rate of manuring and less post burial mixing and truncation. A range of anthropogenic soils were analysed across a number of sites in Europe. In Germany the plaggen soils were analysed in three landuse areas and ranged from 500mm to 1000mm in depth. At Vorden the plaggen soils were located upon the dune sands and a truncated podzolic soil and were in excess of 650mm and a black colour. At the two other sites sampled at Quackenbruck and Osnabruck the anthropogenic soils ranged from 500mm to 1000mm but had much lighter dark grey brown to brown colour and were located upon river loams and loess loams (Eckelmann, 1980). These soils are similar to the brown plaggen soils at Olthof and occur away from the centre of settlement and towards the marginal areas of arable farmland whereas at Vorden the black plaggen soil appears to be much closer to a farmstead centre. Another site sampled on dune sand and an old podzol soil at Seethe, Germany also revealed a black plaggen soil with a 660mm deep stratigraphy (Elwert and Finnern, 1993).

At Valthe in Drenthe province three soil profiles were excavated across the settlement at a number of landuse areas (van Smeerdijk et al., 1995). The profile closest to the settlement centre contains the deepest sequence of two distinctive black to very dark brown plaggen soils with many

anthropogenic inclusions including pottery, brick and charcoal fragments. Further away from the centre of Valthe the sequence shallows from 480mm to 380mm and are typically black to dark greyish brown with less anthropogenic inclusions (van Smeerdijk, et al., 1995). This pattern mirrors the change in depth found at Olthof and historical geography suggests that the areas with the deeper soils sequences occur in the area of the oldest field systems dating from the early Middle Ages, but the majority of the black plaggen soil was deposited from A.D.1450 onwards (Spek, 1996).

The soils found at Olthof farm mirror the anthropogenic soil sequences found on the site through the analysis by Dercon et al (2005) and on a wider regional context from analysis at other Dutch site and sites in Denmark and Germany (Eckelmann, 1980; Blume and Kalk, 1986). Two distinctive anthropogenic soils were found including a brown plaggen soil and a more extensive black plaggen soil representing two distinctive manuring stages.

4 STUDY SITE 4: CAHERATRANT, DINGLE PENINSULA, IRELAND

4.1 INTRODUCTION

Caheratrant is a dispersed settlement located on the southern side of the Dingle Peninsula in County Kerry, Ireland (G.R. V3735, 9826) (Figs 63 and 64). The parish, of the same name, is situated on a smaller peninsula with Ventry Harbour to the north and Dingle Bay to the south. Caheratrant parish is surrounded by four other parishes: Kilfarnnoge to the east, Kilvickadownig and Caherbullig to the west and Ventry to the north. Raheen, a fifth parish, splits Caheratrant in two creating two distinct outliers. The northern part is composed of lowlying salt marsh flooded at high tide and reclaimed farmland to the west of a raised seabank and road.

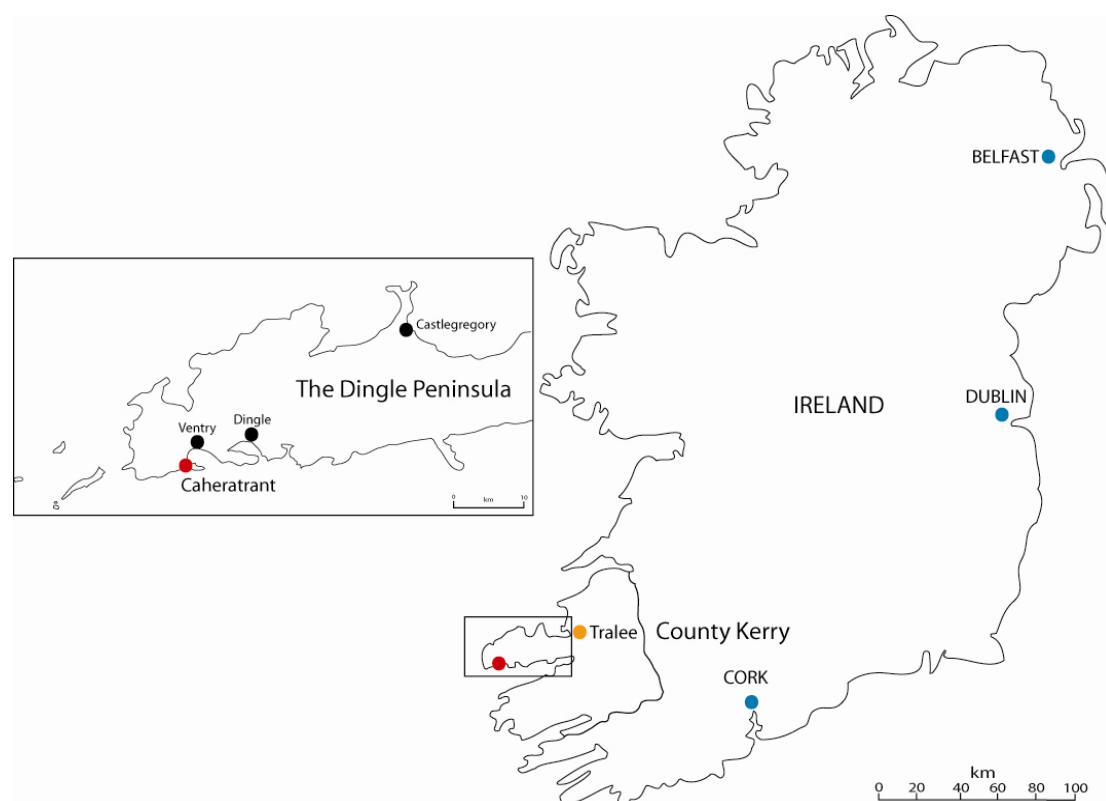


Figure 63, Map of Ireland the Dingle Peninsula and the field site at Caheratrant

Presently the area is very sparsely inhabited, and the majority of the total population live in Caheratrant located in the southern part. The village is

composed of four farms located around a small nucleus of temporary holiday homes and several isolated properties. The orientation of parishes around Ventry Harbour and others on the Dingle Peninsula reflects the need to share the calcareous sand placed on farmland to decrease soil acidity levels, and within Caheratrant the farmsteads have very distinctive land ownership patterns which are orientated as strips between the beach and the cliffs.



Figure 64, Location map of Ventry Bay and Caheratrant on the southern edge of the Dingle Peninsula, County Kerry, SW Ireland (1:50,000 Ordnance Survey Ireland 2005)

4.2 GEOLOGY AND SOILS OF THE DINGLE PENINSULA

The Dingle Peninsula has over 140 million years of geological history expressed through a number of lithologies ranging from the Silurian to the Carboniferous periods (Fig 65). As a general trend the oldest rocks are part of

the Dunquin Group and are located towards the south and west and consist of distinctive marine fossiliferous limestone and a number of volcanic rhyolites both of the Wenlock (428 – 421Ma) and Ludlow epochs (421 – 414Ma) (Holland, 1969).

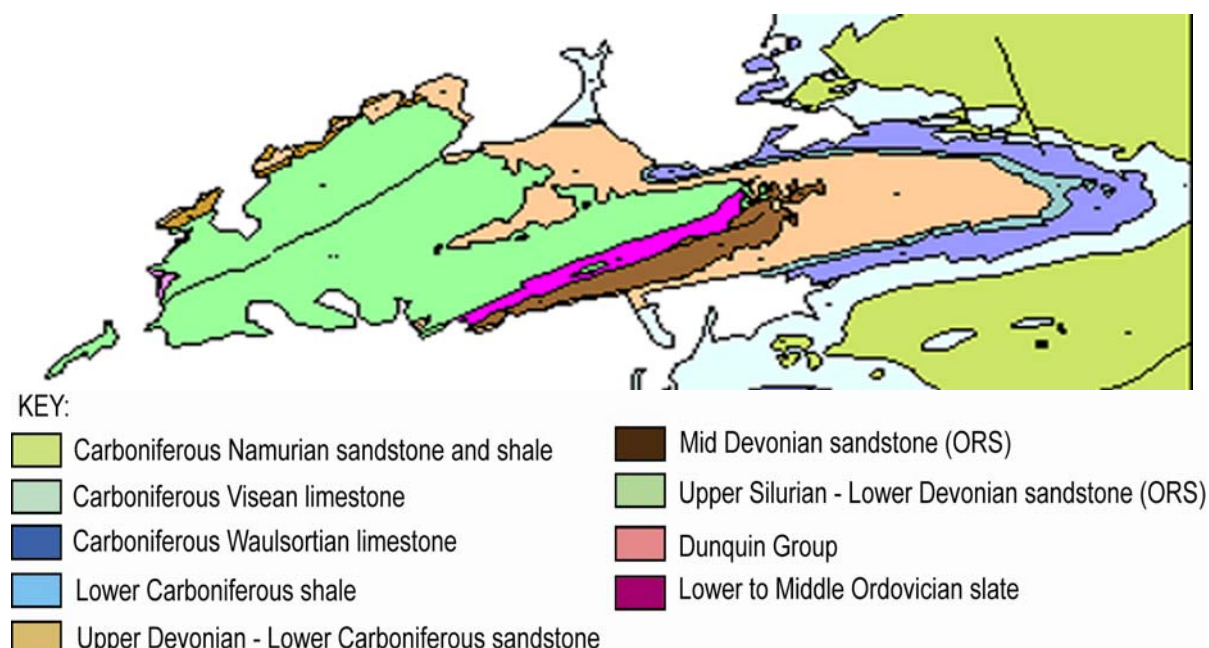


Figure 65, Geological map of the Dingle Peninsula, County Kerry, SW Ireland (The Geological Survey of Ireland – Sheet 20 Bedrock Series 1:100,000, 2007)

The Silurian rocks were heavily deformed and lifted by the Acadian transpression which also led to denudation of the Caledonide mountains within mainland Ireland and the deposition of the Dingle Group, a mudstone, sandstone and coarse conglomerate rock. The deposits are characteristically red/orange coloured rocks and make up the majority of the peninsula including Mt Brandon (953m), the highest peak on the Peninsula, and 4th highest in Ireland. There has been great debate as to the age of the Dingle Group around the contact area with the Dunquin Group as many of the contacts are heavily faulted or unconformable (Todd et al., 1988) but generally the lithostatigraphy is of Early Devonian age consisting of the lower Old Red Sandstone (408-387Ma). Further uplift in the late Devonian led to the reactivation of many faults and the erosion of Middle Devonian (387-384Ma) rocks leaving an unconformity with the Upper Devonian rocks (374-360Ma).

These consist of upper Old Red Sandstone and are located towards the eastern end of the peninsula. The youngest rocks are of Lower Carboniferous age (360 – 320Ma).

Soil Type	Topography	Altitude	Drainage	Vegetation	Geology
Brown Podzolic	Rolling	76m O.D.	Well Drained	Short Grassland	Till, mixture of ORS, shaly sandstone and shale
Brown Earth	Gently Rolling	50m O.D.	Well Drained	Short Grassland	Till of ORS & Carboniferous Limestone
Grey Brown Podzolic	Gently Rolling	50m O.D.	Well Drained	Short Grassland	Till of ORS & Carboniferous Limestone
Lithosols	Summit of mountains	+360m O.D.	Excessively	Heather Only	Old Red Sandstone
Blanket Peat	Mountainous	+280m O.D.	/	Heather and Grass species	Glacial Till
Peaty Podzol	Very hilly, near mountain summit	290m O.D.	Excessively below peat	Heather, Purple Moor Grass, Deer Grass	Old Red Sandstone

Table 17, Natural soil sequences on the Dingle Peninsula (Adapted from Gardiner and Radford, 1980)

These consist of distinctive marine limestones and are located at the very eastern periphery as well as in the Magharee and Inch peninsulas. Around 270 million years ago the Variscan orogeny once again uplifted and folded the rocks of the peninsula to their current orientation (Price and Todd, 1988). During the Pleistocene the peninsula was covered by ice from the Elsterian/ Munsterian glaciation, and even after the ice had retracted from the rest of mainland Ireland, an ice-mass remained over Cork and Kerry until the end of the Midlandian advance. The ice severely scoured the landscape and deposited a poorly sorted sandy calcareous till across the peninsula and upon which shallow soils developed. There are a number of natural soil types present on the Dingle peninsula (Table 17) which are located in very particular geographic locations. The majority of arable soils are Brown Earths and Brown Podzolics on a range of underlying geologies. In upland, mountainous areas the soils are shallower and dominated by large rocky fragments (Lithosols) and in lowland areas where drainage is poor thick peaty podzols

are present which allow heather and in recent years coniferous woodland to grow. The land cover on the peninsula is dominated by mixed arable and small areas of pastoral land. In the upland areas are moors and heathland, marked as light green, and patches of peat soils and estuarine deposits (Figure 66).

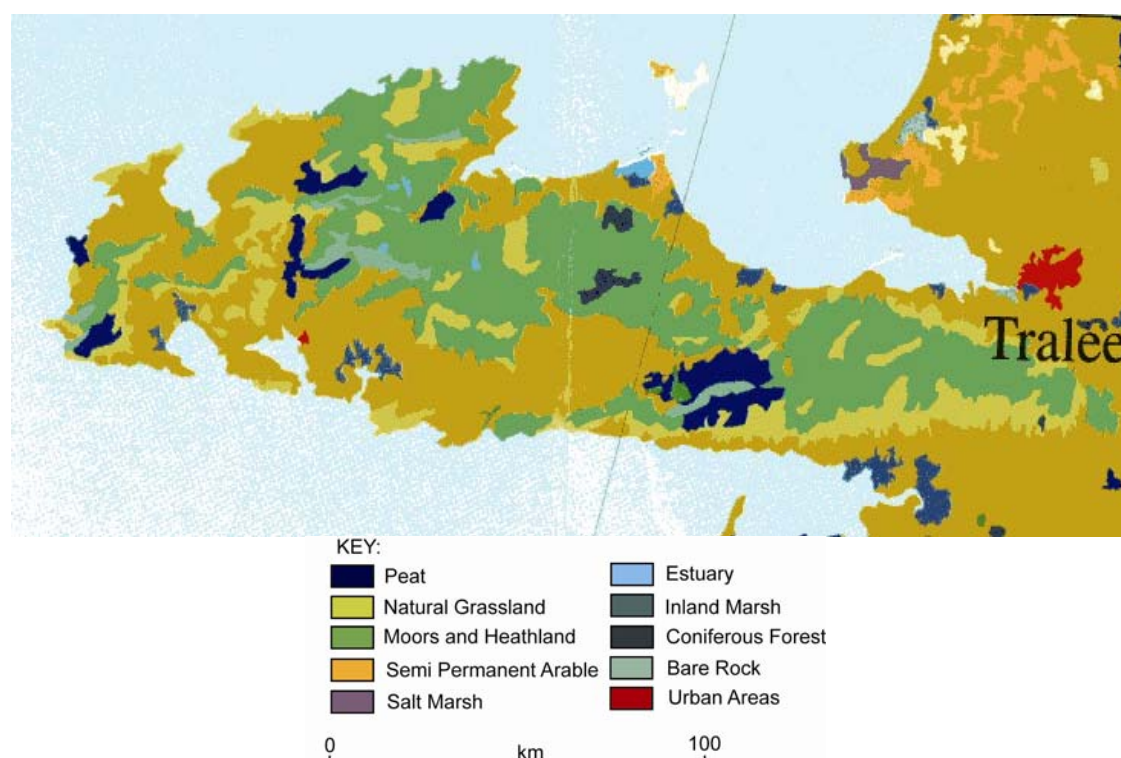


Figure 66, Modern land cover map across the Dingle Peninsula, County Kerry, SW Ireland (CORINE Land Cover Ireland 1:500,000 1990)

4.3 THE HISTORY AND ARCHAEOLOGY OF THE DINGLE PENINSULA

The Dingle Peninsula has a very unique and complex history but there are distinctive gaps in the archaeological record due to a lack of investigation. The Dingle Peninsula was initially inhabited in the Mesolithic period c.6000 by hunter gatherers as shown by excavations at Ferriters Cove (Woodman et al., 1984; 1999). Between c. 4000 – 2000BC there is a distinct lack of Neolithic evidence and it had been suggested that the Peninsula was not occupied during this period, but palynological research has shown that there is considerable human settlement and cereal cultivation occurring 3895 – 2965

BC (Lynch, 1981). A survey conducted by Mitchell (1989) on Valencia Island identified eight pre-bog field systems interpreted as Early Bronze Age (2000 – 1400BC) and thought to represent farmsteads and settlements as well as a very high number of ritual and funerary monuments in the form of standing stones and cairns marking large tomb sites. Settlements increased in size during the Iron Age (500BC – A.D. 400) and became more nucleated. On the Dingle Peninsula promontory forts located on the coast as well as inland on important tribal boundaries indicate increased competition for limited resources. Archaeological evidence of settlement and human activity increases markedly in the Early Christian Period (5th to 12th Century A.D.) with over 450 ringforts, high status dwellings, as well as the atypical Dingle Peninsula 'Beehive' huts or *Clochauns*, a lower status structure. Settlements developed slowly until the Norman colonisation in A.D. 1177 and were relatively unaltered by Viking raids in the 10th and 11th centuries who most likely used the peninsula as a trading point and whose legacy today remains in many of the place names present in the villages (Sections 4.3.1 and 4.3.2). The Normans did not have any direct effect on the peninsula until at least A.D. 1200 when incursion into Kerry brought numerous castles and tower-forts with large areas of land controlled by the 'landed-class'. Around the Ventry area of the Dingle Peninsula, the 'Knights of Kerry', a small branch of the powerful Fitzgerald family, founded the castle at Rahinnane and made it their chief seat in the area.

A combination of Viking trading and sub-settlement and Norman colonial actions had developed the main town of Dingle into a thriving, well defended site. The town, the largest on the Peninsula, had clearly marked burgage plots still visible today, 3 castles and fortified residences and a number of late medieval churches. The majority of the population lived in small villages and settlements and worked the land, a process which continued until very recently but unlike mainland Ireland the landscape has been very well preserved to permit the study of landscape and agricultural history.

4.3.1 THE HISTORY OF CAHERATRANT

The name Caheratrant derives from the prefix “caher” meaning fortified place and the personal family name “Trant” which can be traced back to the Dingle Peninsula for over 800 years. There are records of people with the name Trant in the Barony of Cocaguiney, thought to derive from Danish settlers in south west Ireland but they are certainly in place by the Norman invasion in A.D. 1171 (O'Laughlin, 1999). The first documentation for a castle in the Caheratrant area comes with the crenulation documents for Phillip Trant to build a fortified inhabitation in A.D. 1272, but its location has been lost for many years and no archaeological work has been conducted to locate it, however it may well have taken the form of a classic Irish tower castle as seen at Rahinnane. By the late 16th century certain members of the Trant had made names for themselves including Garret Trant a renowned merchant in the 1580s, and Richard Trant, the first Sovereign under the Dingle charter in A.D. 1585 (O'Laughlin, 1999).

The population of Ventry Parish in A.D. 1659 was 149 which was 13% of the total population of the Barrony of Corcaguiny (1181), or the area covering the Dingle Peninsula today. One particular member of the Trant family is noted as a “tituladoc” in the A.D. 1659 census of Ventry Parish. This position was given to a principal person of the parish with land and title and possibly living in Caheratrant. The data indicates that at this period the settlement had one of the highest populations in the parish (16%), larger even than Ventry, suggesting prosperity and rapid growth. Wealth and power in the vicinity may also be postulated by the lack of English in the parish. Rural areas were on the whole left alone by Cromwell's increasing English military presence in Ireland but Dingle and other important trading venues were the places selected for the “plantation of the English and Scots” between A.D. 1556 to 1620.

The development of the settlement is lost from the records for the next 150 years, but prosperity declined sharply with the onset of the devastating Irish Potato Famine of 1845 – 1850 with over 32,000 people starving to death and over 55,880 emigrating to Europe and the Americas from county Kerry

alone. Alongside the famine and emigration there are also records of a number of evictions which took place in the parish and were published in English newspapers leading to semi to total desertion of whole farms and settlements. In January 1849 the Times stated:

‘From the lands of Cahirtrant, the property of Lord Ventry and in a parish whence that nobleman's title is derived, 36 families, comprehending 188 souls, have been expelled’ (“Evictions in Dingle” London Times 6th Jan 1849)

However, Caheratrant farm continued to be worked and by the late 19th century, had changed ownership to the O’Shea’s who own the farm to this day. Detailed marriage records from the mid 19th century show that the family are mostly farmers and have grown to a considerable size with two sons and a daughter married in the space of three years. The settlement at Caheratrant has increased in size also and at the same time of the O’Shea marriages there are at least five other families with various occupations.

4.3.2 MAP EVIDENCE AND FIELD SIZES

Irish Ordnance Survey maps of the area drawn in the early 1960s clearly show the field systems had a range of sizes and orientations. Caheratrant parish has a distinctive nucleated/clustered form of buildings in the north of the area with a number of smaller isolated farmsteads further south but situated roughly on the 20m contour, using the slope to protect properties from the prevailing Atlantic wind from the south west. A small manorial farm called Toberkievan, located on the edge of Ventry bay is also present but its farmland has been considerably reduced by cliff erosion. In Kilfarnoge parish there are also several small farmsteads but the main settlement site is the large manorial farmstead of Coon. In Raheen there are no occupation sites except a small manorial farmstead called Balbunie located near the beach.

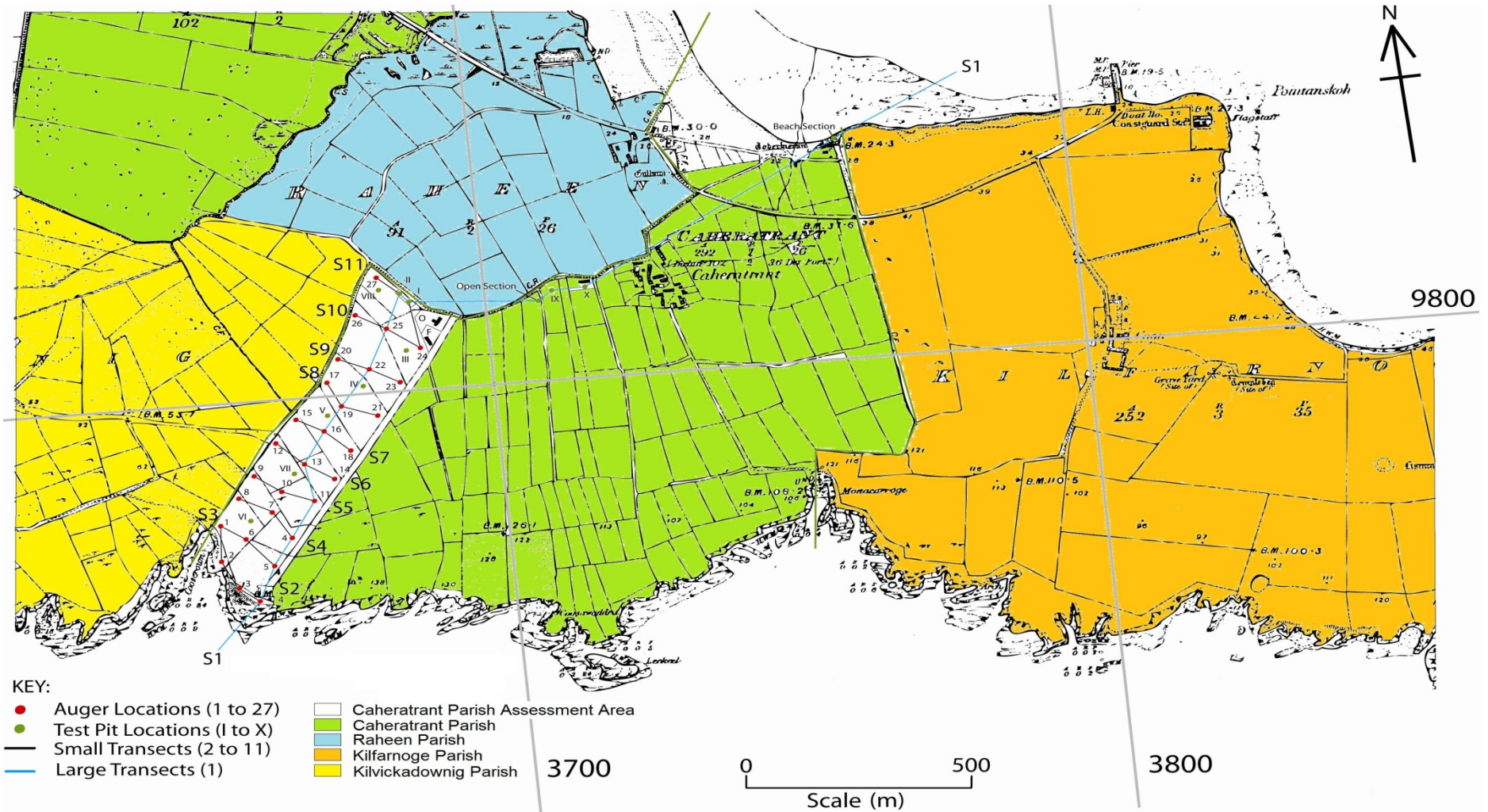


Figure 67, 1963 Ordnance Survey map of Caheratrant illustrating the variations in field sizes between neighbouring Kilfarnoge and Raheen (1963 Ordnance Survey map of the Dingle Peninsula, County Kerry Sheet)

The field systems in each of the parishes are very different and reflect a range of land uses in the past, as illustrated in figures 67 and 68 and appendix 5. In Caheratrant, the parish contains very distinctive elongated, rectilinear fields, orientated north-south between the upland and Ventry Bay. In the assessment area the fields have a very distinctive north west to south east orientation and the overall field size is slightly larger (average 2.01 acres) compared to an average of 1.24 acres in the parish as a whole.

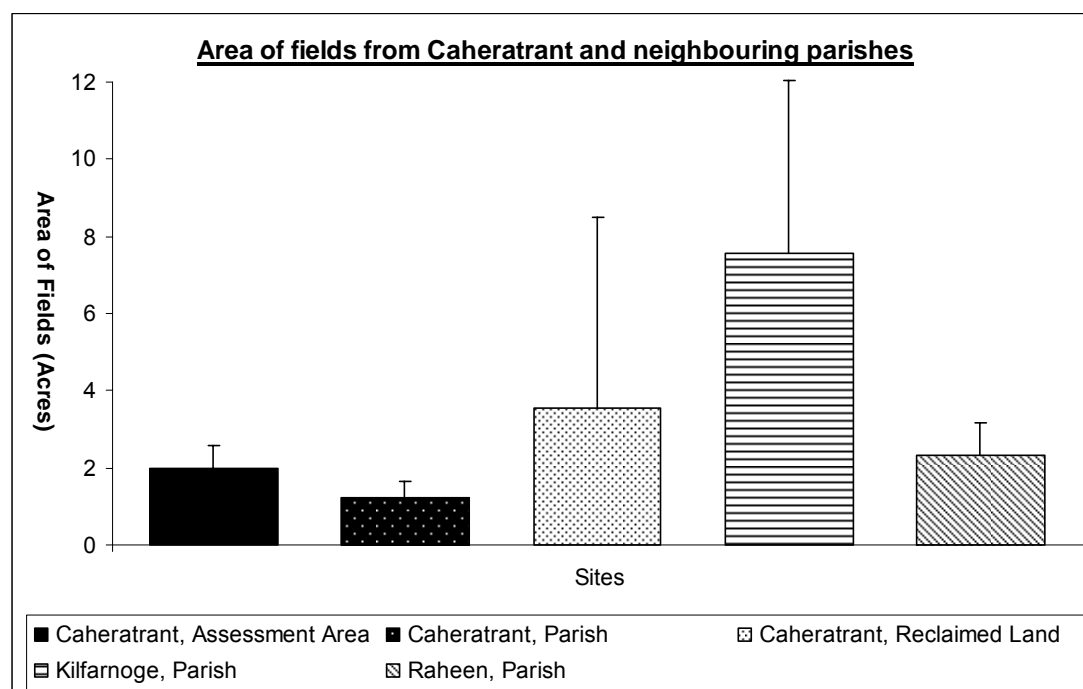


Figure 68, Average area of fields from Caheratrant and neighbouring parishes (Error bars show 95% of the mean)

In the northern area of the parish where a large quantity of reclaimed land is located, fields are considerably larger averaging 3.55 acres, possibly because the land was divided for grazing and for coniferous tree plantations and not for arable land. Certainly the quality of the land is much lower than around the settlements and the map shows that many of the fields have poor quality peaty marsh land. The field sizes in the surrounding parishes of Kilfarnoge and Raheen are very different and suggest different landuse histories. In Kilfarnoge the fields are considerably larger than Caheratrant and average 7.57 acres with no clear fixed orientation and a mixture of square and

semi-rectilinear shapes. In Raheen the field sizes average 2.32 acres and have semi-square to rectilinear shape, orientated north west to south east. At Kilfarnoge the landuse has almost always been pastoral and the field sizes and shapes and lack of anthropogenic soils reflect this history. It is not known whether anthropogenic soils are present in Raheen, but there has been considerable expansion and reclamation of old peat and marshlands which are expressed in the larger, regular field sizes and shapes and markings of marshland on the map, suggesting poorer arable areas.

4.4 THE SPATIAL DISTRIBUTION OF SOILS IDENTIFIED IN THE AUGER SURVEY AT CAHERATRANT

Sections 4.4 and 4.5 illustrate the results of the fieldwork analysis conducted in an attempt to answer the key questions outlined in section 1.11, and this was done by utilising the methodologies detailed in section (1.12). The results of the auger survey and test pit excavation revealed a number of soils which have been affected by humans in various quantities as well as a range of natural soils. Section 4.4 also discusses the variety and distribution of amended arable soils found across the settlement by interpreting the transect diagrams and comparing the diversity and range with the natural geographical landscape. 11 transects (sections 4.4.1 to 4.4.5) illustrate the varying distributions of the soils across the farm. The soils are then analysed across three landuse areas; the kaleyard (section 4.5.1), the inner arable land (section 4.5.2) and outer arable land (section 4.5.3). The overall fieldwork results from Caheratrant are discussed in section 4.6 where comparisons with previous work are made.

Twenty seven cores were taken across the farmstead at Caheratrant to investigate the range and distribution of soils (Fig 69) and the results are illustrated in transects 1 to 11. Transect 1 includes the outer and inner arable land and kaleyard of the farm and also the kaleyard of an adjacent farm as well as an abandoned field directly next to Ventry Strand where calcareous sands were collected for byre bedding material. Sections 2 to 11 are smaller sections across the different landuse areas with three across the outer arable

land and upland area (transects 2, 3 & 4), six transects across the arable land (transects 5, 6, 7, 8, 9 and 10) and one section across the kaleyard (transect 11). (Raw data in appendices 6 and 7)

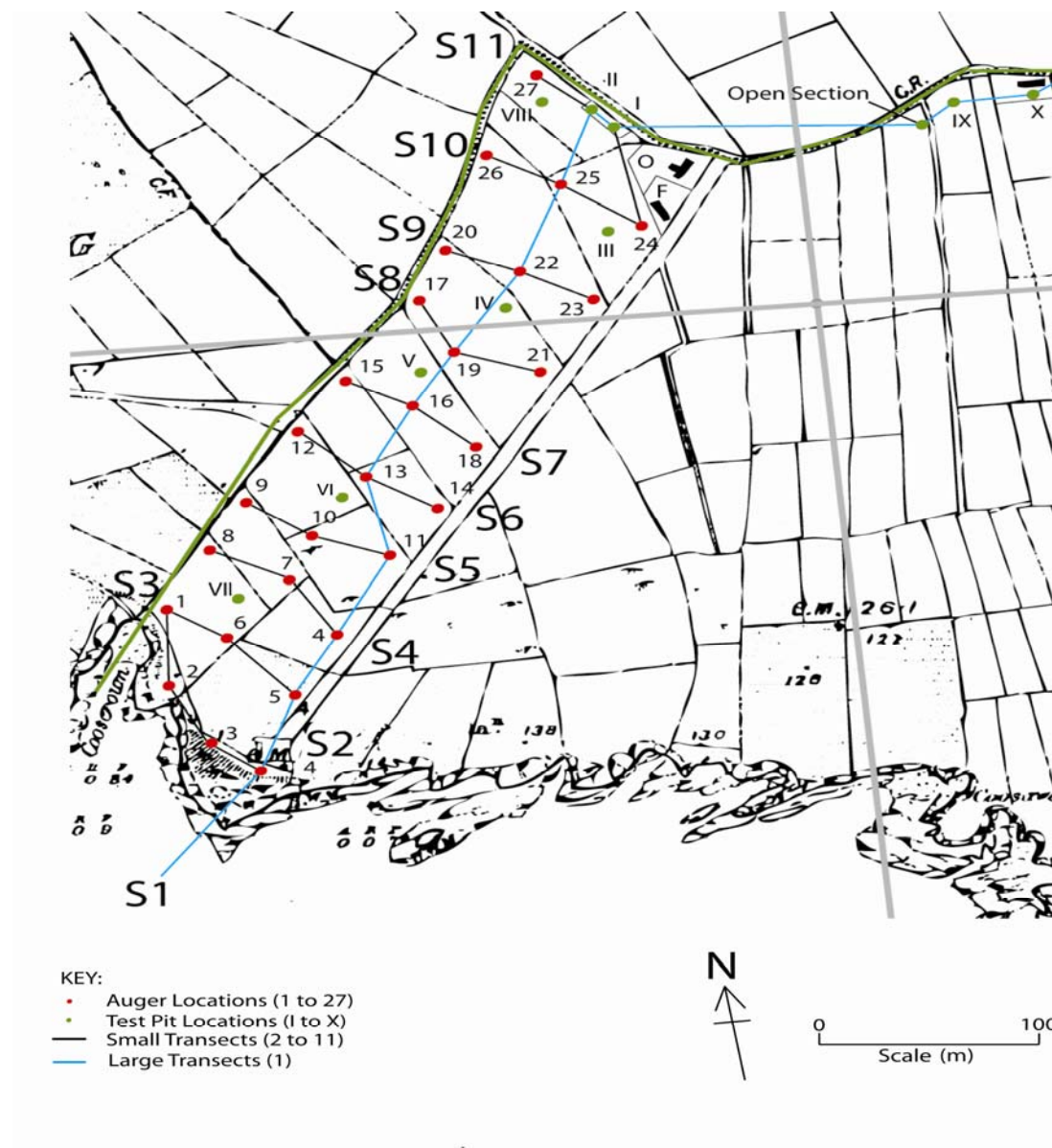


Figure 69, Location map of auger and test pit excavation across Caheratrant (1963 Ordnance Survey map of the Dingle Peninsula, County Kerry Sheet).

4.4.1 TRANSECT 1

Transect 1 (Fig 70) is compiled from the data from 9 cores, 4 test pits and two natural sections in order to show the soil sequence across Caheratrant from the outfield/upland area in the south to the lowland fields next to Ventry Strand. The first three cores (4a, 5 and 4b) contain a very shallow sequence of natural peaty organic soil (H) directly above the natural till (C). Organo-mineral horizons (Ap-1 and Ap-2) first appear in the outfield in core 11 and gradually increase in depth downslope from 305mm to 562mm with particularly deep horizons at cores 16 (550mm) and 25 (562mm). The Ap-1 horizon varies from 170mm at the southern end of the outer arable land and increases to 212mm and 220mm at cores 13 and 16 before rapidly deepening to 350mm at core 19, and then levelling off to 195mm to 220mm in the inner arable land and kaleyard areas. The Ap-2 horizon has a more variable depth ranging from 100mm to 335mm with a gradual increase in depth from the outer arable area to the centre of the farmstead. In the arable area both soils have distinctive dark grey to light brown (10YR 5/2 to 4/2) silty sand loams with some small sub-rounded quartz particles, heavily degraded calcium carbonate particles and small charcoal particles indicating minimal manuring. Closer to the farm the number and size of organic and black carbonised particles increases and the soil colour becomes a darker grey to dark grey brown (10YR 5/2 to 3/3). The transect indicates that between the two kaleyards the organic Ap soil horizons vary little in depth ranging between 545mm to 560mm and thin to 305mm at an abandoned arable area at Ventry Strand where the organic soil is covered by a 180mm deep stony storm horizon..

A natural track section contains 670mm of organic Ap horizons, however, the build up is most likely due to the movement of soil downslope by a mixture of water transportation and ploughing action leading to the development of a headland. The section does however reveal a distinctive organic rich palaeosol which has been buried by the movement and build up of the arable soils.

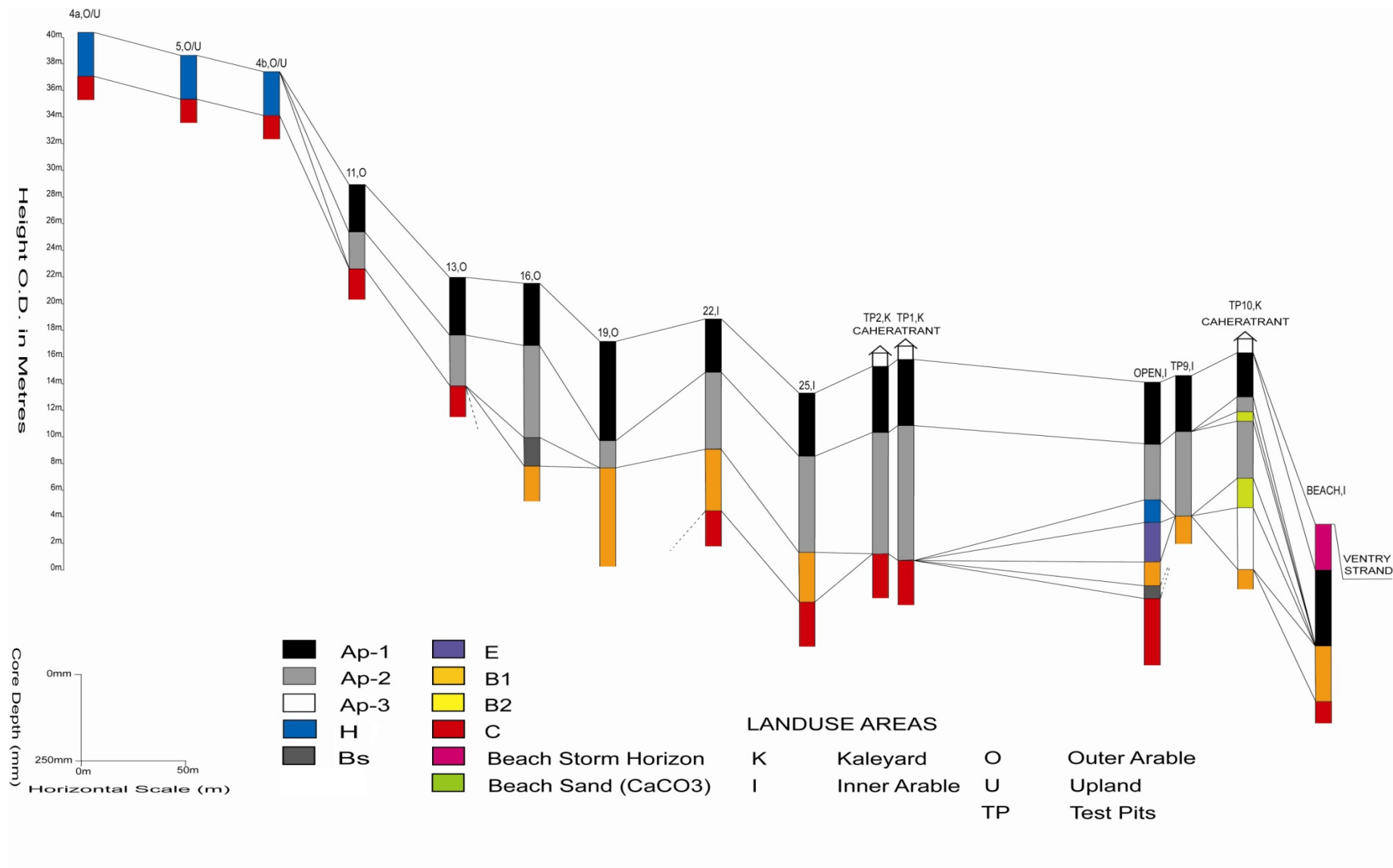


Figure 70, Distribution of soil horizons across Caheratrant farm in transect 1

4.4.2 TRANSECTS 2, 3 AND 4

Transects 2, 3 and 4 (Fig 71 and 72) show the change in soil types from the upland to the outer arable land of the farm and the change from shallow natural peat soils to moderately enhanced organic soils. The most distinctive observation is the change in height from 39.6m around cores 4a, 4b and 5 to 21.7m at core 8 as well as the steep slope angle. In the steep, upland areas the soils present are typically shallow (140mm to 150mm) highly organic peaty soils (H) with no anthropogenic inclusions or amendment, but in the flatter areas shallow organic soils (Ap-1) are present. These range from 80 to 100mm and have a typical loamy sand silt texture and light yellow to brown colour and rare anthropogenic inclusions. A very indistinct, shallow (40mm) Ap-2 horizon is present within core 2 and it consists of a light grey to brown (10YR 5/2 to 5/3) silty sand loam with quartz and some shell inclusions which are well rounded and heavily degraded. Like the Ap-1 horizon though, inclusions of anthropogenic material is rare.

4.4.3 TRANSECTS 5, 6, 7 AND 8

Transects 5, 6, 7 and 8 (Figures 72 to 74) are located across the outer arable area. The slope angle of the fields is significantly shallower and the organic Ap horizons are deeper possibly because of an increase in organic and anthropogenic amendment. At transect five the Ap soil horizons increase in depth from 220mm to 305mm. In cores 10 and 11 the soil sequence consists of an Ap-1 horizon, typically dark grey to light brown colour (10YR 5/2 to 4/2) with a silty sand loam texture and more degraded shell and quartz fragments, but still few visible charcoal and organic fragments suggesting limited input from the farm. The Ap-2 horizon increases from 65mm to 135mm and consists of a light grey to light brown (10YR 5/2 to 5/3) silty sand loam with quartz and calcium carbonate inclusions. Below the Ap soil horizons in core 9 and 12 is a light grey to white (10YR 7/1 to 8/1) leached eluviated silty sand horizon with fine grained quartz inclusions with a thin 40mm iron rich Bs horizon.

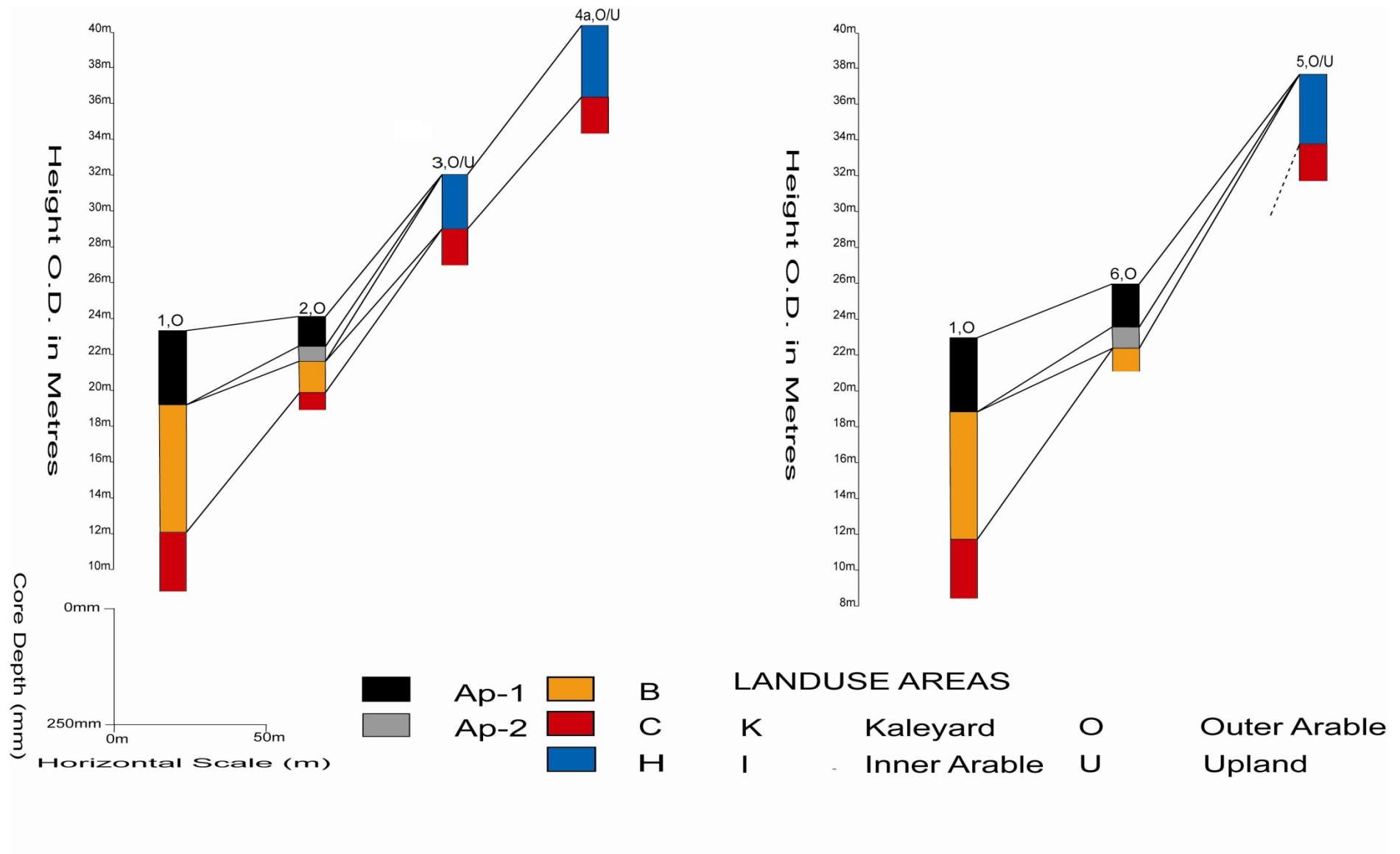


Figure 71, The distribution of soil horizons across Caheratrant farmstead in transects 2 and 3

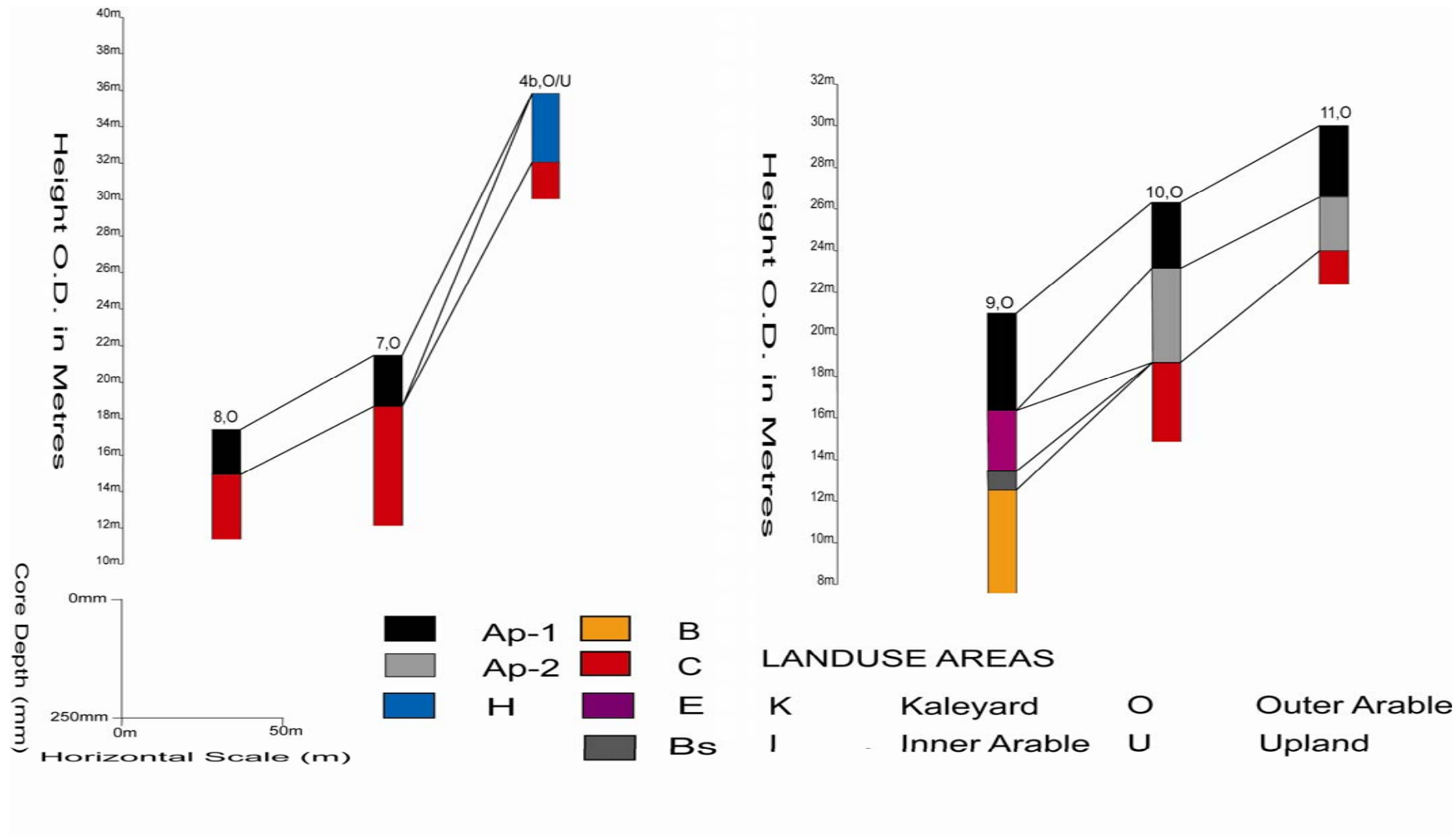


Figure 72, The distribution of arable soils across Caheratrant farmstead in transect 4 and 5

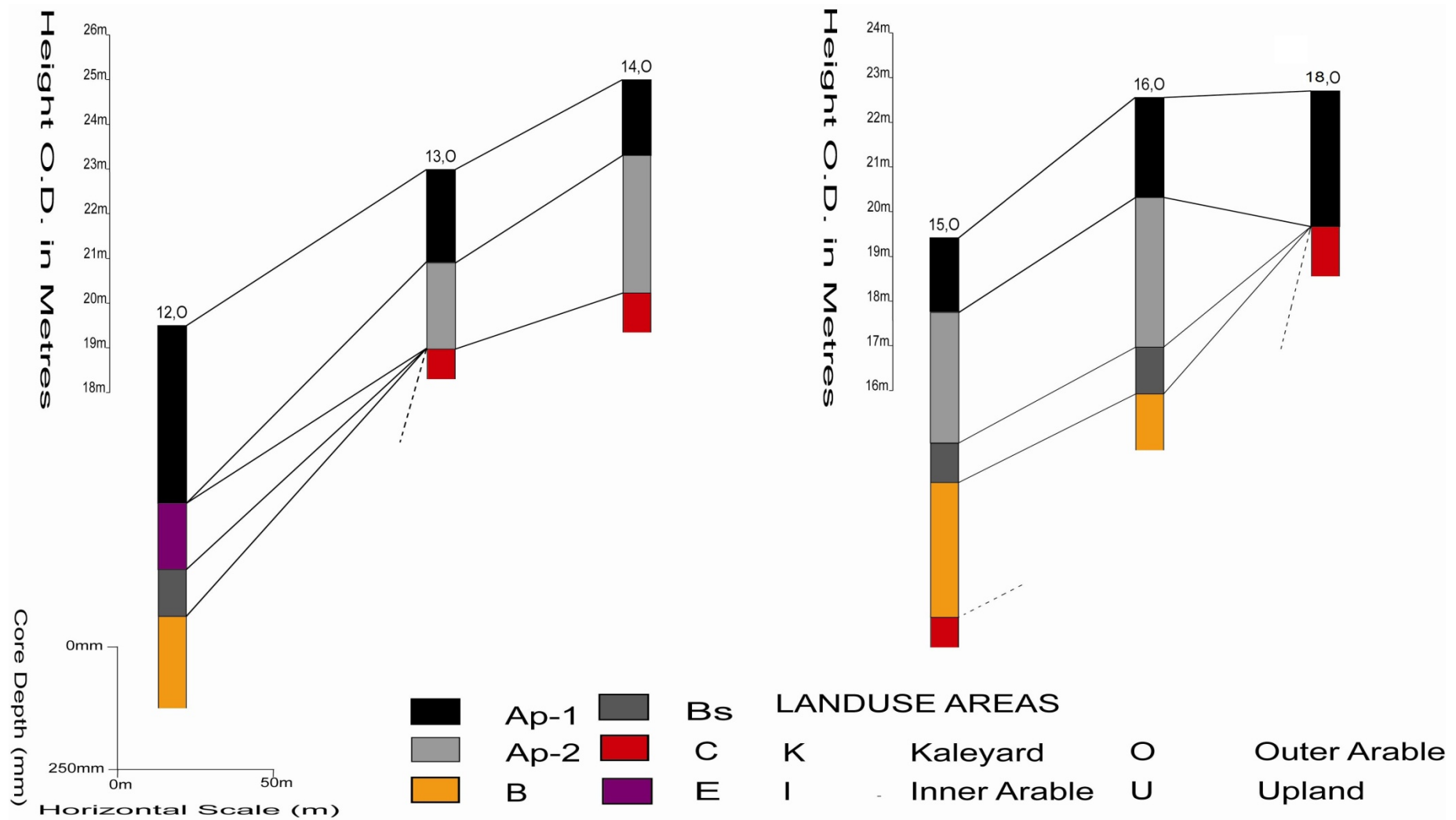


Figure 73, The distribution of soil horizons across Caheratrant farmstead in transect 6 and 7

These soil horizons may be the remnants of an old podzolic soil associated with the organic peat soils seen in the upland area of the site and have been removed through the process of reclamation to expand arable land. Through transects 6, 7 and 8 the Ap soil horizons increase in depth from 300mm to 550mm with steadily increasing anthropogenic inclusions especially charcoal, organic fragments and coarse degraded ceramic fragments suggesting increased addition through a manuring process.

4.4.4 TRANSECTS 9 AND 10

Transects 9 and 10 (Figs 74 and 75) consist of data from 6 cores 20, 22, 23, 24, 25 and 26 and represents the arable landscape around the farm. The organic Ap soil horizons range from 475mm to 525mm but there are also two areas in transect 10 where the soils exceed 560mm towards the north west of the site due to soil movement downslope by water and ploughing processes giving a false indication of soil deepening by anthropogenic addition. However, around the farm the fields are flatter and appear to be deepened as a direct result of manuring. The soil sequence in the area includes an Ap-1 horizon, dark brown to dark greyish brown (10YR 5/1 to 5/3) organic rich silty sand loam with a large quantity of quartz and shell particles and strongly degraded charcoal fragments. In both transects the depth of the Ap-2 horizon increases considerably through transects 5,6,7 and 8 and ranges from 275mm to 300mm, suggesting an increase in the level of manuring and organic addition in the past. The soil has a light grey to grey brown (10YR 5/1 to 5/2) silty sand loam texture with shell and quartz fragments and degraded charcoal and organic particles.

4.4.5 TRANSECT 11

Transect 11 consists of two cores and the data from test pits one and two (Fig 75). The transect shows that the land surface around the two test pits has been increased by organic addition and manuring deepening the Ap-1 and Ap-2 horizons. The Ap-1 ranges from 495mm in core 24 to 580mm downslope in core 26 with a very uniform 530mm to 535mm of Ap soil

horizons in the kaleyard. Of the two soils the Ap-2 horizon shows the greatest increase in depth from other transects, and ranges from 285mm to 310mm whereas the Ap-1 horizon is more consistent and ranges from 215mm to 230mm. Texturally, however, both soils within the kaleyard are considerably different to the soils identified in cores 24 and 26. The Ap-1 horizon is typically a dark grey, brown (10YR 5/1 to 5/2) silty sand loam with a large quantity of sub-rounded to rounded quartz and shell fragments and larger charcoal fragments. The Ap-2 horizon is also darker in colour from dark grey to dark greyish brown (10YR 5/2 to 3/3) with coarse anthropogenic inclusions of ceramics and charcoal fragments. This suggests that the kaleyard areas have had the most anthropogenic amendment and that the level of manuring decreases with distance from the farm.

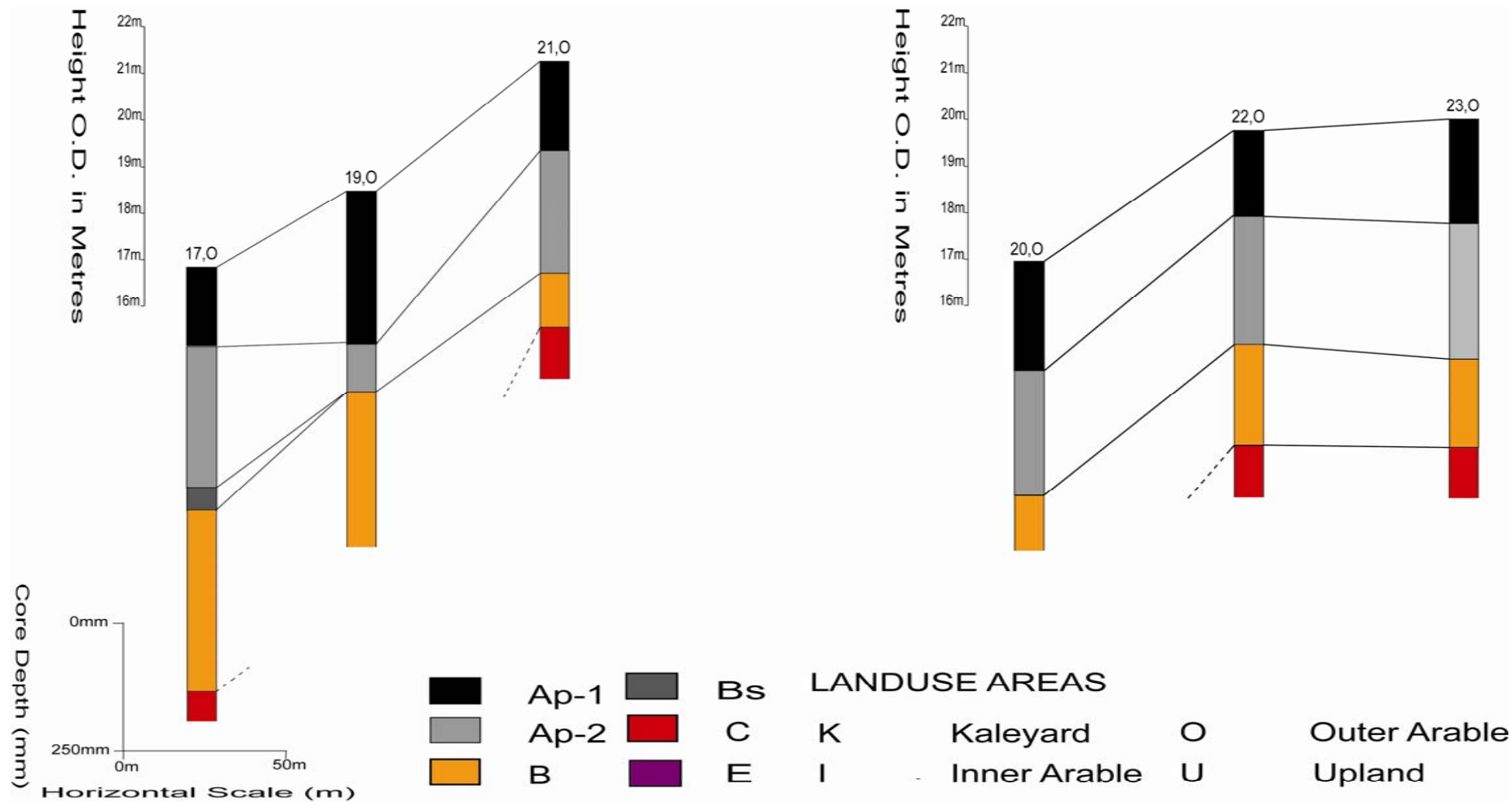


Figure 74, The distribution of soil horizons across Caheratrant farmstead in transects 8 and 9

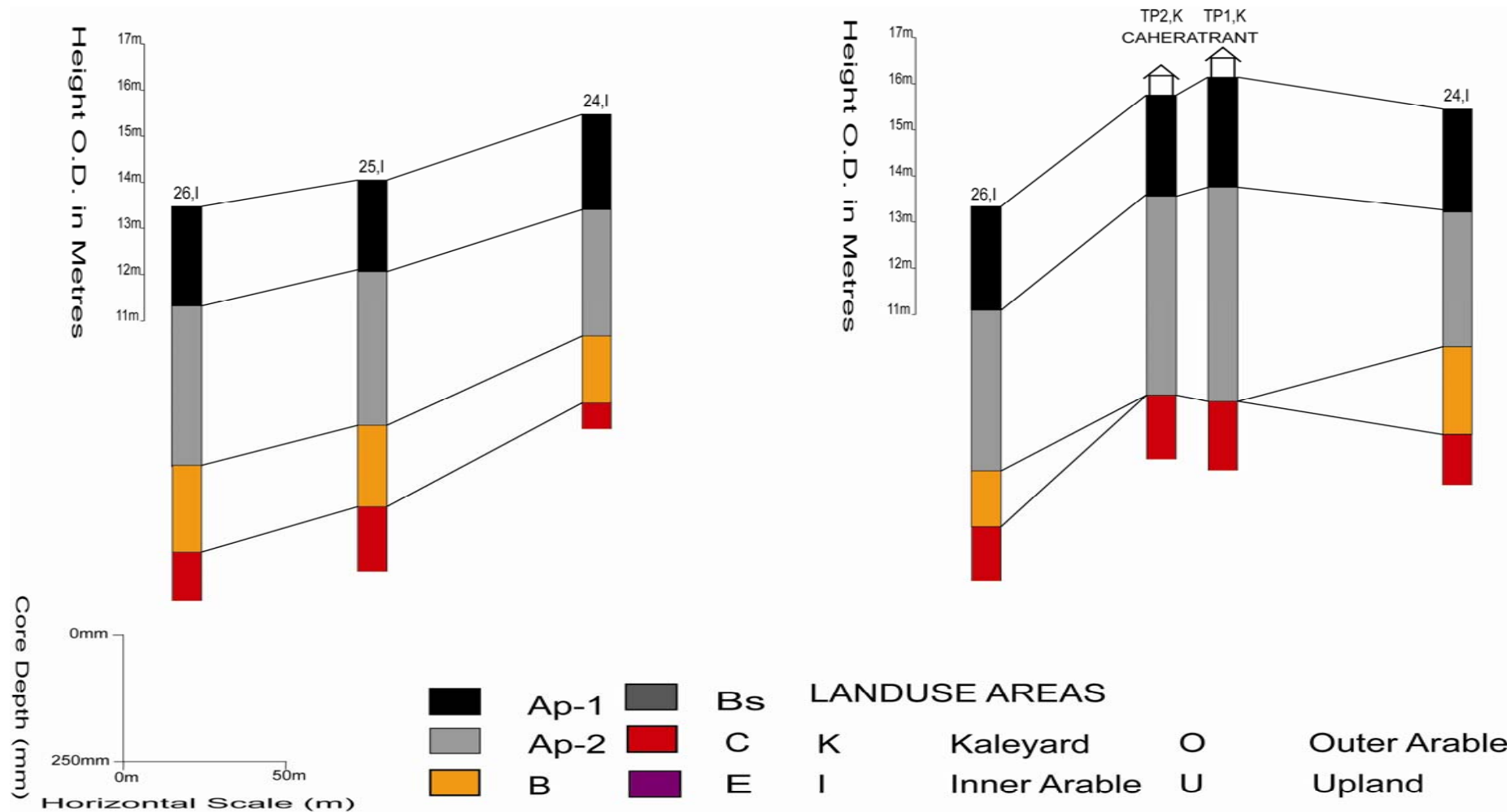


Figure 75, The distribution of soil horizons across Caheratrant farmstead in transects 10 and 11

4.5 DISTRIBUTION OF SOIL HORIZONS ACROSS THREE LANDUSE AREAS

4.5.1 KALEYARD SOILS

Two kaleyards were assessed at Caheratrant to determine the distribution of soil horizons. At Caheratrant farm the old kaleyard has been completely removed and transformed into a small orchard which has since been abandoned and was in no state for sampling. A second kaleyard area was located just to the north west of the farm and it has a distinct elongate shape and measures 25m by 4.5m and had been manured in exactly the same way as the old kaleyard with turf, peat and calcareous sand (Plate 15).



Plate 15, Photo of isolated kaleyard north west of Caheratrant farm (B.Pears)

For direct comparison to the separate kaleyard, a test pit was excavated within the old kaleyard of the neighbouring farm. Both farms had been owned by the O'Shea family, and an identical manuring regime was practised; both used a very traditional Irish method of spade delling which is still conducted today in other parts of the parish (Plate 16).



Plate 16, Photo of distinctive spade delling in kaleyard area as used at Caheratrant farm (D. Davidson, 2007)

Two test pits (1 and 2) were excavated in Caheratrant kaleyard and both revealed two distinctive organo-mineral horizons (Ap-1 and Ap-2) which ranged from 520mm to 535mm deep (Figs 76 and 77). The Ap-1 horizon is a typically dark grey, brown (10YR 5/2 to 4/2) silty sand loam with large quantity of sub-rounded to rounded quartz and shell fragments and larger charcoal fragments. The Ap-2 horizon is also darker in colour from dark grey to dark greyish brown (10YR 5/2 to 4/2) with coarse charcoal fragments. Beneath the Ap horizons a dark yellow, orange (10YR 6/4 to 5/6) sandy silt clay (B) soil was found with large inclusions of sub-rounded sandstone fragments. The soil sequence in test pits 1 and 2 differs considerably from the horizons found in the old kaleyard. The upper most horizon (Ap-1) in test pit 10 (Fig 78) has a light brownish grey (10YR 6/2) sandy silt with some organic inclusions and stone fragments and reworked B horizon which has a yellow, orange colour (10YR 5/8) clay sandy silt and is most likely a redeposited natural soil as it occurs sporadically, ranging from 30mm to 50mm.

Caheratrant - Test Pit 1

IV 36884,98178

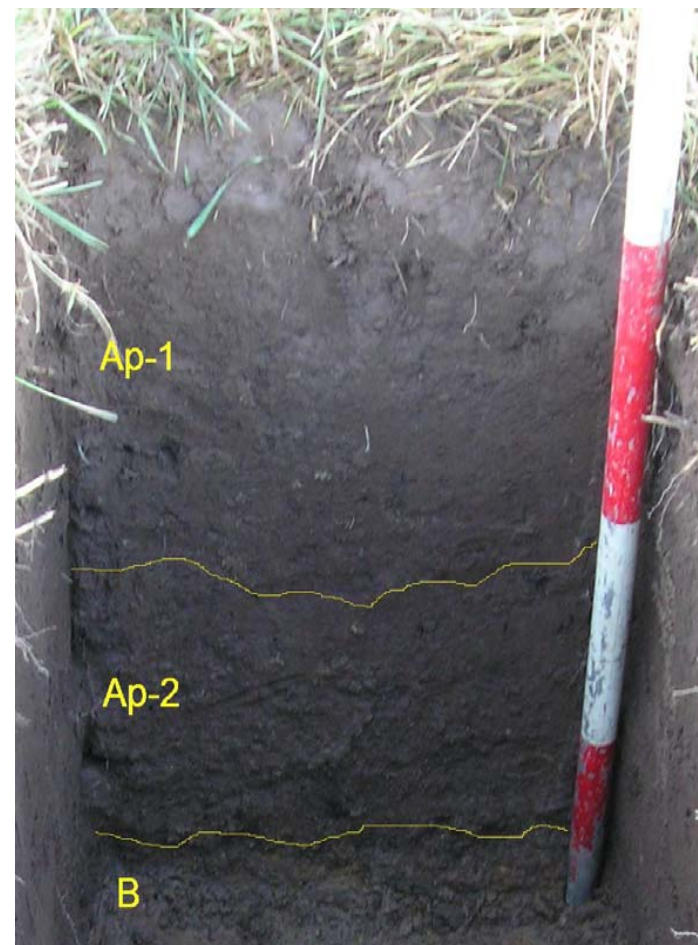
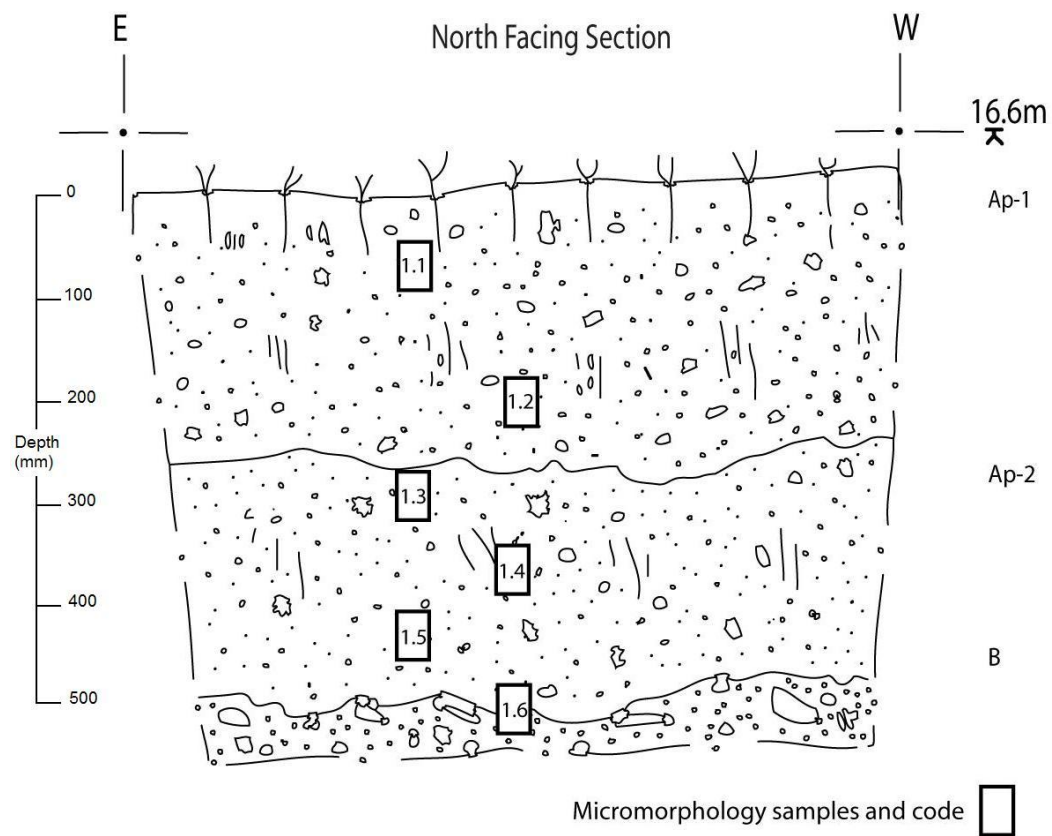


Figure 76, Section drawing and photograph of soil horizons at Caheratrant kaleyard in test pit 1

Caheratrant - Test Pit 2 IV 36871, 98194

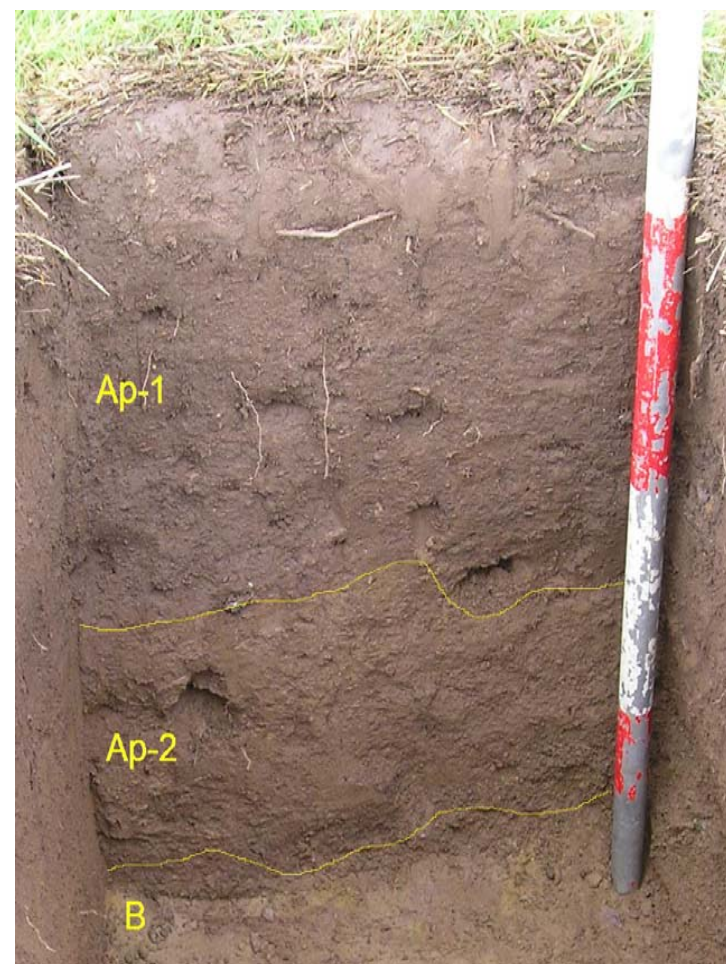
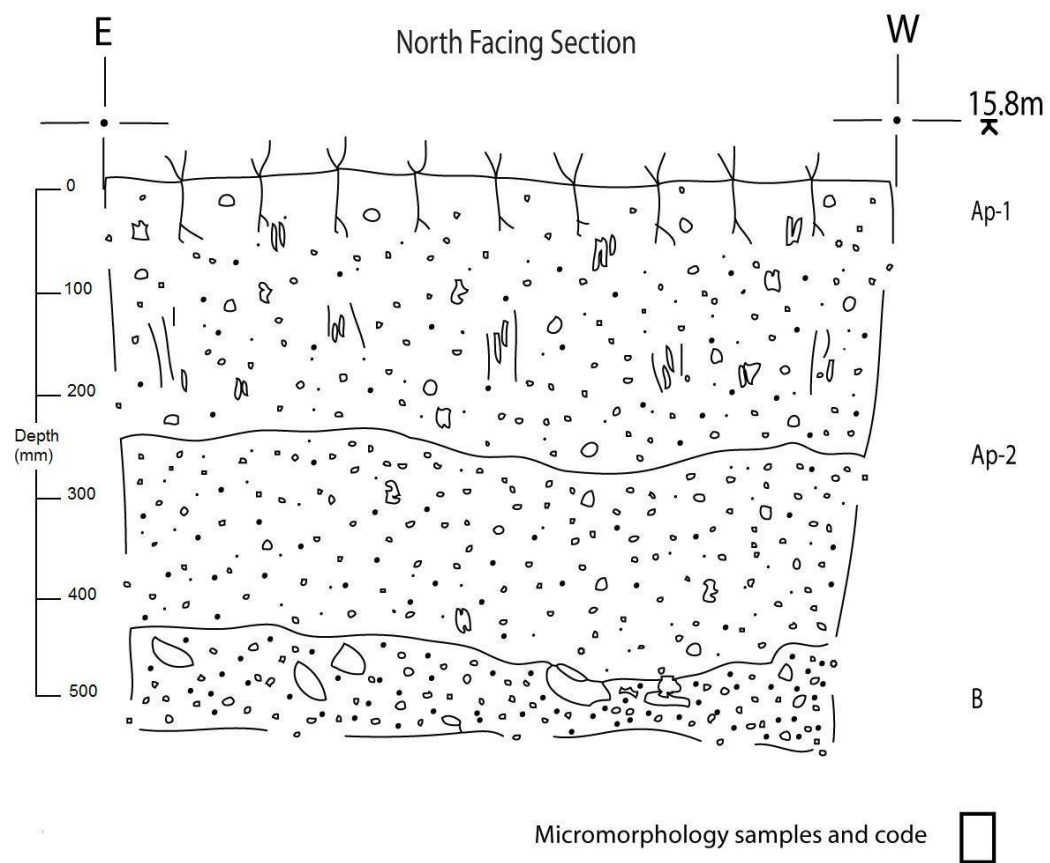


Figure 77, Section drawing and photograph of soil horizons at Caheratrant kaleyard in test pit 2

Caheratrant - Test Pit 10 IV 37137,98187

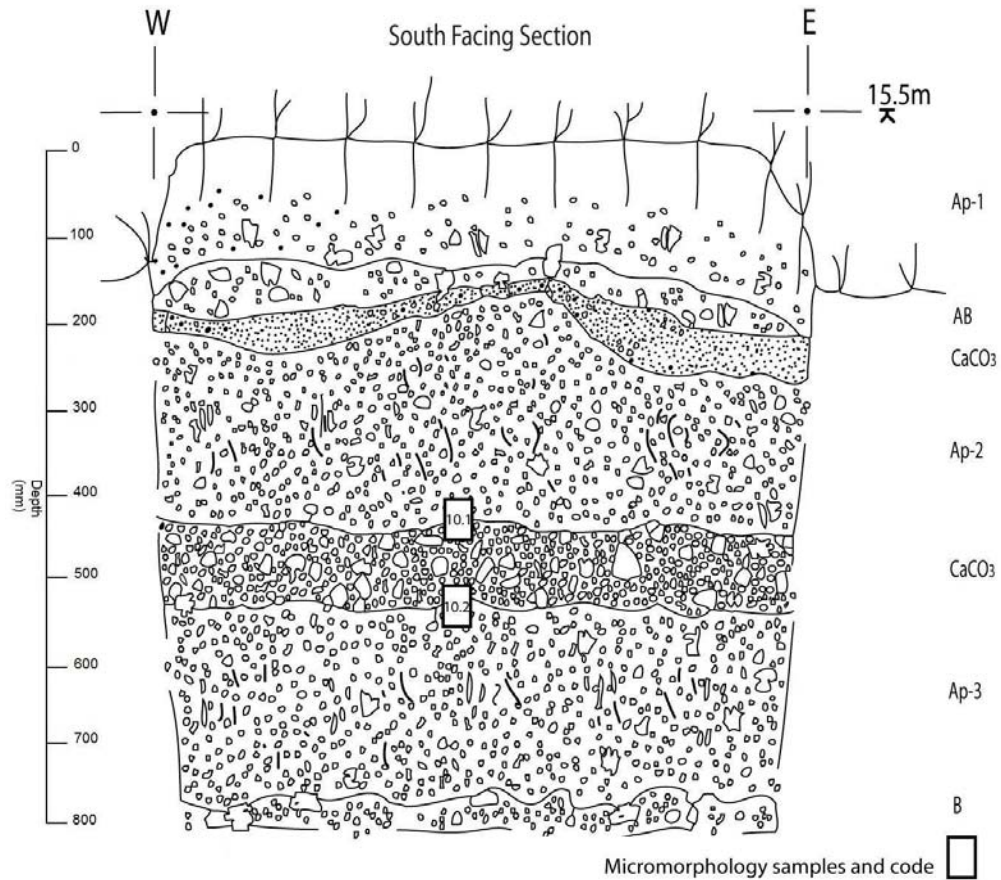


Figure 78, Section drawing and photograph of soil horizons at Caheratrant kaleyard in test pit 10

Below the reworked soil is a very distinctive thin 20mm to 30mm yellow (10YR 7/8 to 8/8) sand sediment composed almost entirely of shell sand and some small organic particles. The sand horizon is likely to represent a dump of calcareous sand added to the soil to reduce soil acidity. Below the shell sand is a second distinctive organic soil (Ap-2) which ranges from 200mm to 210mm, has a dark grey to dark brown colour (10YR 4/1 to 3/3) and a sandy silt loam texture. Within the soil are inclusions of organic material in the form of peat, black carbonised particles and mineral inclusions especially small sub-rounded quartz and degraded shell fragments. Beneath the Ap-2 horizon is a second, coarser calcium carbonate horizon which ranges from 90mm to 110mm and consists of a black to dark grey (10YR 2/1 to 3/1) poorly sorted sandy gravel. The inclusions consist of quartz (2mm to 25mm), shell fragments (<2mm to 10mm) and very small black carbonised particles (<1mm). This horizon represents a second dump of calcareous sand and gravel which has been mixed with domestic refuse in farmyards. A third organic soil (Ap-3) is present beneath the coarse gravel and this consists of a dark grey to very dark brown (10YR 4/1 to 2/2) sandy silt loam with inclusions of small quartz fragments and small degraded shell fragments. At the base of the sequence there is a light yellow, brown (10YR 6/4) sandy silt clay and interpreted as a B horizon.

4.5.2 INNER ARABLE SOILS

The inner arable area at Caheratrant farm was assessed with a number of cores and three test pits (Figs 79 to 81). Transects 9 and 10 show that there is a considerable depth of organic soils and test pits 3, 4 and 8 illustrate a similar pattern with the soils ranging from 495mm to 525mm. The Ap-1 horizon is typically a dark grey brown to light brown (10YR 4/1 to 5/3) silty sand loam with small degraded organic material, charcoal fragments and root and quartz particles. Beneath the upper organic soil is the Ap-2 horizon, a distinctive grey brown to brown (10YR 5/2 to 5/3) silty sand loam with small shell inclusions, charcoal and rounded quartz inclusions.

Caheratrant - Test Pit 3

IV 36898, 98086

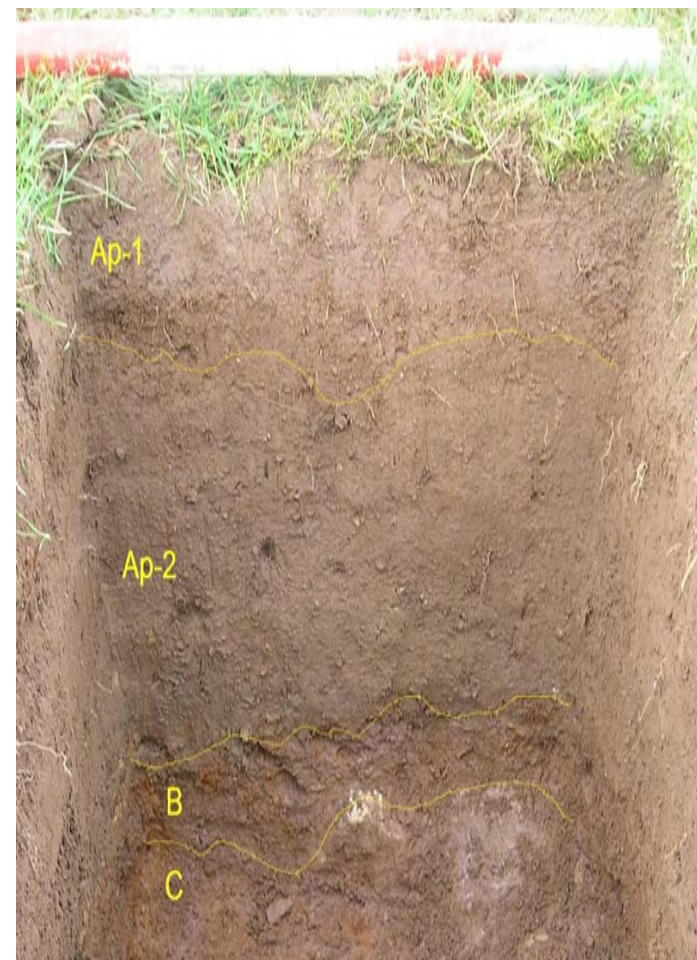
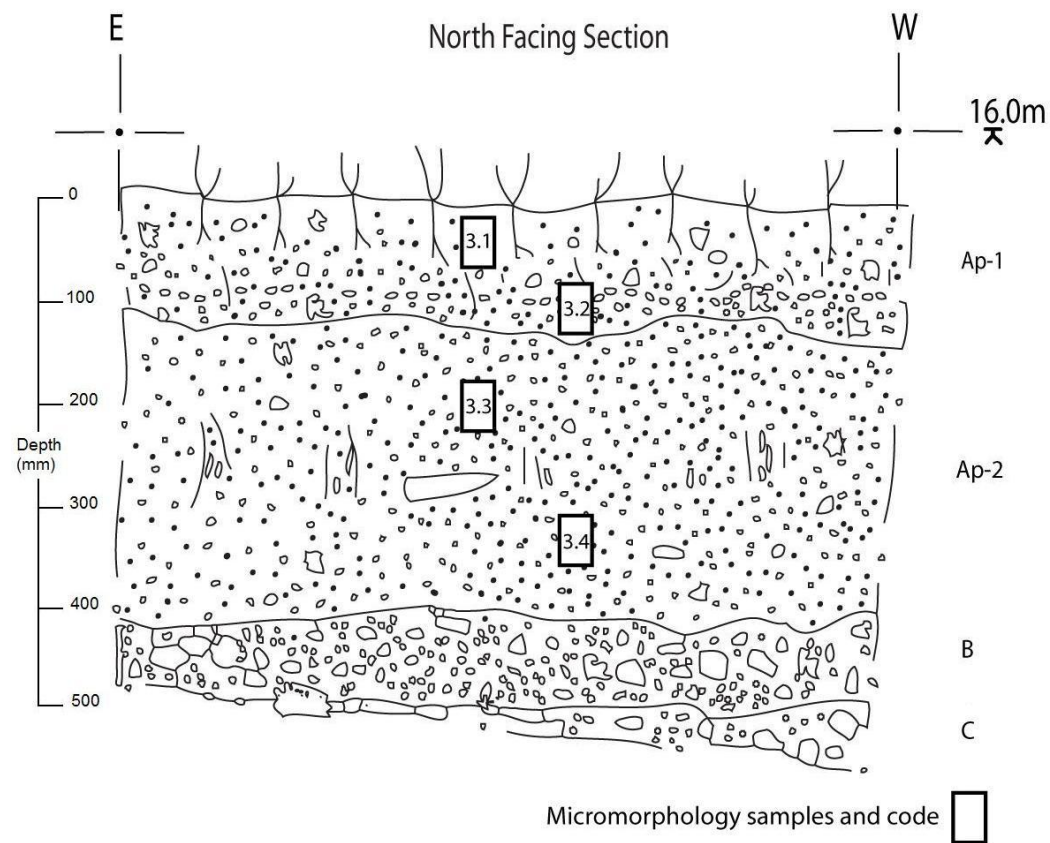


Figure 79, Section drawing and photograph of soil horizons in the inner arable area at Caheratrant in test pit 3

Caheratrant - Test Pit 4

IV 36808, 98042

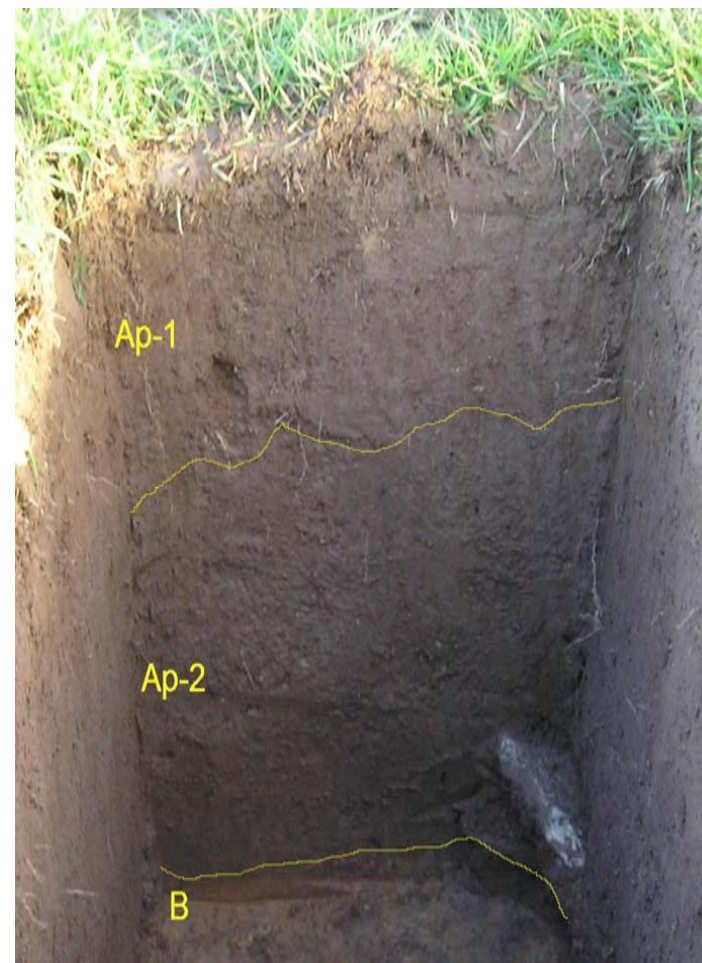
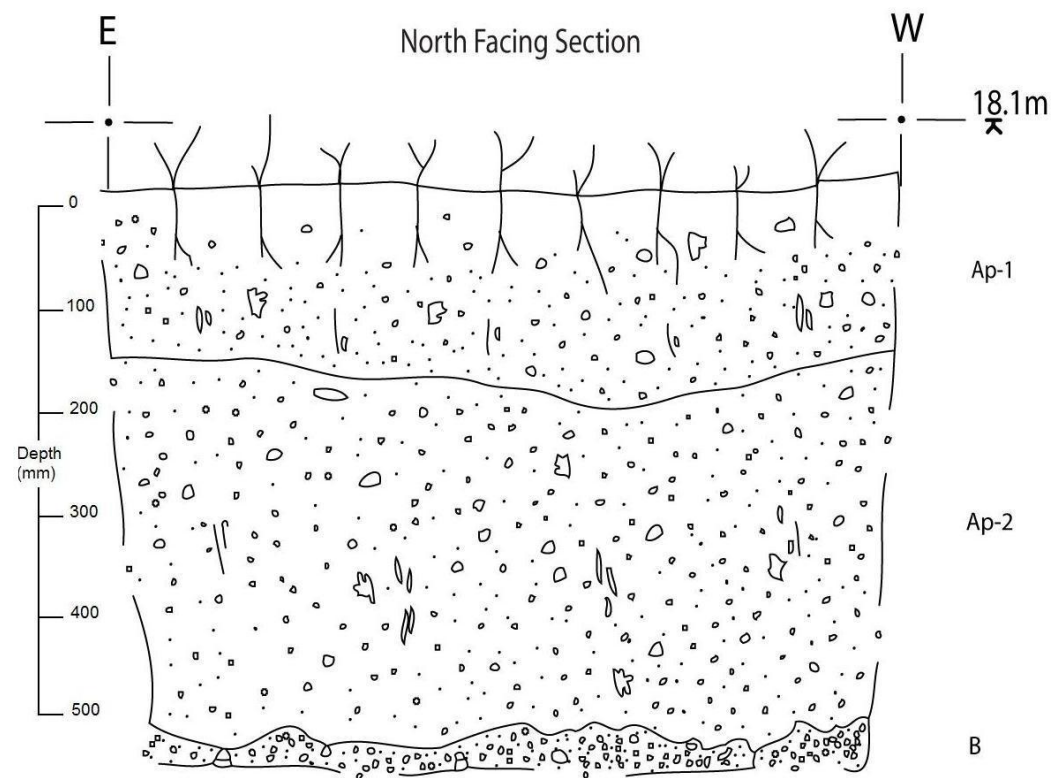


Figure 80, Section drawing and photograph of soil horizons in the inner arable area at Caheratrant in test pit 4

Caheratrant - Test Pit 8

IV 36826, 98203

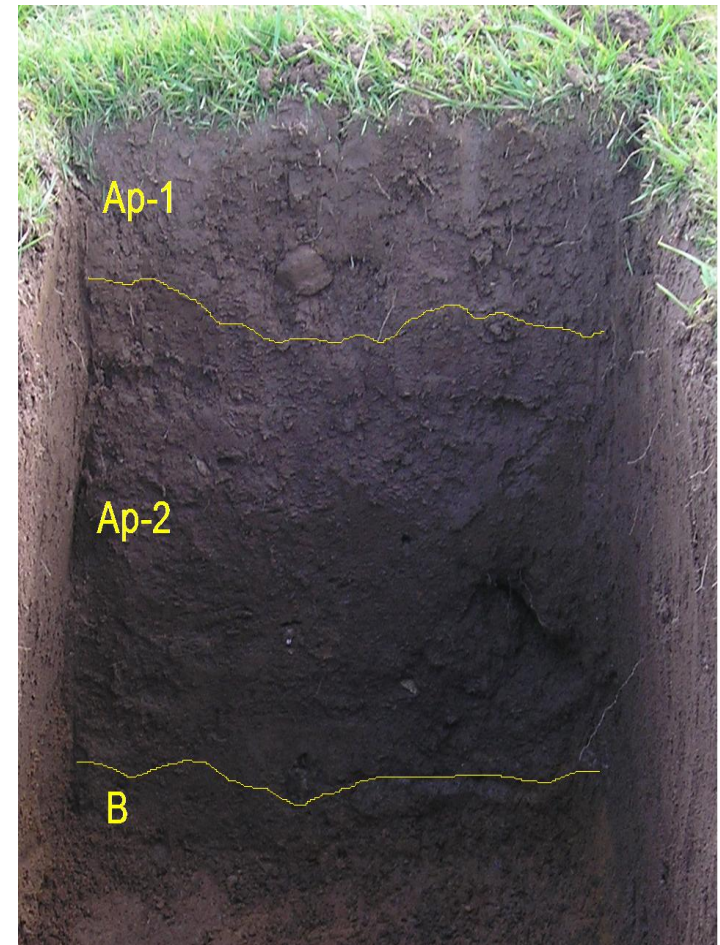
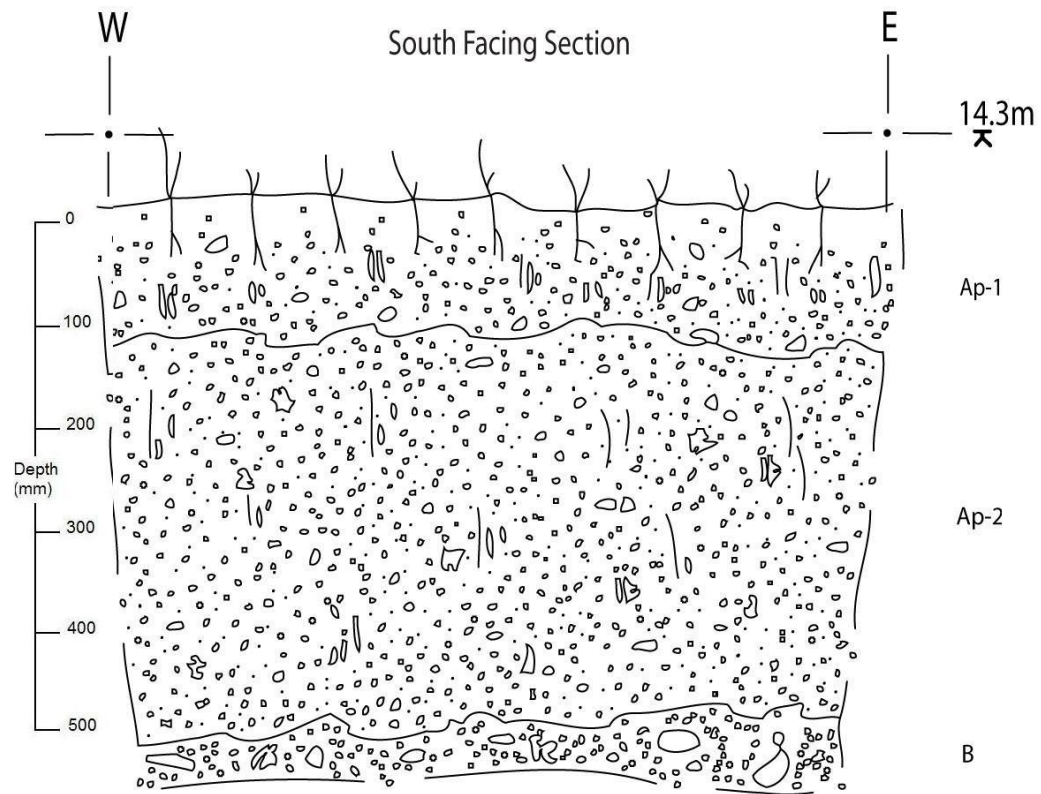


Figure 81, Section drawing and photograph of soil horizons in the inner arable area at Caheratrant in test pit 8

At the base of the sequence is the uppermost natural soil consisting of a light yellow brown (10YR 6/4 to 6/8) sand silt clay B horizon and pale yellow to brown to yellow (10YR 7/4 to 7/6) sandy clay poorly sorted till (C). In the three test pits the Ap-1 soil ranges from 180mm to 220mm and as seen in the auger survey the Ap-2 horizon is deeper and ranges from 275mm to 300mm, especially in test pit 8 towards the bottom of the gentle slope, but there is very little variation in the quantity of anthropogenic inclusions throughout the three pits suggesting a similar rate of organic and mineral input.

4.5.3 OUTER ARABLE SOILS

Three test pits (5, 6 and 7) (Fig 82 to 84) were excavated in the outer arable area of Caheratrant farm and each has a different depth of organic Ap soil horizons from 495mm at test pit 5, 380mm at test pit 6 and 215mm at test pit 7. At test pit 5 the Ap-1 horizon is very similar to the inner arable soils but is typically a dark yellowish brown (10YR 4/4) silty sand loam with considerably less organic and charcoal inclusions but a very similar quantity of sand sized quartz and shell fragments. The soil horizon ranges from 205mm to 220mm and has a very irregular but distinctive boundary with the Ap-2 horizon. In test pit 6 the Ap-1 soil is a lighter brown (10YR 4/1 to 5/3) silty sand loam with a few degraded organics and almost no carbonised particles and thinned to 165mm to 180mm. By test pit 7, located furthest away from the farm, the Ap-1 horizon is only 80mm to 100mm thick and composed of a dark grey, light brown (10YR 4/1 to 5/3) silty sand loam with almost no organic inclusions or shell sand additions. The second organic soil (Ap-2) thins in a very similar way to the Ap-1 horizon from 280mm at test pit 5 to 125mm at test pit 7. The colour and texture range from a brown (10YR 4/3) silty clay loam with inclusions of heavily degraded organic particles and very small charcoal fragments which occur sporadically through the horizon at test pit 5 and 6 to a light grey (10YR 7/2) silty sand loam with almost no organic inclusions or carbonised particles and minimal shell or calcium carbonate sand inclusions.

Caheratrant - Test Pit 5 IV 36772, 97935

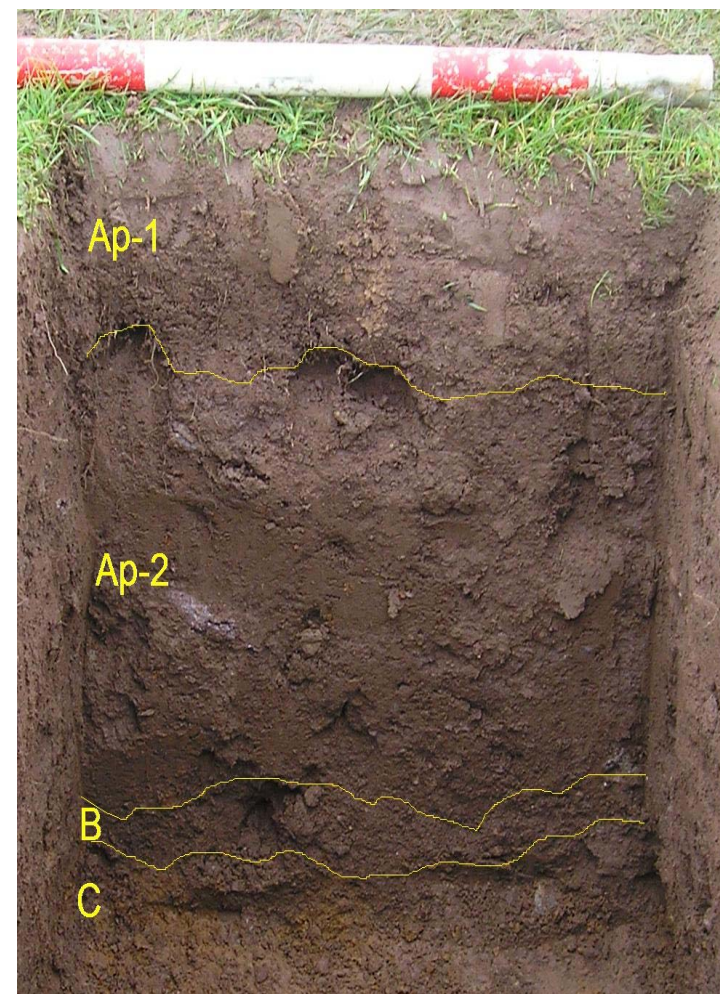
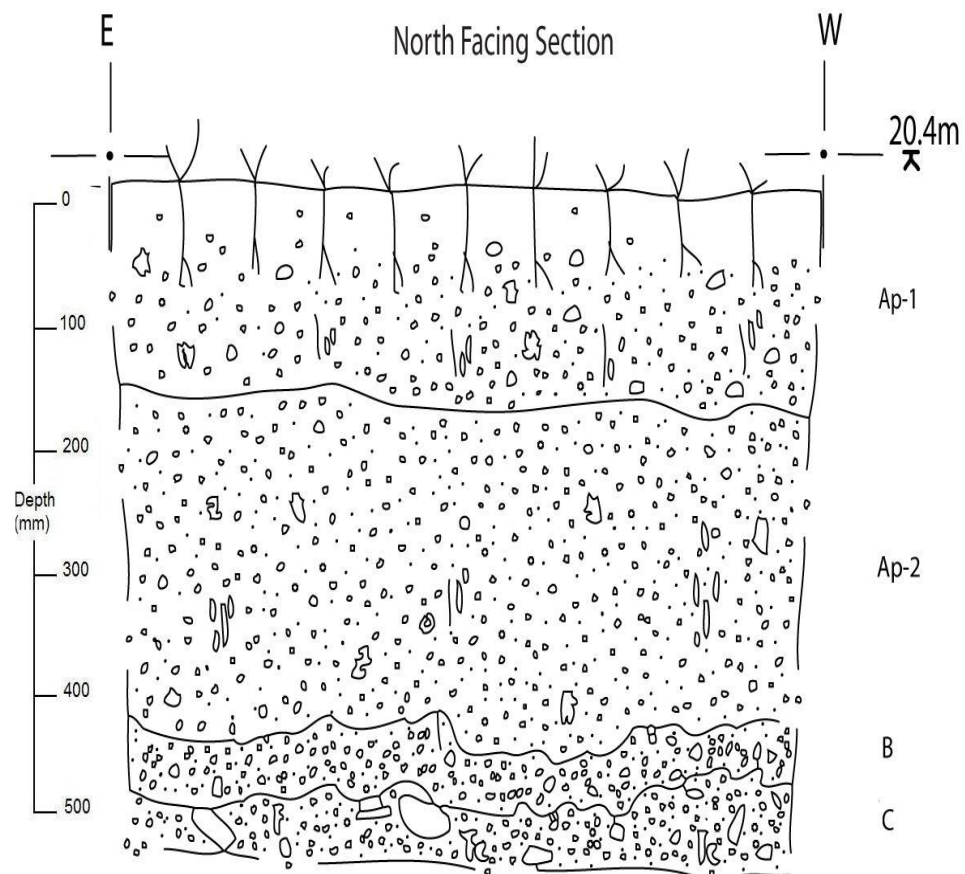


Figure 82, Section drawing and photograph of soil horizons in the outer arable area of Caheratrant in test pit 5

Caheratrant - Test Pit 6

IV 36581,97757

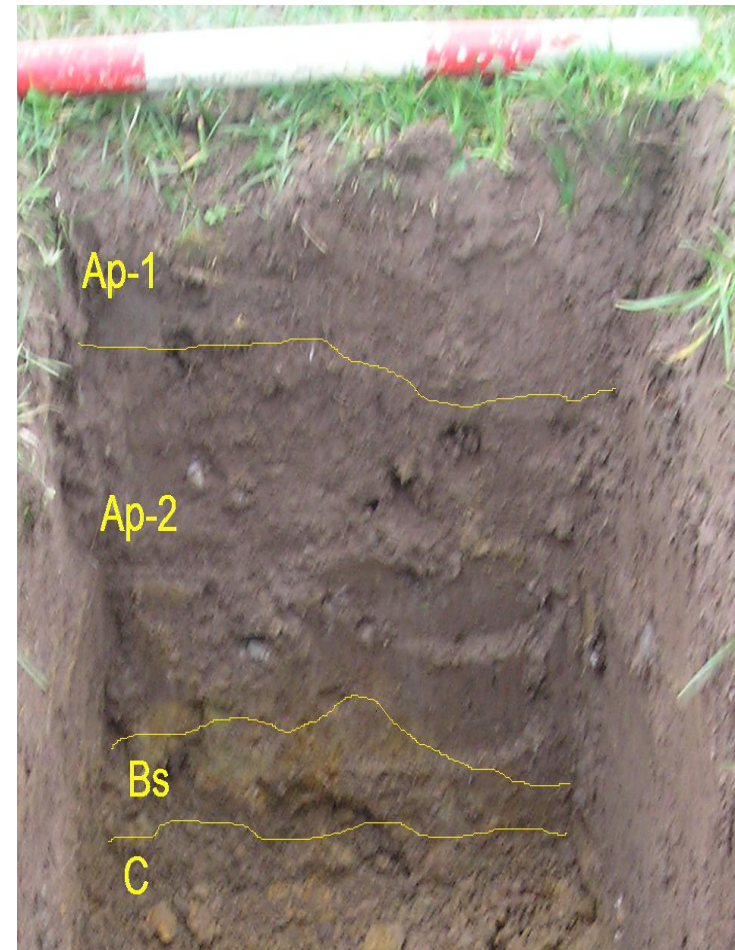
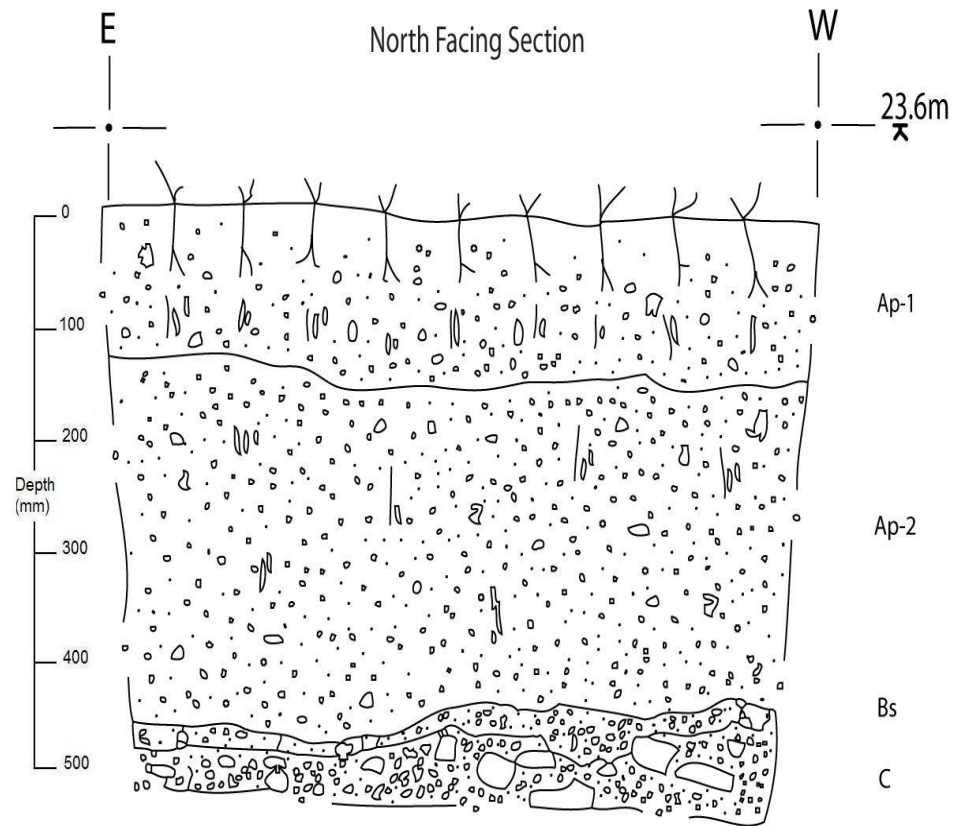


Figure 83, Section drawing and photograph of soil horizons in the outer arable area of Caheratrant in test pit 6

Caheratrant - Test Pit 7 IV 36581,97757

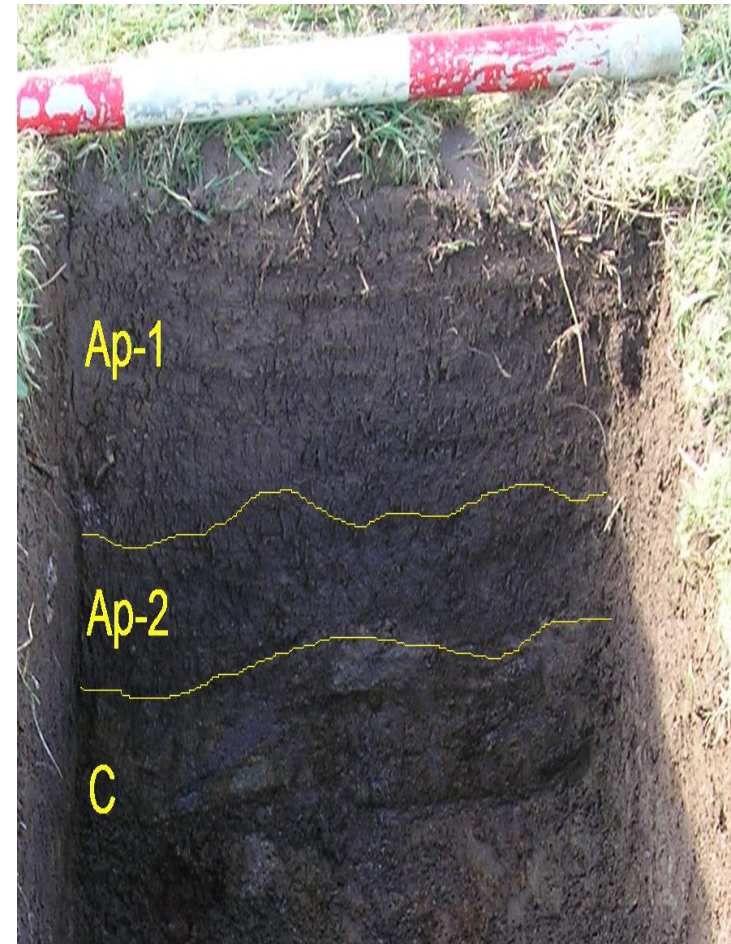
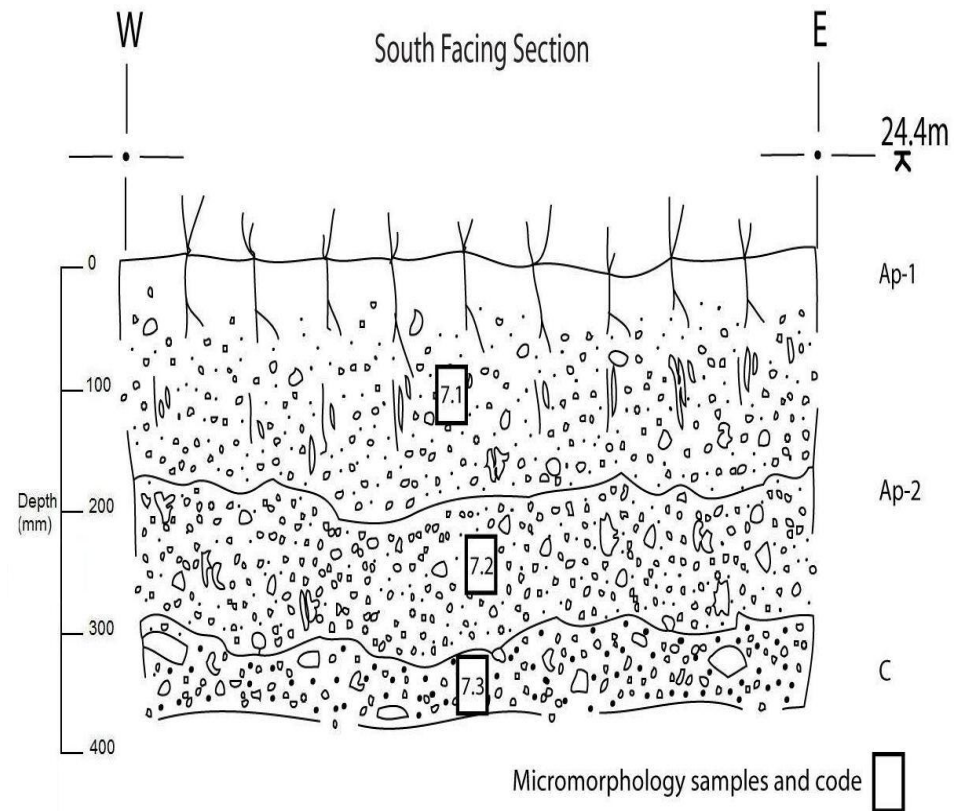


Figure 84, Section drawing and photograph of soil horizons in the outer arable area of Caheratrant in test pit 7

In several of the test pits a thin 40mm to 50mm iron rich horizon (Bs) is present above a lighter yellow, orange B and C horizon marking the beginning of the natural till sediments.

4.5.4 NATURAL SOILS IN UPLAND AREAS

The majority of upland areas and natural soil sequences are situated to the south and west of Caheratrant on the steep slopes of Mount Eagle. However, there are also a number of natural soil sequences closer to the farm especially at the southern end as highlighted in transects 1, 2, 3, and 4 (Sections 4.4.1 and 4.4.2) and in many of the cliff sections bordering Dingle Bay (Plate 17).



Plate 17, Photo of natural peat soils and underlying till in the upland area of Caheratrant

The soils in the upland areas consist of distinctive shallow (150mm) peaty soil (H) with high levels of organic material but no anthropogenic inclusions. Rig evidence on the surface of the upland areas indicates that in the past even these poor quality, shallow soils have been used to grow crops and that reclamation of upland areas into outer arable farmland has been

conducted. To the west of Caheratrant is a large area of pastoral fields which have in the past provided peat to all the farms in the parish, but today only shallow peaty H horizons remain and are either used for grazing animals or growing coniferous plantations. Deep peat horizons are very limited today due to the extreme levels of extraction for manure from the mid 1700s to early 1900s.

Two extra sections (Figs 85 and 86) were also analysed as they provide excellent examples of a distinctive buried soil beneath the organic Ap horizons and beneath a storm deposit. Directly adjacent to Caheratrant farm is a small trackway which was used in the past to transport cartloads of sea sand up to the fields and to drive cattle to the upland grazing areas (Fig 85). The section reveals an extensive build-up of organic soil, because of extensive downslope movement through plough action and surface erosion. As a result the Ap-1 horizon is a 200mm to 220mm deep dark greyish brown (10YR4/2) silty sand loam with organic inclusions and a number of large well rounded quartzite pebbles (20-50mm). Beneath the Ap-1 horizon is a second deepened Ap-2 soil consisting of a dark yellowish brown (10YR 4/4) iron rich silty sand loam with organic inclusions and small carbonised fragments and quartz grains. The section also reveals a very distinctive 280mm to 300mm buried peat soil (H). The layer is intact at the base but the border with the Ap soils is heavily disturbed, possibly by plough action, with large angular fragments of palaeosol in the lower Ap-2. The buried soil is dark brown (10YR 2/2 to 2/1) and with a peaty loam texture and plant inclusions, but no anthropogenic input. Below the soil is a heavily leached eluviated horizon (E) consisting of a light grey to white (10YR 7/1 to 8/1) silty sand with no organic inclusions. Beneath the buried soil and leached horizons were a sequence of brownish yellow B soils, iron rich soils (Bs) with a typical brownish yellow colour (10YR 6/6) and laminated in places and the natural olive green (2.5Y 5/3) coarse grained, poorly sorted till (C).

Caheratrant Open Section IV 37096, 98186

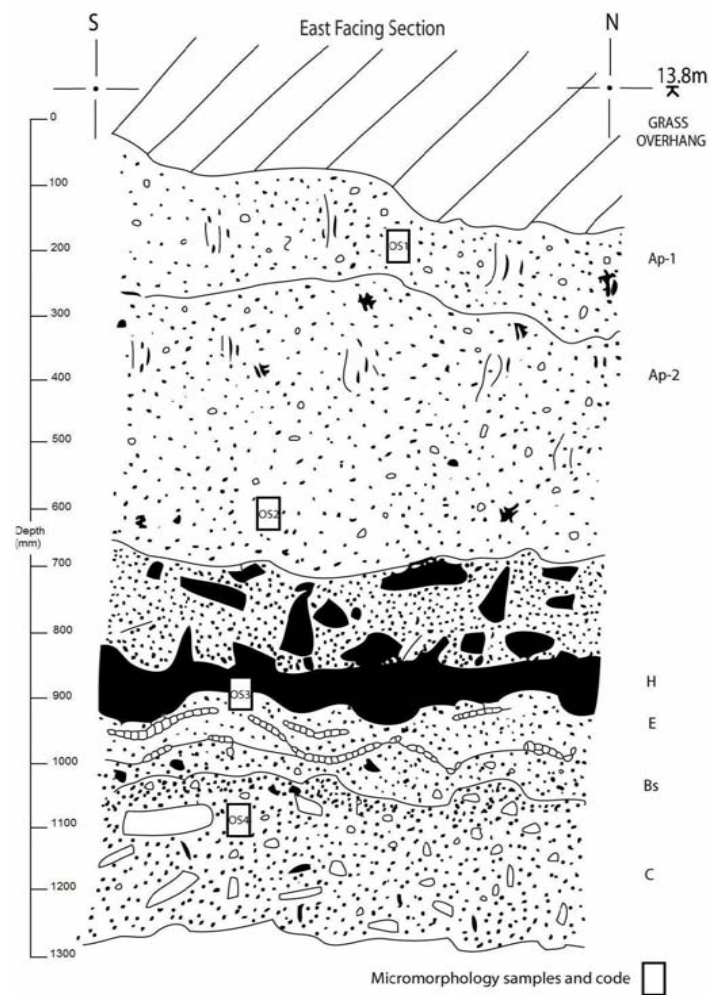


Figure 85, Section drawing and photograph of soil horizons in an open track section

Caheratrant Beach Section IV 37594, 98461

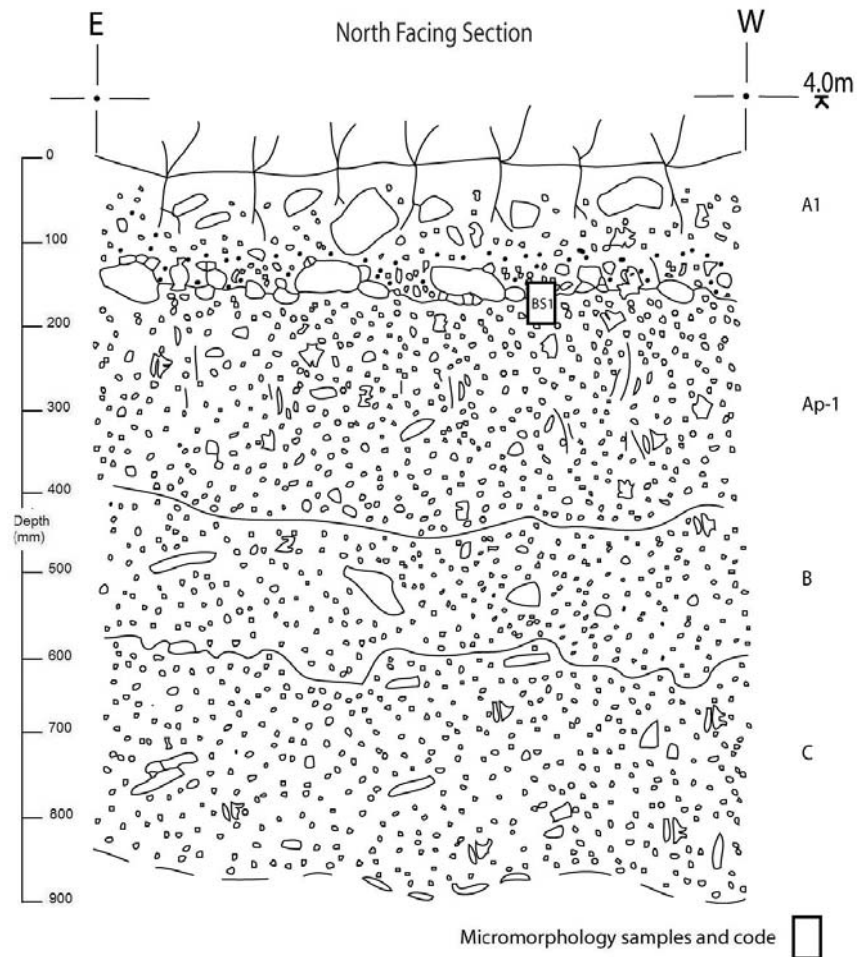


Figure 86, Section drawing and photograph of soil horizons in an open beach section

The second natural section is directly adjacent to Ventry Strand in an old disused field and has been exposed by continual marine erosion (Fig 86). The section has a 275mm to 295mm thick organic Ap-1 horizon. The soil has a distinctly dark brown to very dark greyish brown colour (10YR 2/2 to 3/2) with a silty sand loam texture with large charcoal and organic fragments as well as quartz and shell inclusions.

Overlying the Ap soil horizon is a 160mm to 200mm thick, dark grey, brown (10YR 4/1 to 4/2) silty loam sand (A1). The horizon contains a large number of very poorly sorted, well rounded lithic inclusions ranging from 2mm to 100mm, and coarsening towards the base of the sequence where a grouping of very large quartzite pebbles occurred. This horizon is present as a result of sea storms depositing large quantities of stones and mineral rich marine sediment onto the old field, and as a result, has, buried the amended soil. Beneath the arable soil is a distinctive olive grey to olive (2.5Y 5/3) sandy silt clay B horizon with inclusions of large sub-rounded to sub-angular sandstone fragments together with translocated iron leading to red/orange colouration. In places the upper C, till horizon has a dark grey (2.5Y 3/1) sandy clay texture and extremely poorly sorted fragments of sandstone and schist.

4.6 DISCUSSION OF THE SOIL HORIZONS AT CAHERATRANT

Distinctive organic soil horizons are present across Caheratrant farm and their texture and composition are quite different to the natural soil horizons in the area. The soils are summarised in tables 18 and 19. Overall the Ap horizons have similar dark colours, distinctive silty sand textures and contain larger quantities of organic and anthropogenic inclusions compared to the natural soil horizons. The evidence from the field analyses suggests that these soils have been amended by manuring in order to create and maintain soils for arable farming. However, the depths of the soils are considerably shallower than the Dutch plaggen soils and appear to be composed mainly of peat and turf mixed with calcareous beach sand.

Context	Location		Description	Range of Depths (mm)
	Transects	Test Pits		
Ap-1	All	All	Dark grey to light brown (10YR 5/2 to 4/2) silty sand loam (20%, 40%, 40%) with quartz and shell inclusions 250µm to 500µm sub-rounded shape with an increase in charcoal and carbonised material and some heavily degraded organic material <125µm. Rootlets throughout soil and iron concentrations towards base.	80 – 400
Ap-2	All	All	Light grey, brown (10YR 5/2 to 5/3) silty sand loam (20%, 40%, 40%) with quartz and shelly inclusions which increase towards the base of the horizon. Mineral grains small 250µm to 500µm sub-rounded and partially spherical (+20%) occurrence. Charcoal and carbonised particles frequent <1mm to 5mm at 15-20% occurrence.	40 – 360
Ap-3	/	10	Brown to dark brown (10YR 5/3 to 5/4) silty sand loam (20%, 40%, 40%) with fine grained quartz inclusions. Mineral grains are mainly 250µm to 500µm but there are also (10 – 20%) of larger rounded gravel fragments of quartz and silica fragments mixed in from the calcareous gravel material above. Anthropogenic inclusions include charcoal and carbonised particles <1mm at 20-30% occurrence	200

Table 18, Summary of all arable soils identified with auger surveys and test pits at Caheratrant, Ireland

Context	Location		Description	Range of Depths (mm)
	Transects	Test Pits		
H	1,2,3,4	Open	Dark brown to very dark brown (10YR 3/3 to 2/2) silty sand loam (45%, 10%, 45%). Highly organic peaty soil with very frequent rootlets with no anthropogenic inclusions.	150
E	5	Open	Light grey to white (10YR 7/1 to 8/1) silty sand (40%, 60%), well sorted quartz fragments, <500µm strongly leached layer with no organic or charcoal inclusions.	140
B	1,2,5,6,7,8, 9,10,11	All	Brownish yellow (10YR 6/6 to 6/8) sandy silt clay (10%, 25%, 65%) with few to no organic inclusions except post-burial movement from Ap horizons. Strongly iron stained with medium to large sub-rounded sandstone fragments <2mm in places.	40 – 360
Bs	5,6,7,8	6	Red to yellowish red (2.5YR 5/6 to 5YR 5/6) sandy silt clay (30%, 10%, 60%). Distinctive iron rich horizon with large +2mm to 5mm sub-rounded to sub-angular lithic fragments and iron nodules. No organic inclusions.	40 – 110
C	All	3,5,6,7 Open, Beach	Brownish yellow to yellowish brown (10YR 6/8 to 5/8) sandy clay (20%, 80%) with very poorly sorted fragments of Old Red Sandstone 50mm to +100mm with sub-rounded to sub-angular shape and other foreign lithics (limestones and basalts).	+100

Table 19, Summary of all natural soils identified with auger surveys and test pits at Caheratrant, Ireland

These soils are more consistent with the amended arable soils similar to the ones identified on Fair Isle rather than the extensively deepened horizons found in the Netherlands and Orkney. The distribution of organic Ap soil horizons at each of the three landuse areas is illustrated in figure 87. The kaleyard sequences have the deepest amended soils ranging from just over 500mm to 550mm, a good 200mm deeper than the soils in the inner arable land which range from 375mm to 412mm.

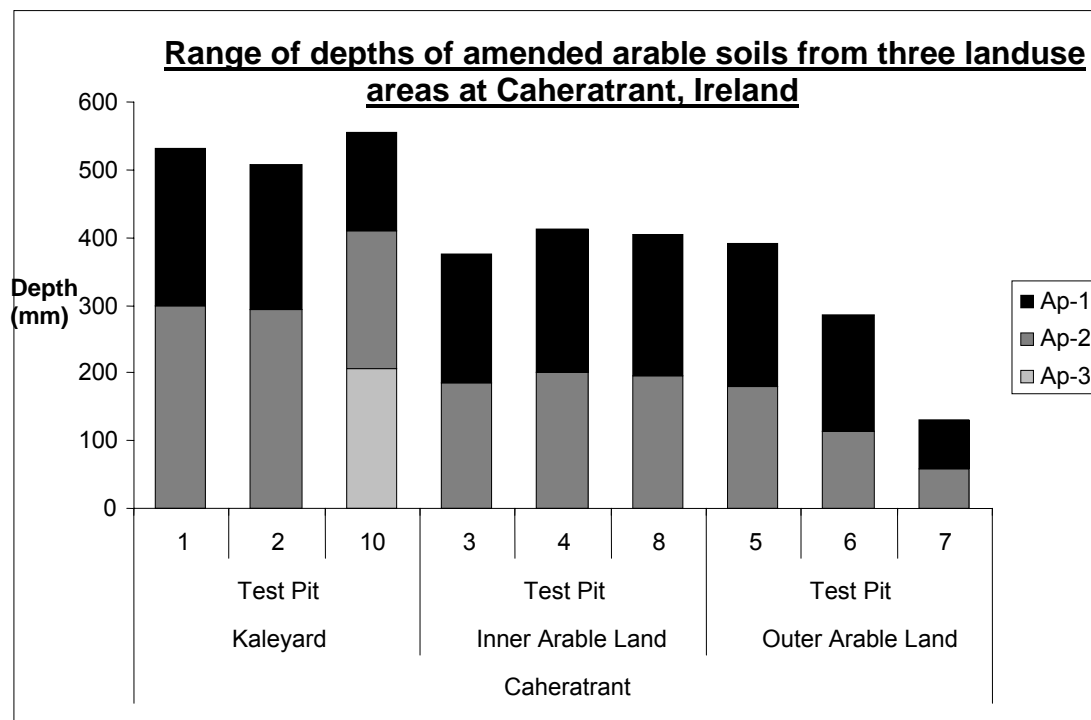


Figure 87, Range of depths of amended arable soils from different landuse areas at Caheratrant

In the outer arable fields the depth of enhanced soil has a much larger range with test pit 5 mirroring closely the depth of soils in the inner arable land and at the furthest extremity the amended soils are only 200mm deep. Two amended soils are present at each of the test pits, except for the kaleyard sequence in test pit 10. Here a third amended soil is present bounded by distinctive calcium carbonate beach sand and gravel horizons. No such sandy organic manure horizons were identified in test pits 1 and 2, but the soil colour, texture and inclusions were very similar, suggesting a greater level of mixing of added manure material. Alternatively, the sequences at test pit 1

and 2 represent a relatively new kaleyard sequence because of the development of an orchard in the old kaleyard and the sequence at test pit 10 represents a more typical kaleyard hortisol sequence developed over a much longer period. The depth of the Ap-2 horizon is considerably deeper than any of the other test pits, also suggesting an increase of addition from the creation of the new kaleyard area whereas in the other landuse areas there is little difference in depth between the Ap-1 and Ap-2 horizons suggesting a more constant process of addition over time.

	Conry & Mitchell (1971)	Pears (this volume)
Area of study	Caheratrant, Ireland	Caheratrant, Ireland
Depth of soils	Infield – 400mm to 480mm	Kaleyard – 525mm Inner Arable Land – 395mm Outer Arable Land – 240mm
Colour	Very dark grey to brown/very dark brown	Dark grey to brown and black in places
Texture	Silty sand loam	Sand loam to silty sand loam
Inclusions	Shell sand and quartz mineral with organics	Organics fragments, quartz and shell fragments and carbonised particles

Table 20, Range of amended soils found during two studies at Caheratrant farmstead

The sequence of amended soils in the inner arable fields (test pits 3, 4 and 8) are extremely consistent and this continues in test pit 5 in the outer arable fields suggesting that there is little difference in the manuring programme. This interpretation is backed up by the field description of the soils which have a very similar texture, colour and anthropogenic inclusions whereas the soils in test pits 6 and 7 are considerably lighter in colour and contain much less organic fragments and carbonised material. The amended soils were initially identified at Caheratrant as part of a much wider analysis of Irish Plaggen soils by Michael Conry in the early 1970s, summarised in table 20.

Conry and Mitchell's analysis of the soils of Caheratrant was based upon minimal excavation in a carefully considered location in the infield area of the farm. The soil was a distinctive very dark grey to brown/very dark brown silty sand loam with a very large quantity of shell sand and quartz, and interpreted as a plaggen soil.

Conry's fieldwork at Caheratrant has been placed into a more detailed localised context by the present work, which has shown a very similar depth of anthropogenic soils in the infield areas from both auger transects and test pit data. However, it is clear that there is far more variation in colour, texture and inclusion from test pit to test pit as well as across landuse areas. The focus of Conry's work was, however, on a much larger scale and was aimed to detail the range of plaggen soils across different areas of Ireland. As a result over four locations were sampled, as illustrated in table 21. After initial mapping, (Section 4.3.2) Conry focussed upon the south west of the country and in particular County Cork and County Kerry (Conry, 1969). Two sites in Cork revealed a range of anthropogenic soils. At Donoure 970mm of anthropogenic soil was found in five distinctive horizons, all very similar to each other with a distinctive dark greyish brown coarse sandy loam with beach stones and calcareous inclusions.

Authors (Date)	Anthropogenic soils	
	Site	Depth
Conry (1971)	Donoure, Ardfield, Clonakilty, Cork	Plaggen Soil – 970mm
Conry (1971)	Pillmore, Youghal, Cork	Plaggen Soil – 480mm
Conry (1971)	Cloghaneanode, Castlegregory, Kerry	Profile 1 – 270mm Profile 2 – 850mm
Conry (1971)	Ballydavid, Murreagh, Kerry	Plaggen Soil – 910mm

Table 21, Depths of plaggen soils identified in Ireland

A shallower profile was found at Pillmore where 480mm of a dark greyish brown sandy loam with a similar number and type of inclusion

suggesting a large addition of organic and beach sand material. The difference in depth of anthropogenic soils at different sites was also clearly seen in County Kerry. At Castlegregory two sections were excavated within 20m of each other and both showed a very different depth of plaggen soil. Profile 1 was a non-manured arable soil with a variable profile between 200mm to 270mm of a black peaty sand with no recorded organic or anthropogenic inclusions. Profile 2 was considerably deeper, 850mm, plaggen soil and consisting of a very dark grey loamy sand with beach sand and a black peaty sand with some calcareous material but no recorded anthropogenic inclusions. The second site analysed in further detail by Conry was at Ballydavid near Murreagh, also on the northern side of the peninsula. The anthropogenic soils were 910mm deep with a typical reddish brown to dark brown coarse sandy loam to loamy sand with beach sand. Conry's work on the distribution of the anthropogenic soils across the south west of Ireland was extremely important, however, the lack of detailed geoarchaeological recording has made interpreting the context of deposition extremely difficult. The deepened sequence at Castlegregory occurs in the grounds of an old farm and therefore the sequence of 850mm could well be a kaleyard hortisol but without the knowledge of the landuse history this cannot be confirmed. At Ballydavid the exact locality of Conry's test pit is unknown and this lack of information is key as the sequence could occur close to Murreagh and be more of an urban anthrosol or hortisol to explain a depth of 910mm.

The identification and field analysis of plaggen soils by Conry in Ireland was a very important step forward in the analysis of anthropogenic soils in Europe, however further soil analysis is needed including soil pH, soil organic matter and multi-element analysis in order to more fully understand the processes by which these amended soils developed. Indeed comparative analysis of the geochemistry of anthropogenic and amended soils from each of the sites and in a range of historic landuse areas has not been conducted. More detailed analysis and interpretation is urgently required to fully understand their form and function at a local and regional scale.

5 BULK PHYSICAL AND CHEMICAL ANALYSES OF SOILS

5.1 INTRODUCTION

Chapter five discusses and interprets the results from physical and chemical analyses of bulk samples taken from the anthropogenic and amended arable soils (Ap-1 to Ap-4) from the test pits of the three study sites. The results are analysed on a local scale from horizon to horizon and between landuse areas as well as on a wider regional scale between the sites in order to interpret cultural addition to the amended and anthropogenic soils. The five analyses utilised were soil pH, loss on ignition (LOI), particle size analysis, magnetic susceptibility and multi-element analysis. These tests have been shown in other studies (chapter 1, section 1.4.2) to assist with quantifying human influence in anthropogenic soils and allow comparison with similar soils, formation materials and changes in landuse.

The structure of the chapter is in a number of sub-headings; initially the sampling strategy and preparation followed by the results of the techniques used; soil pH (section 5.2), loss on ignition (section 5.3), particle size (section 5.4), magnetic susceptibility (section 5.5) and multi-element analysis (section 5.6) from the main landuse areas at each of the three sites used. The final section (5.7) is a discussion and interpretation of the results with detailed reference to the field results discussed in chapters two, three and four and the consideration of results with other physical and chemical results from anthropogenic and natural soils.

5.2 SOIL pH RESULTS FROM FAIR ISLE, THE NETHERLANDS & IRELAND

Soil pH is the measurement of the concentration of H^+ ions in soil and is directly affected by chemical, biological and physical soil properties (Brady and Weil, 2002). The measurement is expressed as negative logarithms of the H^+ ion concentrations on a scale from 1 to 14 with 1 to 6 acidic and 8 to 14 alkaline and 7 representing neutral. The change of soil pH in soils is determined by the mobility of cations and different soil textures have different abilities to maintain soil chemistry. Typically sandy soils are more acidic due

to leaching from water movement through soil horizons which commonly wash alkaline base elements (Ca, Mg, K and Na) out leaving concentrations of hydrogen. In clay soils and organic rich soils the micelles can retain cations and therefore maintain chemical stability through a 'buffering capacity'.

The aim of the soil pH measurement was to ascertain the influence of anthropogenic additions and parent material upon the soils at each of the sites and within the landuse areas. Traditionally soil pH analysis has been used within archaeology because the data are very easily gathered from small samples and the variability in results between archaeological deposits, anthropogenic soils and natural soils can indicate a range of human influences on landscapes and settlements.

Anthropogenic activity is interpreted from soil pH values by analysing the differences in results from sample soils and natural horizons (Entwhistle et al., 2000). Different soil pH values affect archaeological soils and artefacts in a number of ways. Acidic soils damage delicate organic inclusions as well as bone, pottery and the corrosions of copper and iron but good for the preservation of pollen, diatoms and some macrobotanical material which can protect delicate organic material if waterlogged. Alkaline conditions are good for the preservation of molluscs, bone and phytoliths but pollen is oxidised and salt encrustations are commonplace (Renfrew and Bahn, 1996, Goldberg and Macphail, 2006).

The soil pH was determined in the laboratory following the methods of Avery and Bascomb (1982) and the methodology used is summarised in chapter 1, section 1.13. Figures 88 to 90 illustrate the soil pH results from each of the sites and by each landuse area. (Raw data in appendix 8).

5.2.1 SOIL pH RESULTS FROM FAIR ISLE

The soil pH results from Fair Isle illustrate some very interesting results. In the three kaleyard areas there is a subtle difference between the three sites and through the soil horizons (Fig 88). At Shirva the highest results occur in the Ap-1 horizon (pH 5.8 – 6.7) with lower results in the Ap-2 and Ap-3 horizons (pH 3.9 – 6.1) these amended soils are all higher than the natural

soils indicating the addition of domestic refuse, peat and turf alongside seaweed and possibly calcareous sand.

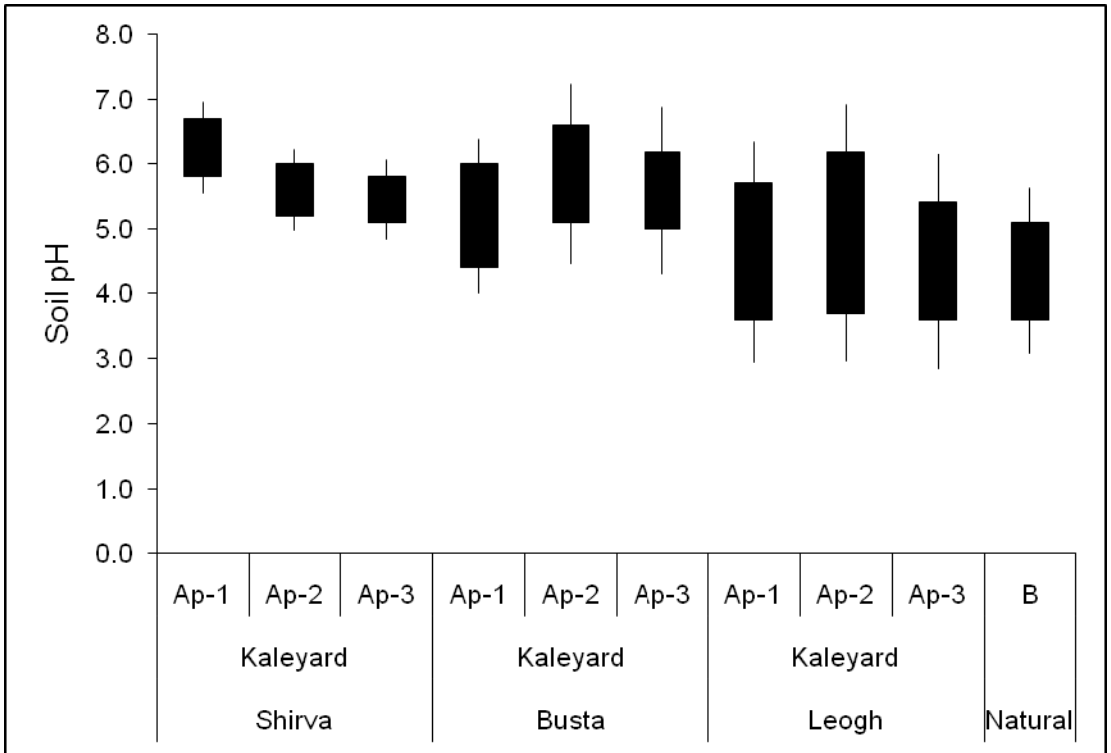


Figure 88, Soil pH results from amended arable soils from three kaleyard areas on Fair Isle

A different pattern of soil pH results is evident at Busta. The range of results is higher than at Shirva in all the amended horizons illustrating a different manuring strategy. Unlike Shirva the range of soil pH results is slightly higher in the Ap-2 and Ap-3 horizons (pH 5.0 – 6.6) illustrating a slightly higher input of organic and inorganic material earlier in the history of the area. Both Shirva and Busta kaleyard have clear increases in soil pH compared to the natural. At Leogh, however, the results are comparable with the B horizon. Overall the range of results is considerably higher than the other kaleyards and again illustrates a different strategy of manuring. The difference in results may also be closely related to post burial soil processes occurring since the cessation of manuring and the movement of soil water.

Clearer variations in soil Ph results can be seen in the results from the three different landuse areas from Shirva (Fig 89). As discussed the kaleyard

results have a small range with a clear decrease of results with depth illustrating the clear input of organic and inorganic material.

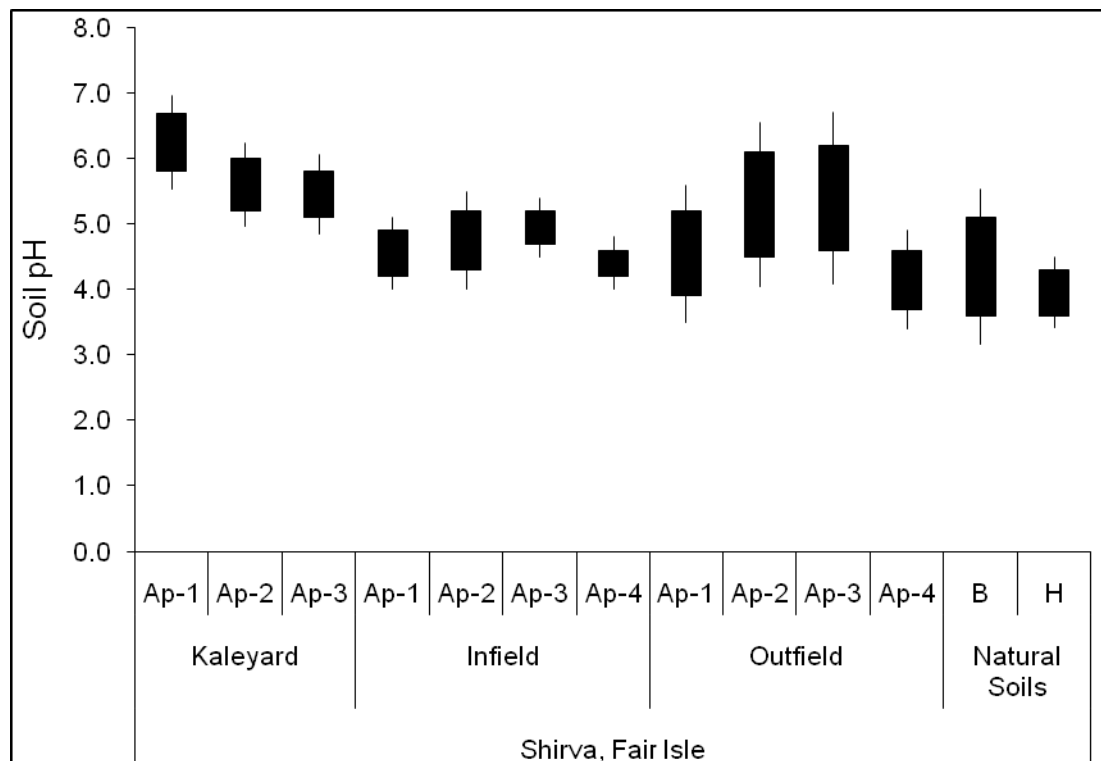


Figure 89, Soil pH results from amended arable soils from three landuse areas at Shirva, Fair Isle

By contrast the amended soil sequence in the infield area show a slight increase with depth from pH 4.2 – 5.2 in the Ap-1 to Ap-3 horizons. This suggests that manuring was conducted at a higher level in the past when the area was used for arable agriculture, whereas more recently addition has decreased because of a landuse change from arable to pastoral. The widest range of soil Ph results are present in the outfield area. There is a distinct increase with depth mirroring the infield areas which shows a possible change of landuse (pH 4.6 – 6.7). There is a considerably lower pH in the Ap-4 horizon which is similar to the B and H horizons and illustrates that the initial amended arable soils were formed of the mixing of the natural peat horizon with organic and inorganic material. The increase in addition of manuring material during the arable stage therefore leads to much higher soil pH in the Ap-2 and Ap-3 horizons.

5.2.2 SOIL pH RESULTS FROM OLT Hof, THE NETHERLANDS

The range of soil pH results from Olthof, the Netherlands are illustrated in Fig 90. Overall the results have a considerably wider range compared to the results from Fair Isle. The results from Olthof garden increase slightly with depth illustrating the addition of heathland and meadowland turves alongside settlement waste and carbonised particles. In the Ap-1 and Ap-2 horizons the results range from pH 4.0 to 6.9 which illustrate the input of podzolic heathland turves alongside carbonised material. The low results may also be due to the leaching and post burial mixing. The results from the Ap-3 horizon range from pH 5.7 – 7.4 and mirror the addition of the meadowland turf resulting in the brown plaggen soil.

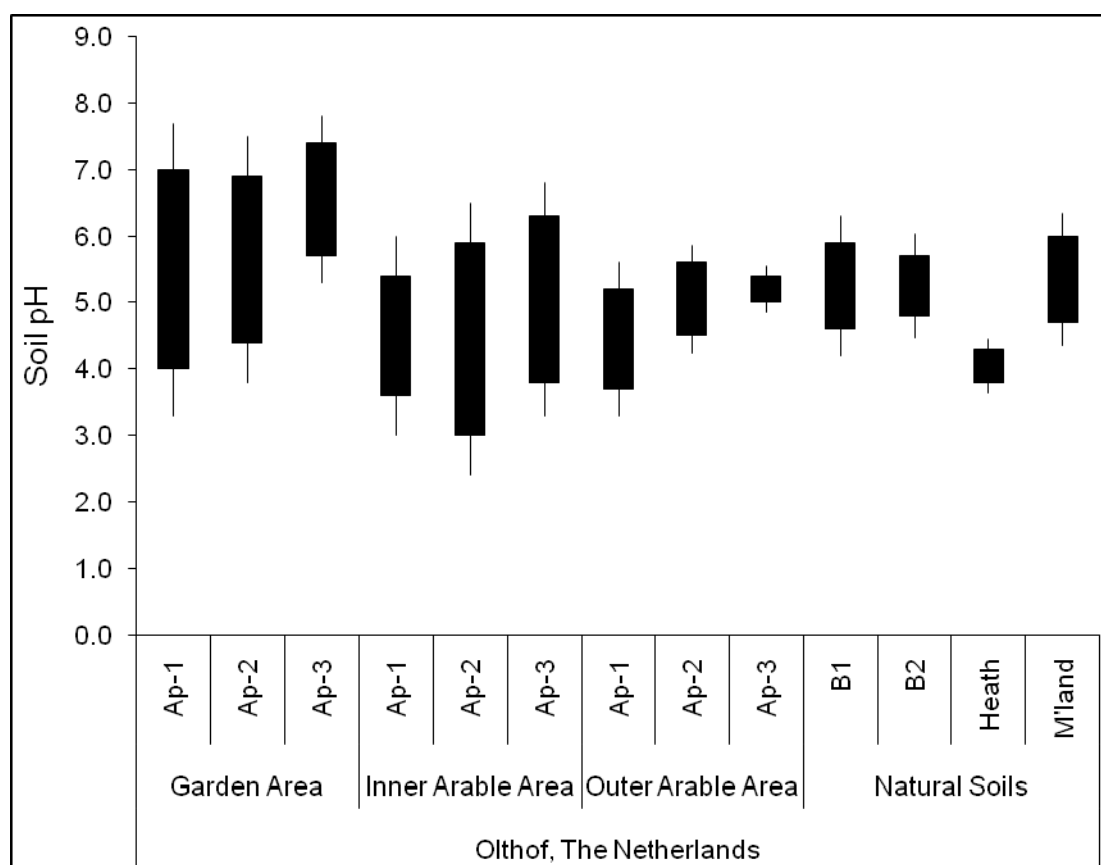


Figure 90, Soil pH results from anthropogenic soils from three landuse areas at Olthof, the Netherlands

In the infield area the results also show an increase with depth between the Ap-1 to Ap-3 horizons reflecting a similar pattern of amendment

to the garden area. The results in the black plaggen soil (Ap-1 and Ap-2) range from pH 3.0 to 5.8 and brown plaggen soil (Ap-3) pH 4.0 to 6.4 suggesting a range of anthropogenic additions and also significant post burial alteration and mixing. A similar pattern of results is also present in the outfield area but there is a closer relationship with the manuring system of the infield rather than the garden area.

In the black plaggen soil horizons there is more variation between the Ap-1 (pH 3.7 to 5.2) horizon and the Ap-2 (pH 4.5 to 5.6) horizon illustrating a distinct variation in the organic and inorganic input alongside more post burial mixing. The overall results are lower than the in the garden area and illustrate considerably less input of settlement waste and carbonised particles and an emphasis of organic manuring.

5.2.3 SOIL pH RESULTS FROM CAHERATRANT, IRELAND

The range of soil pH results from Caheratrant, Ireland are illustrated in Fig 91. Overall the amended arable soils in the kaleyard have considerably higher results than the inner arable area and outer arable areas as a result of a focus of manuring in the areas directly adjacent to the centre of the farms. In the kaleyard area the soil pH results range from 6.9 to 9.0 in the Ap-1 horizon and 6.2 to 8.7 in the Ap-2 horizon. These results are considerably higher than the results from the C horizon (5.5 to 6.5) and show that there has been the addition of calcareous beach sand alongside the addition of domestic waste material and organic peat and turf. The soil pH results from the Ap-3 horizon are even higher (7.9 to 8.2) and indicate a greater emphasis of organic and inorganic addition to the kaleyard in the early history of the area. The higher results may also be due to less weathering and post burial breakdown of manuring components than the overlying horizons.

In the infield area the soil pH results are lower and more akin with the natural soils. There is a slight increase in the range of results between the Ap-1 (4.4 to 6.6) and Ap-2 (5.2 to 6.7) horizons. The field analysis illustrated that inclusions of calcareous sand and organic peat and turf were added to the soils but the Ph results show that there is a marked difference in enhancement between the kaleyard and infield.

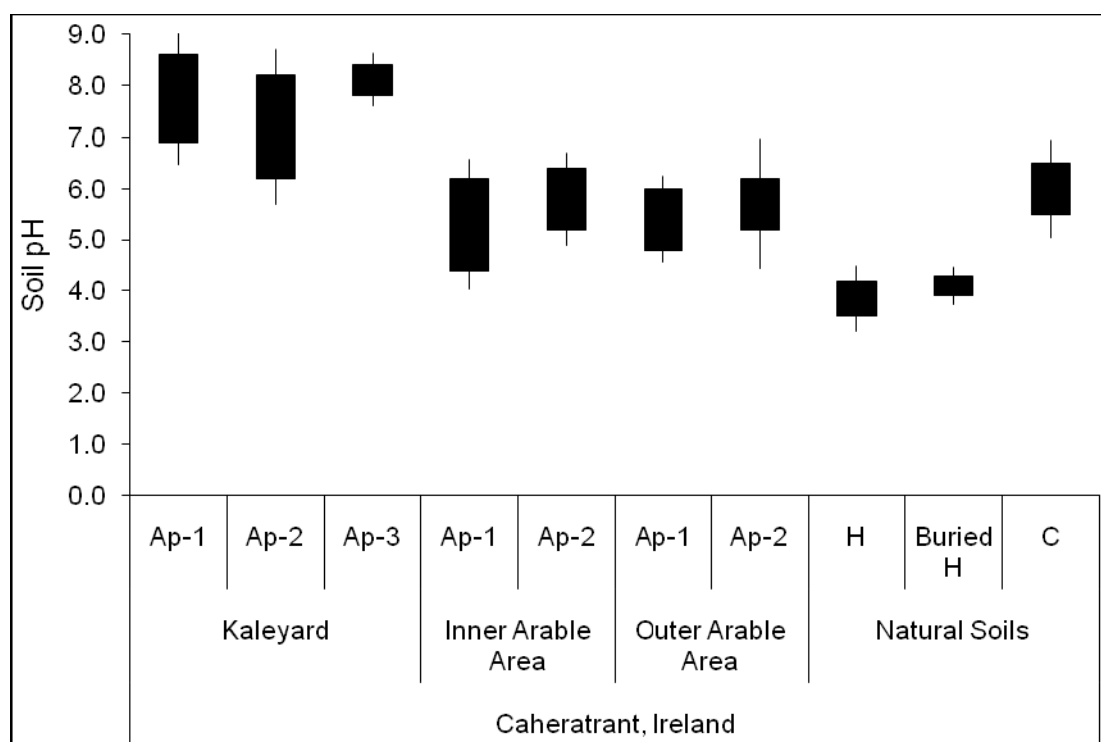


Figure 91, Soil pH results from amended arable soils from three landuse areas at Caheratrant, Ireland

A similar range of soil pH results are also present in the amended arable soils in the outfield area. The outfield areas results range from 4.8 to 6.2 in the Ap-1 horizon and 5.2 to 6.2 in the Ap-2 horizon. The similarity of the results in the infield and outfield suggest that a very similar manuring regime is in place in these landuse areas and that arable activity has created considerable mixing between the horizons. The results are very similar to the natural C horizon but are higher than the natural peat soils which are the main organic manuring components in the area.

5.2.4 SOIL pH RESULTS FROM UPLAND AREAS AND NATURAL SOILS

At each site the soil pH of the natural sandy soil is, in most cases, very similar or slightly lower than the soil pH of the amended or anthropogenic soils. The natural sediments on Fair Isle (soil pH 3.5 – 5.0) and Olthof (soil pH 4.9 – 6.0) contain moderately acidic soils but at Caheratrant (soil pH 6.0 to 7.9) the results are considerably higher as a result of having more calcium carbonate in the till and this may have assisted the development of a higher

soil pH in the anthropogenic soils. The natural peat soils on Fair Isle (soil pH 3.9 to 4.3) and at Caheratrant (soil pH 3.9 to 4.5) have very similar values but in places the peat results from Caheratrant are considerably more acidic with a soil pH of less than 3.5 and the addition of these soils may have required more intensive sanding. At Olthof the soil pH of the natural sandy soils is slightly less than the plaggen soils, ranging from soil pH 4.9 to 6.0. At all three sites a buried peaty palaeosol was found but the soil pH results differ from the undisturbed horizons indicating distinct post burial alteration by ploughing and biological mixing. At Shirva (soil pH 5.5 – 5.8) and Caheratrant (soil pH 6.6 – 6.9) buried peaty palaeosols increased in soil pH because of the higher soil pH in the natural sediments. At Olthof, however, the buried soil has considerably lower values (soil pH 5.0 to 5.2) more akin to the anthropogenic soils.

5.2.5 DISCUSSION AND COMPARISON OF SOIL pH RESULTS WITH PAST WORK

The results from this research project can be directly compared to past work conducted on the three sites to enable comparable interpretation. In Scotland the soil pH of anthropogenic soils was initially identified by Glentworth (1944) who analysed a range of soils from the Inch valley and showed that “80% of the deep topsoils had a soil pH of 6.0+” (Glentworth, 1944 in Simpson, 1985). In the Northern Isles the soil pH of the anthropogenic soils present at Marwick ranged from soil pH 5.6 – 6.2 (Simpson, 1997) and at Nairn, Dercon, et al., (2005) showed that modern land use could affect the soil pH of anthropogenic soils ranging from soil pH 5.6 – 5.9 in arable areas, soil pH 5.5 – 5.7 in pastoral areas and soil pH 4.5 – 5.0 in deciduous woodland. On Fair Isle the range of soil pH values across all landuse areas is 4.3 – 6.8, moderately acidic to almost neutral level which accords with past results from other Scottish deepened topsoils but the results can also be interpreted between landuse areas. The soil pH results from a variety of landuse areas mirror those from Greaulin, Isle of Skye where the onsite soil pH was higher than off site areas, especially kaleyards (Entwistle, et al., 1998). Both the results from the kaleyards indicate a similar range (5.5 – 6.5, Entwistle, et al.,

1998) and (4.9 – 6.8 section 5.2.1) with a slightly more acidic infield (<5.5 – 6.0 Entwistle, et al., 1998) and (4.3 – 5.7, section 5.2.1) and a similar range in the outfield (<5.5 – 6.0 Entwistle, et al., 1998) and (4.9 – 5.9 section 5.2.1). This suggests possible similarities between the manuring methodologies and that the added components were very similar (peat, turf, seaweed) and also that environmental conditions are likely to have been similar.

Results from Olthof in the Netherlands (section 5.2.2) can be directly compared to results from the black and brown plaggen soils (Pape, 1970), historical landuse (van Smeerdyk, et al., 1995) and present day landuse (Dercon, et al., 2005). Both types of plaggen soils were identified at Olthof and by combining all the data from the different horizons a range in soil pH results was calculated. In the black plaggen soils a range of soil pH 4.0 – 6.0 was found, considerably less acidic than for the black plaggen results identified by Pape (soil pH 3.8 – 3.9). In the brown plaggen soils a soil pH range of 4.6 – 5.9 was identified compared to a soil pH of 3.9 – 4.2 in Pape's analysis. In both cases the soils became less acidic with the change from black to brown plaggen soil, however the overall soil pH is considerably lower in Pape's work, possibly because this project utilised a larger data set in a number of landuse areas. The soil pH figures and ranges are more closely linked to the analysis conducted by van Smeerdyk, et al., (1995) at Valthe where an infield area was compared to several outfield fields manured at different times in the past. The results ranged very little, from soil pH 3.8 – 4.4 (inner arable) to soil pH 4.0 – 4.8 (outer arable), but the soils were slightly more acidic. In this analysis the inner arable area revealed a large range between soil pH 4.0 and 6.0 and 4.0 – 4.8, suggesting that whilst there was no differentiation in the natural soils, there was a different localised change in soil pH in the infield areas because of a range of environmental factors, including different manuring strategies, post burial leaching and surface landuse change. Recent analysis of anthropogenic soil pH has considered the role of modern landuse and vegetation cover as a factor in differing soil chemistry (Dercon, et al., 2005; Mackenzie, 2006). A number of the sample areas were placed in a range of modern landuse areas namely: arable, pastoral and woodland. In the arable areas a range of soil pH 4.0 – 6.0 was identified compared to a range of soil pH 4.4 – 4.9 which indicates some

variability, but the results but still show a moderate acidic soil. In the pasture area a range of soil pH 4.7 – 5.6 was identified by Dercon, et al., (2005) compared to a similar range between soil pH 4.0 – 5.8. The greatest difference came in the woodland samples where Dercon revealed a range between soil pH 3.6 – 4.8 but this analysis indicated a higher range between soil pH 4.8 – 5.5, possibly because the test pit excavated in this thesis was only on the very edge of a small wooded area whereas Dercon's samples were taken from a pit positioned in the middle of a wood. Nevertheless the results gathered in both analyses are very similar.

In Ireland soil pH (section 5.2.3) has been used very successfully to assist the interpretation of sanded soils, especially in the coastal areas where calcareous beach sand has been used in a substantial way to decrease the acidity of the upland soil (soil pH 4.0 – 4.5). Conry's interpretation of the soil pH results from four sites on the Dingle peninsula showed that sanded soils (soil pH 7.3 – 8.4) had considerably higher soil pH than unsanded ones (soil pH 5.8 – 6.0) (Conry, 1971). This pattern was also found at Caheratrant (soil pH 7.8 – 8.5 sanded) to (soil pH 4.9 – 6.1 unsanded) but on closer analysis within test pit sequences and also across different landuse area more varied patterns of sanding could be seen through the soil pH values. The older kaleyard sequence (test pit ten) had distinctive horizons of almost pure calcareous sand and gravel giving very high soil pH values (7.8 – 8.5) but there were also horizons of more neutral anthropogenic dumps and redeposited natural horizons with a lower soil pH ranging from 6.8 – 7.0. In the inner and outer arable areas there were areas of moderate acidity (soil pH 4.9 – 6.1) and also distinctive areas of neutrality (soil pH 6.8 – 7.1) alongside areas which appeared to have no direct sanding ranging from soil pH 4.0 – 5.2. If the use of calcareous sand is taken as a marker for anthropogenic manuring, then there is clearly an increase towards the centre of the farm and a focus in kaleyards with less regular additions in the inner arable areas and even rarer additions in the outer arable areas and reclaimed and semi-upland areas.

5.3 SOIL ORGANIC MATTER RESULTS FROM FAIR ISLE, THE NETHERLANDS & IRELAND

Soil organic matter (SOM) comprises stable organic matter partially disintegrated and heavily decomposed plant and animal residue together with other organic compounds broken down by microbial activity. It heavily influences the physical, chemical and biological properties of soil (Brady and Weil, 2002). Organic matter helps to bind mineral particles which in turn creates a granular structure and forms the basis on which plant species may grow and continually add more organic material. Soil organic matter is a major source of soil nutrients in the form of phosphorus, sulphur and nitrogen and increased fertility (Brady and Weil, 2002). High nutrient levels can be maintained through careful management of tillage and grazing but more importantly can be very easily lost through a lack of organic or mineral manuring, erosion of soils by water and wind, intensive deep cultivation or overgrazing (French, 2003).

Most soils contain a range of organic matter in a range of forms depending upon environmental conditions, therefore identifying and interpreting human influence on soil organic content arises with detailed sampling of a range of soils alongside analysis of natural sequences in order to compare and contrast natural results with anthropogenically enhanced sequences. Humans can affect the level of input of soil organic matter indirectly by inhabiting a site but more commonly anthropogenic increases in soil organic matter is most evident from the deliberate process of manuring with natural components (turf, peat, seaweed etc) and waste deposits from settlements. The anthropogenic effects of soil organic matter can also be used to interpret human effects on the landscape (Crowther, 1997).

In archaeological deposits, soil organic matter analysis has been used alongside other soil chemical methods (soil pH, section 5.2, particle size analysis, section 5.4 and elemental analysis, section 5.5) to identify the differences and development of compacted organic floor deposits through experimental archaeology at Butser (Macphail and Cruise, 2001) and Umeå (Engelmark and Linderholm, 1996). In anthropogenic soils, soil organic matter analysis has been utilised to indicate the level of human input (Pape, 1970;

Conry, 1971; Davidson and Simpson, 1984; Adderley, et al., 2000), to determine the input in a variety of different landuse areas across a settlement (Bryant and Davidson, 1996; Entwistle, et al., 1998) and used to analyse the levels of soil organic matter before and after manuring (Simpson, 1985; Entwistle, et al., 2000).

The results of the soil organic matter were analysed using loss on ignition (LOI) and the methodology used in this project is described in chapter 1; section 1;13. A full list of data is displayed in (appendix 9) and the data is displayed by site Fair Isle (section 5.3.1), the Netherlands (section 5.3.2) and Ireland (section 5.3.3) and figs 91 to 93.

5.3.1 LOSS ON IGNITION RESULTS FROM FAIR ISLE

The LOI results from Fair Isle have very distinctive patterns which are a consequence of the addition of organic material and are also due to the soils ability to retain organic matter (Fig 92). At all three landuse areas there is a distinct decrease in mean percentage LOI with depth as a result of organic manuring and a regular post burial breakdown over time.

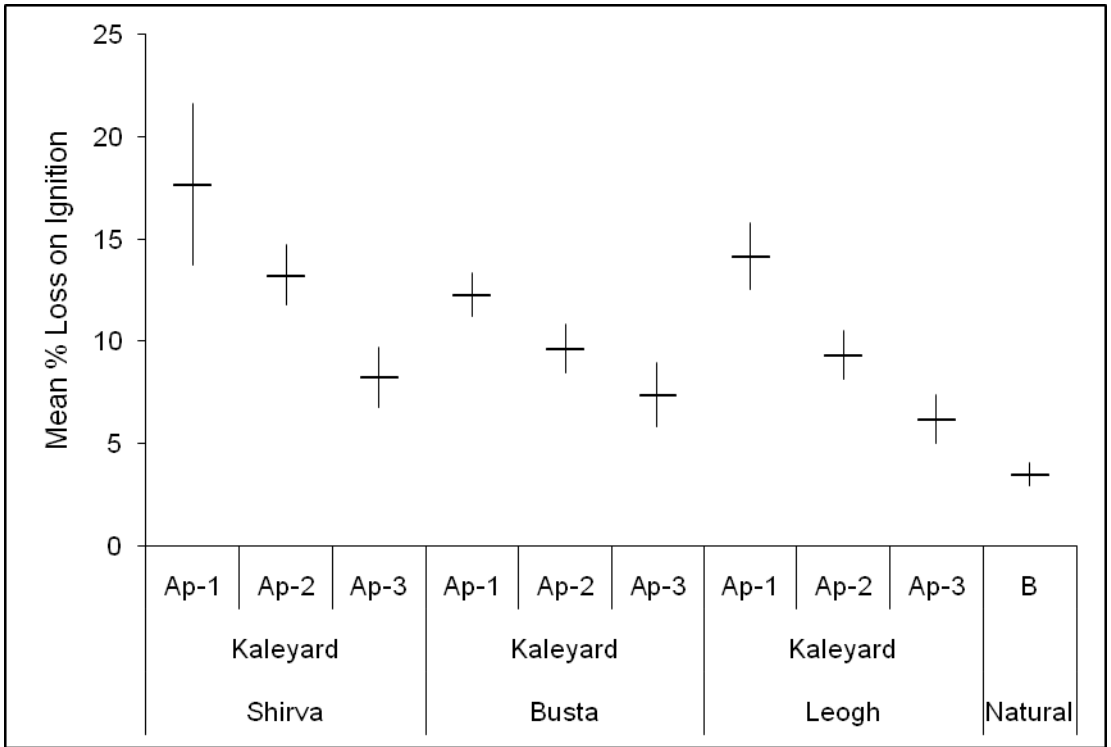


Figure 92, Mean percentage loss on ignition at three kaleyards from Fair Isle

In Shirva kaleyard the mean results decrease from 17.69% in the Ap-1 horizon to 8.27% in the Ap-3 horizon suggesting a considerable addition of peat and turf organic material. The high percentage LOI in the kaleyard clearly illustrates the importance of the areas directly adjacent to the farms. The range of results in the Ap-1 indicates, however, that there is large variation in the results. This may be due to the infrequency of organic addition or possibly because of high levels of mixing resulting in the decomposition of organic components. In the Busta kaleyard area the Ap-1 horizon has a mean percentage LOI of 12.29% to 7.40% in the Ap-3 horizon. These results suggest that there has been a fairly consistent input of organic inclusions into the soil horizons alongside a similar level of post burial breakdown. A slightly greater contrast between the upper and lower amended arable soils is evident in the Ap-1 horizon at Leogh kaleyard. The results decrease with depth from 14.16% (Ap-1) to 6.21% (Ap-3). The similar pattern of results from all three kaleyards illustrates a very similar overall pattern of manuring with organic material over time along with distinctive post burial decomposition.

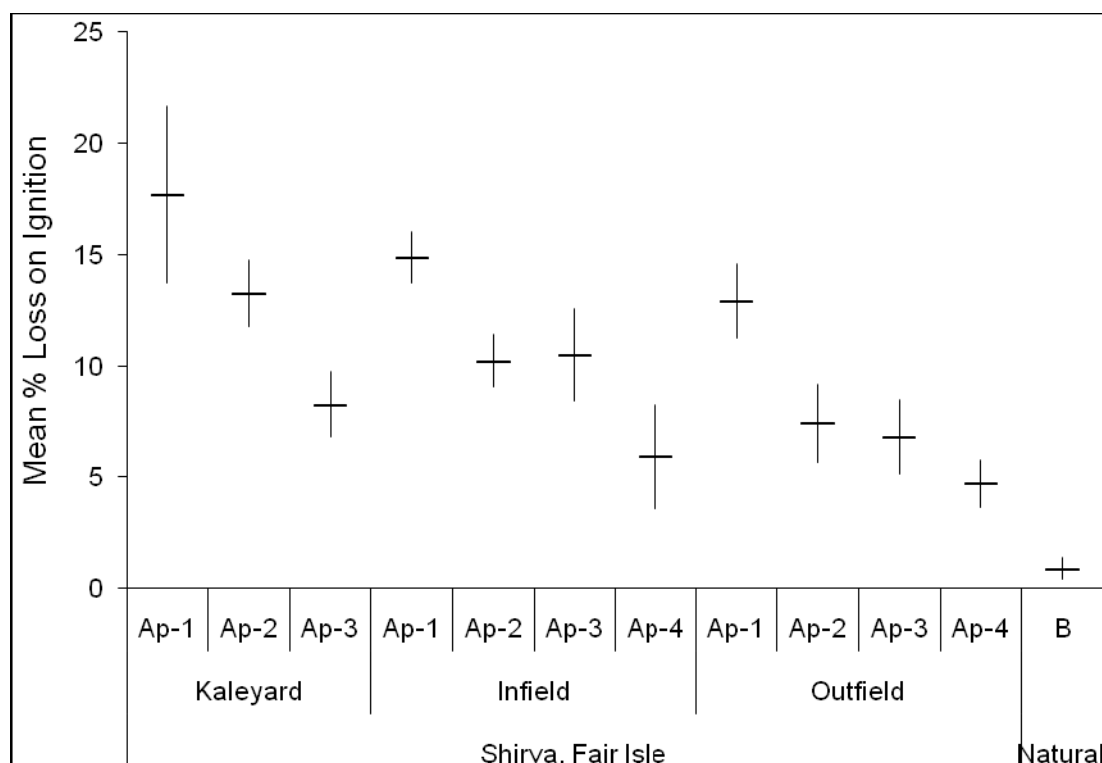


Figure 93, Mean percentage loss on ignition from three landuse areas at Shirva, Fair Isle

A similar decrease in results with depth is evident in the three different landuse areas at Shirva (Fig 93) but there are a number of distinctive differences. As discussed the results from Shirva kaleyard show a clear decrease with depth with particularly high results in the Ap-1 horizon. Similar peaks in LOI results are also present in the upper horizons of the infield area (14.87%) and the outfield area (12.93%) and these may reflect an increase in the input of organic manure or because of the presence of grass since the change from arable to pastoral landuse. There are more distinctive differences in the infield and outfield area results in the Ap-2 and Ap-3 horizons. In the infield the mean results range from 10.24 to 10.51% and the outfield results range from 6.81 to 7.43%. These results suggest that the traditional manuring of the infield and the outfield appears to have occurred in a very similar way possibly as a result of the careful management of a limited organic peat and turf source. Certainly in all cases the amended arable soils contain considerably higher percentage LOI compared to the natural soils of the island.

5.3.2 LOSS ON IGNITION RESULTS FROM OLTROF, THE NETHERLANDS

The results from the Netherlands are considerably lower than at Shirva, however a similar pattern is evident (Fig 94). The Ap-1 horizon contains a higher mean percentage (3.81%) than the Ap-2 horizon (2.79%) and Ap-3 horizon (2.00%) which have levels closer to the natural (1.02%), indicating a steady increase of organic material in the lower anthropogenic soils, then a distinctive increase in the upper horizons which fits the hypothesis of increased manuring in the upper black plaggen soil than in the brown plaggen soil. The range of results from the different soils is much less defined than from Fair Isle, possibly because less organic material was added to the soils but this seems unlikely due to the depth of anthropogenic soil excavated (+1.75m); a far more likely explanation is that the organic levels have been subjected to severe post burial leaching by soil water flowing easily through the sandy soils removing organic matter since manuring ceased.

In the inner arable area the LOI results are very similar to the garden results with a steady reduction with depth from 3.51% in the Ap-1 horizon to 1.85% in the Ap-3. The range of results in the anthropogenic soils is also very similar with very slightly higher ranges in the Ap-1 and Ap-2 horizons suggesting similar post burial process are occurring in the inner arable area but perhaps at a more uniform rate.

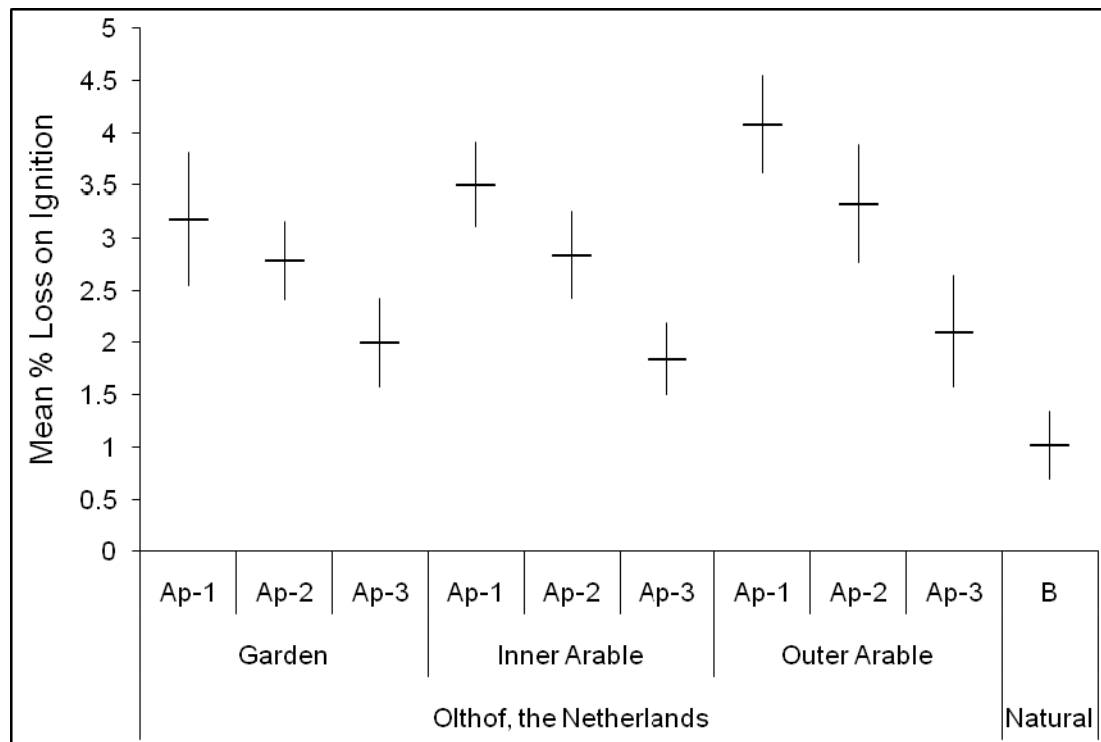


Figure 44, Mean percentage loss on ignition from three landuse areas at Olthof, the Netherlands

The mean LOI results in the outer arable areas at Olthof are highest in the Ap-1 (4.08%) and similar results in the Ap-2 horizons (3.33%) and reflect the addition of heathland turf but also the remnants of existing organic material left over from recent crop growth. In the Ap-3 horizon the results are slightly lower (2.11%) but have a similar range suggesting a similar organic input rate over time. The natural soils have a lower percentage still (1.02%).

5.3.3 LOSS ON IGNITION RESULTS FROM CAHERATRANT, IRELAND

The LOI results from Caheratrant are illustrated in Fig 95 and have a distinctive distribution across the site. In the kaleyard area the mean LOI values decrease down profile from 8.94% in the Ap-1 horizon, 5.34% in the Ap-2 horizon, 4.21% in the Ap-3 horizon, indicating a higher organic input in the upper amended horizons and an increase in post burial processes over time. The range in results in the Ap-1 horizon also, indicates localised changes in soil organic matter through the increased addition in places and post burial depletion. The Ap-3 horizon has a very low organic level and its proximity with the natural soil may have resulted in the very similar results.

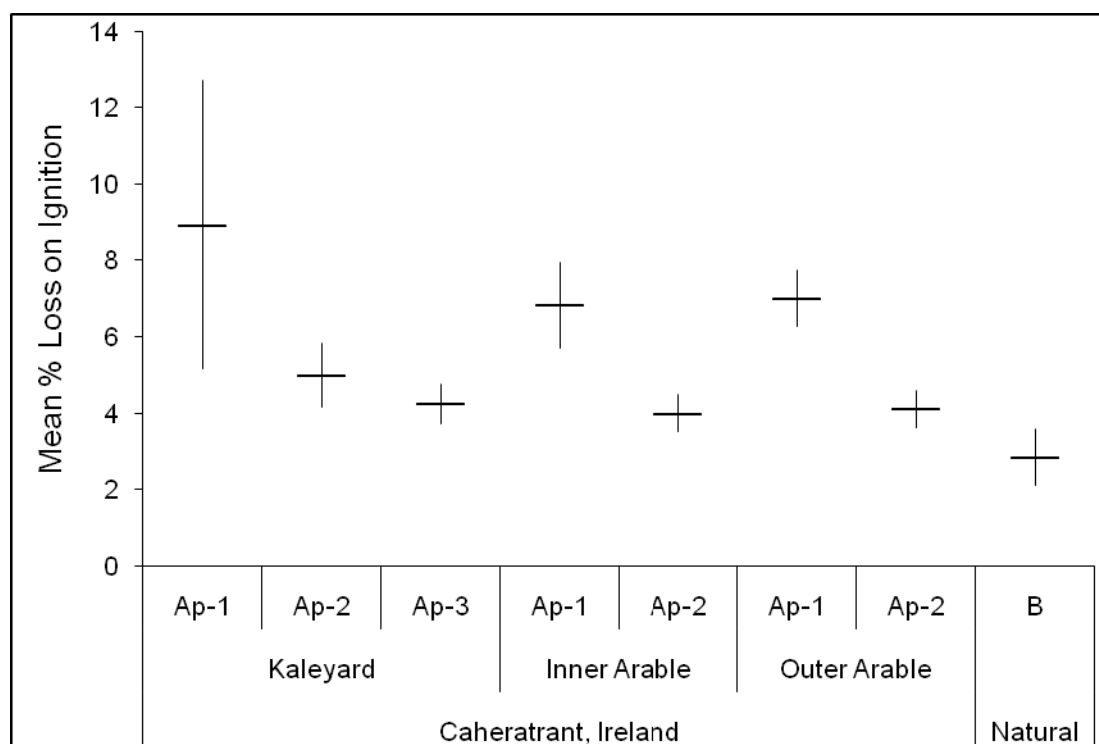


Figure 95, Mean percentage loss on ignition from three landuse areas at Caheratrant, Ireland

In the inner and outer arable areas the LOI results are highest in the Ap-1 horizon (6.90%) and (6.88%), indicating considerably less organic manure addition compared to the kaleyard. Alternatively, the LOI results in the upper horizon of these areas may represent the continued addition of manure by the grazing of cattle on the old arable area, a process which would mask

past manuring activity. The Ap-2 horizons in the two areas are also similar (4.12%) and (4.02%) suggesting that throughout the history of the two areas there has been a similar pattern of organic input and no distinct change of landuse. This interpretation fits well with the agrarian history of the site which has only includes arable and pastoral farming. In all the amended soil horizons there is a clear increase compared to the natural soils (<3.50%).

5.3.4 LOSS ON IGNITION RESULTS FROM UPLAND AREAS AND NATURAL SOILS

At each site samples of the natural organic manuring components and natural soils and sediments were collected in order to determine the loss on ignition and aid the interpretation of the results gathered from the amended and anthropogenic soils. Organic results are highest in the peat and turf samples from Fair Isle (92 – 94%) and Caheratrant (79 – 88%) but high results are also present in seaweed samples (58 – 65% Shirva) and (71 – 77% Caheratrant), both of which could have easily led to higher loss on ignition results in the anthropogenic soils. By contrast, at Olthof, the meadowland horizons have between 5 – 7% loss on ignition and the heathland soils, used in the development of the black plaggen soils, only 7 – 9%. The distinctive low loss on ignition results in both types of manure at Olthof is reflected in the low results at each landuse area, and may explain the depth of anthropogenic soils if constant, heavy manuring was required to maintain the soil fertility. The three buried soils identified at each of the sites illustrate a decrease in loss on ignition compared with the natural horizons. The most obvious reduction is seen at Shirva where the peaty palaeosol contains only 10 – 12% as a direct result of truncation by heavy ploughing. At Caheratrant, less truncation and burial by colluviation has resulted in the buried peat containing 40 – 42%, however the remnant, buried heathland soil in Olthof outfield illustrated only a minor reduction in loss on ignition (2 – 5%) because it was concentrated in a tree-bowl feature.

5.3.5 DISCUSSION AND COMPARISON OF THE LOSS ON IGNITION RESULTS WITH PAST WORK

The first study to analyse soil organic matter in anthropogenic soils took place in the Netherlands. Pape, (1970) showed that the percentage loss on ignition differed between the black plaggen 5.3 – 6.1% and brown plaggen soils 2.8 – 4.2% and that an increase in the soil organic matter increased with soil colour because of the manuring components (Pape, 1970). Overall the Dutch samples taken at Olthof (section 5.3.2) mirror Pape's results and show that the black plaggen soils range from 2 – 6% with an outlier of 9% and the brown plaggen soils range from 1 – 4%. The results from the analysis of the natural components also compare to direct statements from Pape who suggests that the *“A1 material of heather sods, from which the black plaggen soil in particular have developed, already had a higher organic matter content than the material of grass sods. Moreover, it is less affected biologically. In brown plaggen soils with approximately 10% clay, the organic matter content of approximately 3% corresponds with what is often encountered in alluvial soils”* (Pape, 1970 p241 – 42). The results in figure 94 also show that there is a difference in the organic levels between the two main components of plaggen soils but that more detailed sampling across a single site indicates much more variation in the soil organic content based upon addition, mixing and post burial pedogenesis.

In Ireland loss on ignition was conducted on a range of soils from coastal sites in order to determine organic input by manuring (Conry, 1971). The highest organic levels identified were in both the sanded (1.9 – 5.5%) and non-sanded (6.2%) anthropogenic soils of Castlegregory on the Dingle Peninsula. Conry's sampling was very limited and the results suggest that there is a higher organic level in the more acidic soils whereas the sanding process was conducted to add mineral to the soils and raise the soil pH. At Caheratrant the sample areas did show a large range of results and there were areas where natural peaty soils revealed a higher organic level than the anthropogenic soils (section 3.5.3). At other areas sampled by Conry the organic level of anthropogenic soils was even lower, Clonakilty, County Cork (1.0 – 2.9%), Ballydavid, County Kerry (0.8 – 1.5%), Pillmore, County Cork

(0.7 – 1.2%) (Conry, 1971). Historically, these areas were very well manured with calcareous sand and manure and the low LOI results suggest that since the end of the addition of organic material the soil has lost a large amount of organic components.

In Scotland the deep topsoils of Orkney were the first to have loss on ignition analysis conducted upon them and this revealed an equally low but consistent sequence of results ranging from 2.0 – 3.1% and decreasing with depth regularly (Davidson and Simpson, 1984). More recent approaches to analysis have taken into consideration the different landuse areas (van Smeerdijk, et al., 1995; Bryant and Davidson, 1996 and Entwistle, et al., 1998). The soil organic matter of the infield and outfield areas were analysed at Valthe in Drenthe and the results showed that the infield ranged from 2.8 – 4.9% whereas in the outfield areas a range between 2.2 – 6.0% was found with a minimal 1.2 – 1.3% in the natural soils (van Smeerdijk, et al., 1995). A similar pattern was identified by Entwistle, et al., (1998) who increased the sample size and showed that at Grealin on the Isle of Skye, the offsite loss on ignition levels were higher than the on site results. In the majority of the kaleyards tested the percentage loss on ignition ranged from 10 – 15% on Fair Isle though, the overall range from the kaleyard is 9.3 – 17.7% but within that there was much more variation which reflects methods of manuring specific to individual farms (Fig 92). The infield areas at Grealin were very mixed with an almost equal number of fields with little organic matter (1 – 4%) to some with over 20%, but clear patterns were evident in fields around particular farms averaging 10 – 15%. At Shirva there was a minor drop in organic content in the infield soils but many areas maintained a similar average of 8 – 15% in upper layers and 3 – 8% in lower horizons (Fig 93). There was a major difference in the results, however, from the outfield areas which at Grealin were almost all over 20%, but at Fair Isle had decreased further to 5 – 10%. This may be because of the limited quantity of natural undisturbed organic soils still present on the island or because of arable activity in the upland areas which could have decreased the available of organic material (Entwistle, et al., 1998). The comparison of Grealin with Fair Isle may not be an entirely fair one because of the size of the island and therefore the quantity of available manuring material. In 1996 loss on ignition

analysis at Olligarth on the island of Papa Stour, Shetland showed very high percentages suggesting high organic levels as a result of poor drainage. In the kaleyard the results ranged from 16.6 – 17.8% whereas in the infield area the results were considerably lower and ranged from 3.9 – 10.6% (Bryant and Davidson, 1996). The Fair Isle results are more concordant with Bryant and Davidson's results suggesting a similar method of manuring was undertaken in both areas. The evidence at Fair Isle indicates an enormous level of peat removal which would be responsible for high organic levels. As with some examples from Fair Isle and Ireland, in places a remnant peat horizon was identified with a high organic content and a similar horizon was encountered at Papa Stour with an LOI percentage of 38.6% suggesting a landuse change after the removal of the overlying peats for manure.

However, it is also very important to understand the process and level of organic loss in anthropogenic soils subsequent to their formation. Dercon, et al., (2005) measured the LOI in a number of anthropogenic soils from a range of modern landuse areas. Direct comparisons of the Olthof results show that the modern arable areas had a range of between 2.2 – 4.7% and in this analysis ranged from 2.0 – 6.0% with an outlier of 9.0% in the modern pastoral areas. Dercon's results indicate a range between 1.3 – 3.0% and the results from this analysis complement that data ranging from 1.0 – 4.0%. The highest percentage loss on ignition identified by Dercon was in the woodland area (2.4 – 6.3%) and again a very similar range was identified in the present work (3.0 – 6.0%).

5.4 PARTICLE SIZE RESULTS FROM FAIR ISLE, THE NETHERLANDS & IRELAND

Particle size analysis is the measurement of sand, silt and clay particles within a soil or sediment. The quantification of this enables the texture and particle size distribution of the soil to be determined. On the whole the particle size of soils is determined by the nature and texture of underlying sediments and the geology of the site, but the analysis can also be utilised to indicate unnatural variations in texture and changes in the physical nature of soil e.g. structure, drainage, organics which in some cases can be attributed

to human action. The three areas under analysis are all located on very similar sandy geologies and this was to enable a fairer comparison of the particle sizes present in the anthropogenic soils and attempt to interpret any differences. This detailed analysis will complement the soil texture analysis conducted in the field which has already illustrated that many of the soils have predominantly silt and sand textures. The particle size methodology is discussed in chapter 1, section 1.13 and the graphs in the following section illustrate the results site by site; Fair Isle (5.4.1 to 5.4.3), the Netherlands (5.4.4 to 5.4.6) and Ireland (5.4.7 to 5.4.9). (Raw data in appendix 10).

5.4.1 PARTICLE SIZE RESULTS FROM FAIR ISLE KALEYARDS

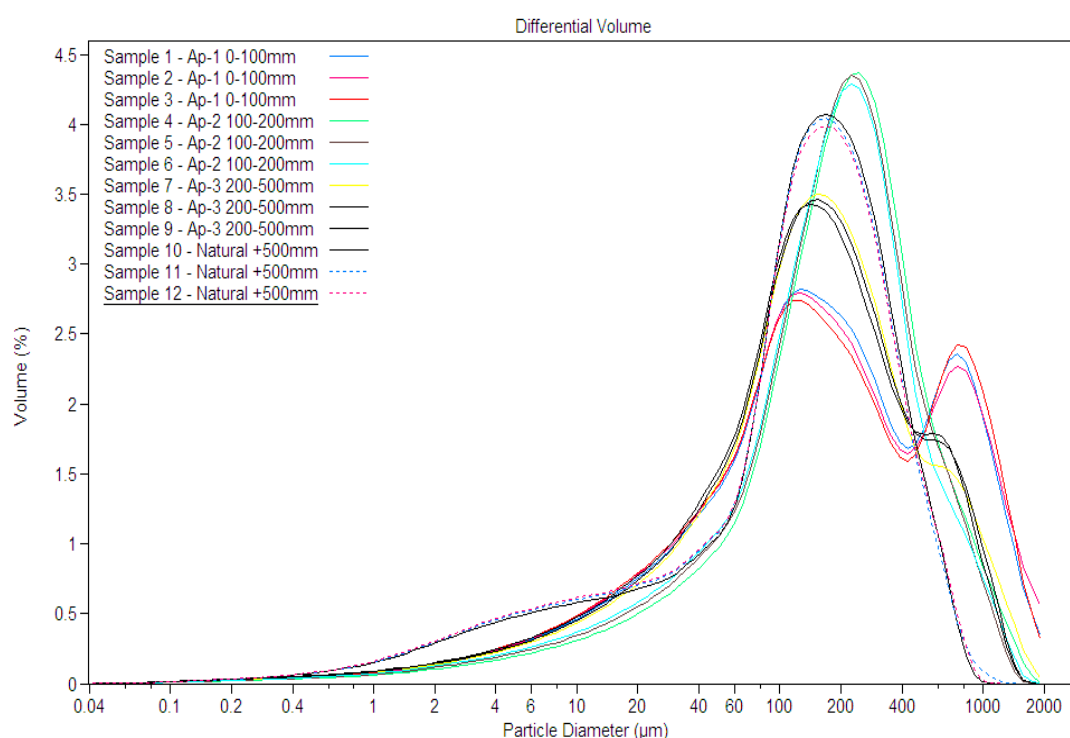


Figure 96, Particle size results from test pit 2, Shirva kaleyard, Fair Isle

The particle size results from the three kaleyards on Fair Isle have very similar particle size distributions, however there are small textural differences throughout the amended horizons which may be due to varieties in input material (Fig 96). At Shirva the particle size results in the amended soils is very consistent, between 60 – 500µm, and the volume increases with depth towards the natural which has a similar range of results. This similarity

suggests a large input from natural sources deriving from either the deliberate addition of peat and turf, sanding or marked post depositional mixing. There is a very small peak of coarser sediment in the upper Ap-1 horizon which decreases with depth and this may correspond to the addition of modern waste material in the form of brick, tile and stone fragments or possibly an increase in carbonised particles.

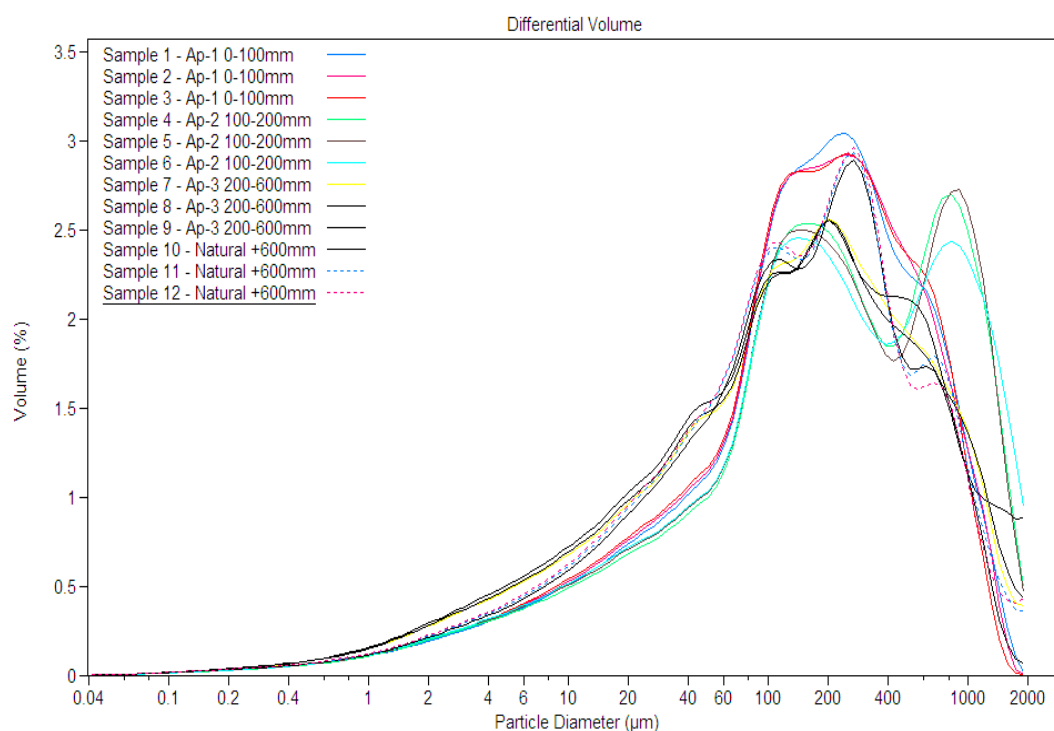


Figure 97, Particle size results from test pit 8, Busta kaleyard, Fair Isle

The particle size results from Busta kaleyard (Fig 97) reveal a different textural pattern which suggests different methods of soil development and post burial processes. Like Shirva most of the amended horizons have a soil texture between 60 – 500μm but there are a larger percentage of results which are over 1000μm indicating coarser grained material, possibly anthropogenic material. There is also a larger finer grained component to the soil horizons from the breakdown of organic inclusions and the natural till soils, most likely from deep mixing through the regular use of a soil rotivator.

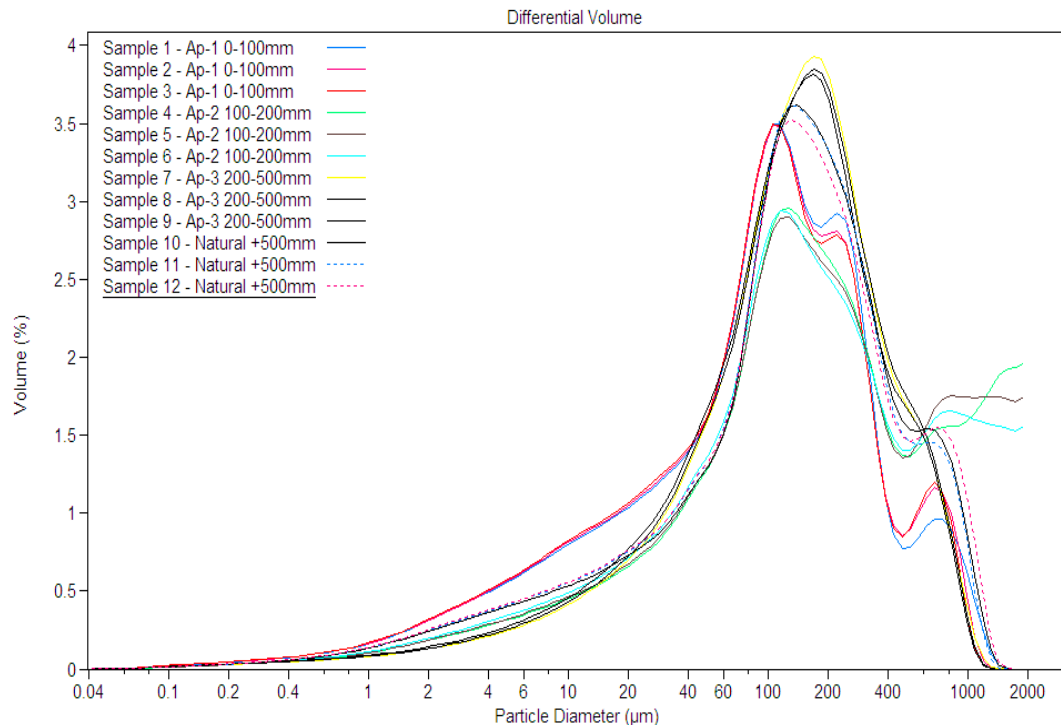


Figure 98, Particle size results from test pit 9, Leogh kaleyard, Fair Isle

The particle size results from Leogh (Fig 98) are very similar to the results from Shirva and the amended horizons are dominated by particles diameters of between 40 – 500μm. The soils have very similar particle size to the natural sandy soils and this suggests input from organic fragments with large quantities of natural mineral material alongside considerable mixing from spade and plough action. The Ap horizons also contain some finer grained inclusions which may derive from the organic manuring components or from the frequent washing of silt and clay particles downslope with time. Evidence of the inclusion of anthropogenic material in the soils is inferred from the inclusion of coarser material over 1000μm which decreases with depth from the Ap-1 to the Ap-3 horizons and is absent from the natural soils. This is likely to be fragments of mineral and black carbonised and amorphous fragments added to the soils as part of the manuring process. Overall the kaleyards on Fair Isle have very similar particle size diagrams suggesting very similar methods of manuring over time, and this maybe a direct reflection of the limited resources available on the island.

5.4.2 PARTICLE SIZE RESULTS FROM SHIRVA INFIELD

Compared to the kaleyards the infield area of Shirva (Fig 99) has a much more varied particle size distribution, although there is a clear pattern of particle size between 60 – 500 μ m. The soil horizons in test pits 1, 3 and 4 have very similar results suggesting a similar manuring process, with a large input of sand particles in the organic material. Interestingly there is a larger finer clay and silt component, possibly from the natural till or from peat and turf fragments included in the manure. The lack of a distinctive coarse tail over 1000 μ m suggests that less anthropogenic material from settlement centres was added to the infield areas. The archaeological feature found during fieldwork was sampled and this has a considerably coarser particle size than the surrounding horizons due to the inclusions of very large stone fragments along with a very sandy, organic rich packing sediment which may also contain evidence about the structures construction and destruction.

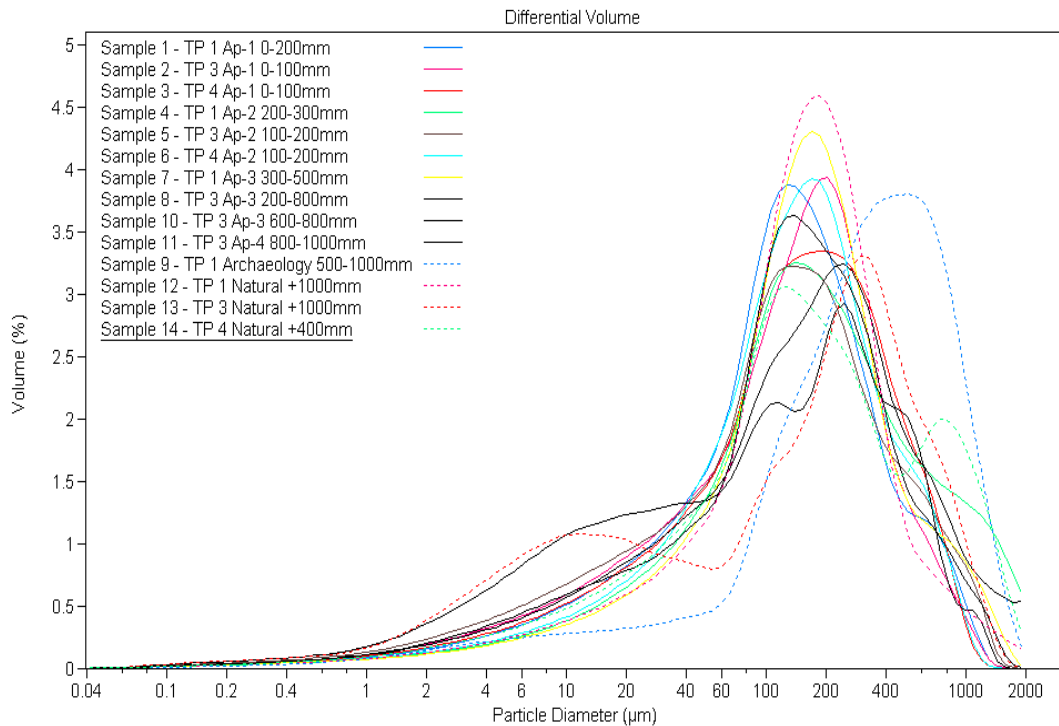


Figure 99, Particle size results from test pits 1, 3 & 4 Shirva infield, Fair Isle

5.4.3 PARTICLE SIZE RESULTS FROM SHIRVA OUTFIELD

The amended soils in the outfield area at Shirva have the most diverse range of particle size distributions (Fig 100). The Ap soil horizons at all three outfield test pits contain considerably more silt and clay particles than the natural soil horizons as a result of the inclusion of fragments of the peaty H horizon. The palaeosol also contains a large amount of coarser grained sandy inclusions ranging from 100 – 400 μ m, derived from considerable mixing with the natural and amended soils. The arable soils contain a very diverse range of results from 60 – 1000 μ m and this variation may be closely linked with the mixing of coarser natural sandy till (1000 – 2000 μ m) during ploughing. The coarse fraction may be due to amendment with waste material from the centres of the farms, but the field evidence discussed in chapter 2, section 2.6.4 suggests that very little waste input was occurring in the outfield areas unlike the kaleyard and infield areas.

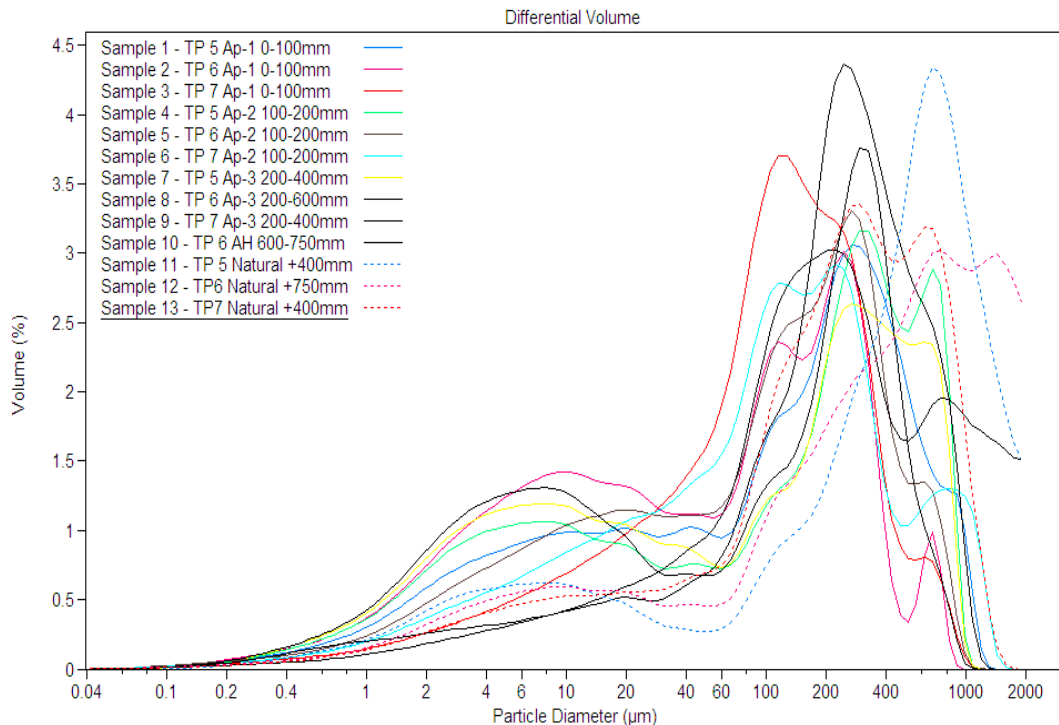


Figure 100, Particle size results from test pits 5, 6 & 7 Shirva outfield, Fair Isle

5.4.4 PARTICLE SIZE RESULTS FROM OLT Hof GARDEN

The particle size results from the garden at Olthof show very distinctive uniformity throughout the anthropogenic horizons with most of the soils containing particles between 60 – 600 μ m (Fig 101). The graph also shows that the soils contain almost no fine grained silt and clay particles but a more varied coarse fraction between 600 – 2000 μ m, derived either from the natural coversands or from the addition of coarse human waste material from farms. Field evidence revealed the presence of large amounts of building material including brick, tile and stone. The particle size results of the anthropogenic soils and the natural coversands are very similar suggesting either a source from considerable mixing by ploughing or from the addition of heathland and meadow turves which have a similar particle size and make the boundary between the brown and black plaggen soil almost impossible to determine.

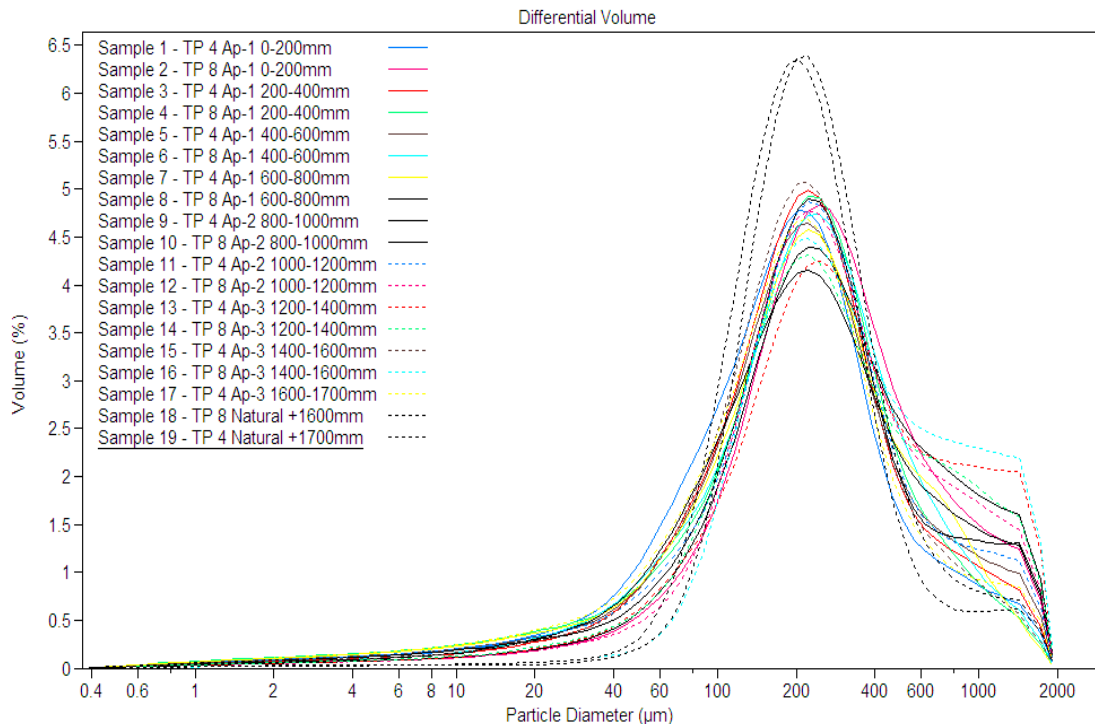


Figure 101, Particle size results from test pits 4 & 8 at Olthof garden, the Netherlands

5.4.5 PARTICLE SIZE RESULTS FROM OLT Hof INNER ARABLE AREA

The particle size results from the Olthof inner arable area (Fig 102) are more diverse than the results from the garden but the anthropogenic soils still contain a particle size between 100 – 600µm. The three sample areas illustrate a very slight increase in coarse sand inclusions with depth and there are very few fine grained silt or clay particles below 40µm. By comparison the coarse fraction of the soil horizons is much more variable, illustrating either the input of more anthropogenic waste material in the form of brick, tile, pottery and bone or the addition of coarser sands from the natural soils used as manure. There are particularly coarse fractions in the Ap-1 and Ap-2 horizons suggesting more material from settlements was incorporated into the soils during the development of the black plaggen soils.

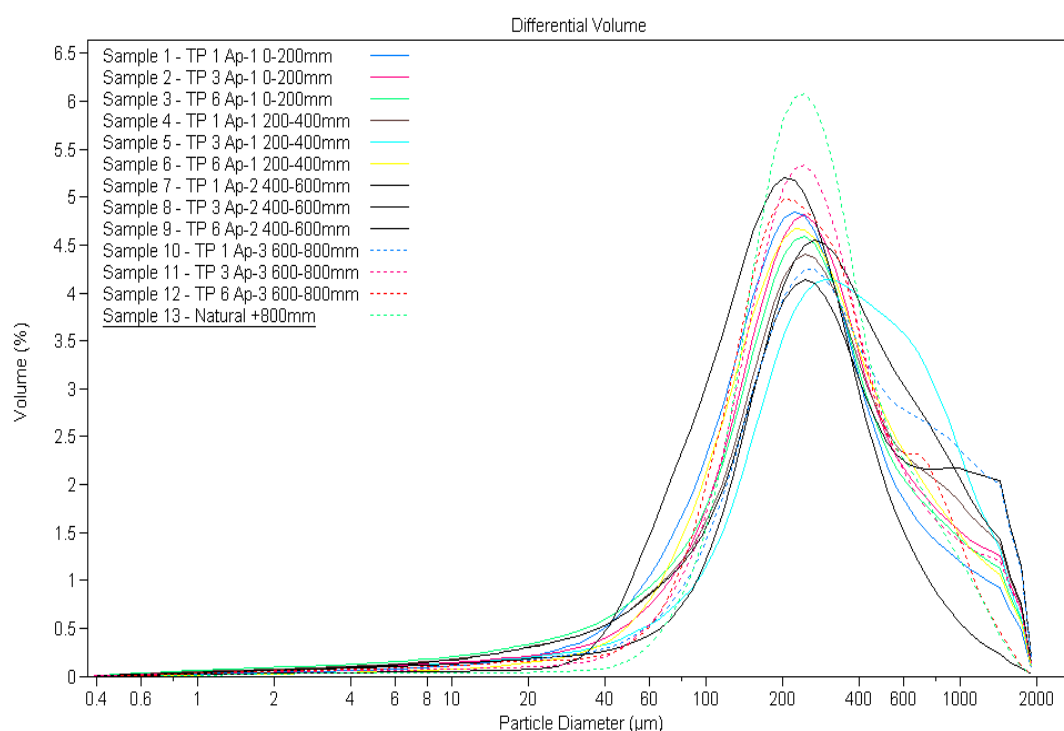


Figure 102, Particle size results from test pits 1, 3 & 5 at Olthof inner arable area, the Netherlands

The lack of coarser anthropogenic inclusions in the brown plaggen soils may be due to post burial breakdown or transportation by soil organisms resulting in a loss of information regarding the formation of the horizons. The results may also reflect the Coulter Counter's inability to accurately measure

above 2000 μ m and possible ‘settling’ above 500 μ m which would affect the results.

5.4.6 PARTICLE SIZE RESULTS FROM OLT Hof OUTER ARABLE AREA

The particle size results from the Olthof outer arable area are illustrated in figure 103 and like the inner arable farmland and garden area they have very similar particle size results in the anthropogenic soils compared to the natural. Each of the anthropogenic soils contain results between 60 – 600 μ m with very little fine grained silts and clays (<60 μ m) and a more variable amounts of coarser sands (+600 μ m). In each of the test pits sampled there is a very slight increase in particle size with depth illustrating substantial mixing with the natural but also a distinctively lower volume of inclusions, suggesting the inclusion of coarser natural sediment or possibly anthropogenic material from settlements. The former is likely to be the case as very little anthropogenic inclusions were found in the outfield soils during fieldwork.

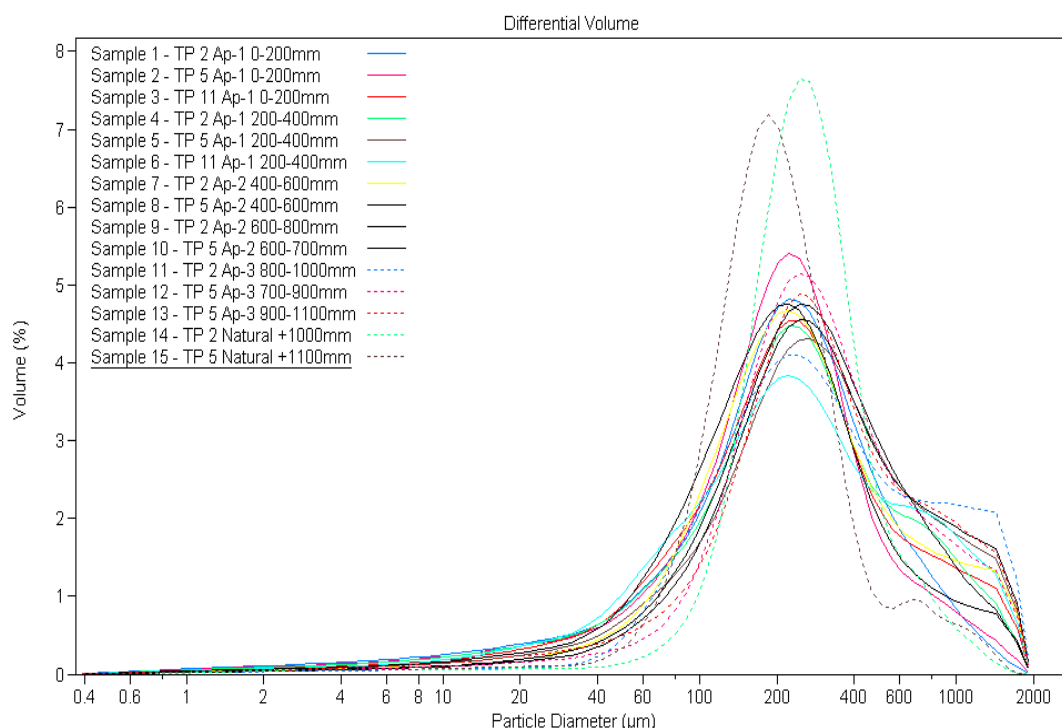


Figure 103, Particle size results from test pits 2, 5 & 11 at Olthof outer arable areas, the Netherlands

5.4.7 PARTICLE SIZE RESULTS FROM CAHERATRANT KALEYARD

The particle size results from Caheratrant show the greatest variation of all the kaleyards analysed (Fig 104). Overall the amended Ap horizons and the natural till soil contain a much larger fine grained component ($<100\mu\text{m}$) and a highly variable coarse fraction due to the incorporation of beach sand and till in the manuring process. In test pits 1 and 2 the soil horizons contain mainly sediment between $100 - 400\mu\text{m}$ which mirrors very closely the particle size of the beach sands used to increase the soil pH.

There is also a coarse component within the soils which most likely derives from the addition of charcoal, black carbonised particles, pottery and bone found in the field analysis. The natural soils in test pits 1 and 2 contain considerably coarser particle size results and considerable mixing by ploughing may have also transported these into the amended soils. In test pit 10 the buried sanding horizons have very distinctive particle size results.

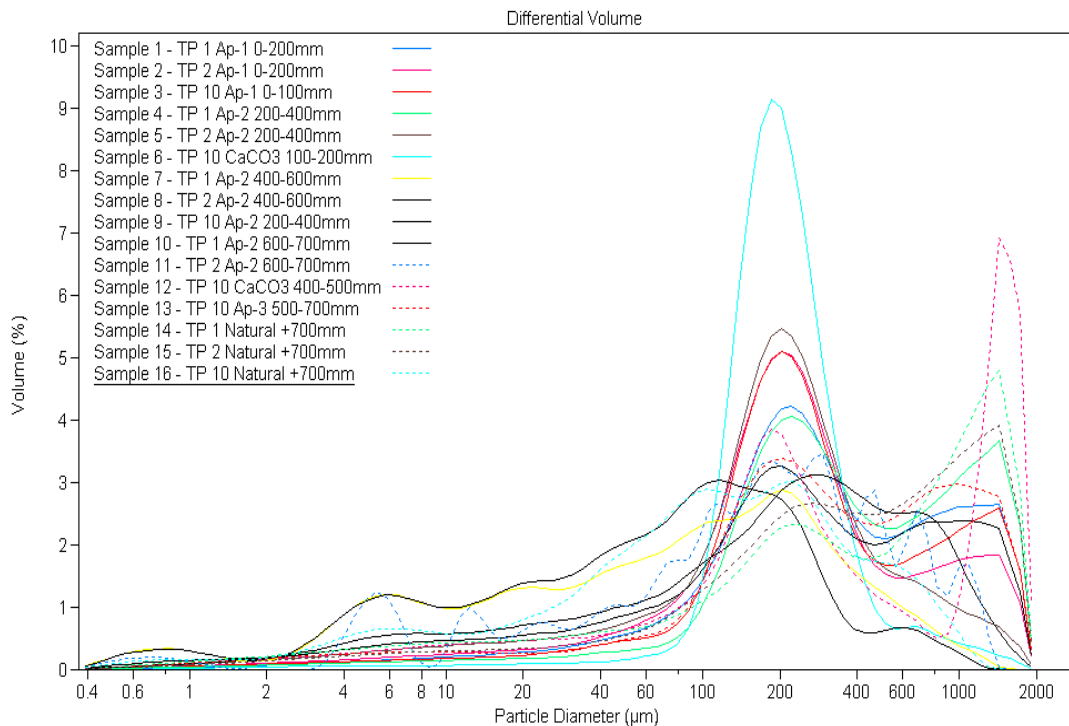


Figure 104, Particle size results from test pits 1 and 10, Caheratrant kaleyard, Ireland

The upper horizon is composed of sand between 100 – 400µm and appears to have been added directly to the kaleyard. The lower horizon is much coarser with results mainly between 1000 – 2000µm alongside a clearly coarser gravel component identified during fieldwork. The particle size analysis suggests that this horizon was probably mixed with organic material before being added to the kaleyard as a slightly higher fine grained component was found along with charcoal, organic and burning evidence from the fieldwork. The amended soils in test pit 10 contain very similar grain sizes to test pits 1 and 2 and illustrate a similar manuring regime across the farm. At each of the sample areas the Ap soil horizons contain more fine grained material than the natural tills soils and the results may derive from the addition of peat and turf.

5.4.8 PARTICLE SIZE RESULTS FROM CAHERATRANT INNER ARABLE AREA

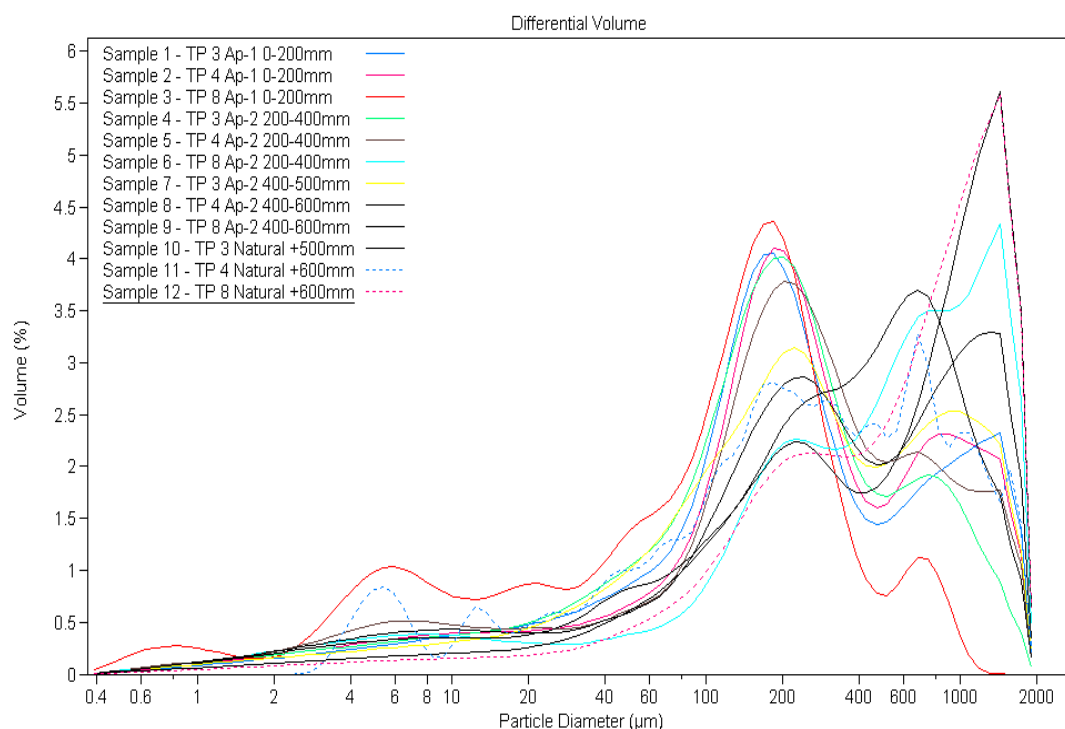


Figure 105, Particle size results from test pits 3, 4 & 8 Caheratrant inner arable area, Ireland

Like the kaleyard soils, the inner arable soils at Caheratrant contain highly variable particle size (Fig 105). Each of the amended soils contains inclusions between 100 – 400µm which derived from the natural sands and the addition of beach sand. The silt and clay inclusions are particularly prominent in the upper Ap-1 horizon as a result of the addition of organic turf and peat but the amount of inclusions over 400µm has increased particularly in the Ap-2 horizons due to mixing with the particularly coarse natural soils. The very coarse inclusions in both amended horizons may be present because of the addition of coarse fragments from settlement centres but the fieldwork evidence suggests that most of the coarse fraction is natural stone material and the anthropogenic inclusions which are present are considerably smaller.

5.4.9 PARTICLE SIZE RESULTS FROM CAHERATRANT OUTER ARABLE AREA

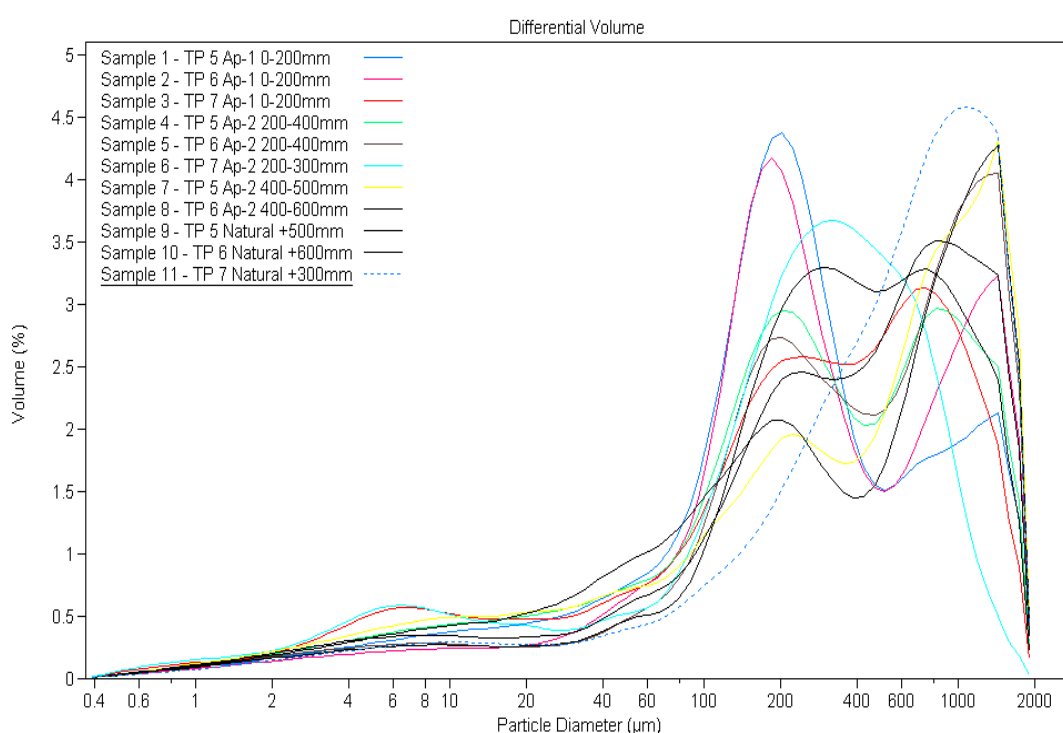


Figure 106, Particle size results from test pits 5, 6 & 7 Caheratrant outer arable area, Ireland

The particle size results from the soils in the outer arable area at Caheratrant show that there is an even more pronounced influence from the natural soils and inconclusive evidence of manuring (Fig 106). In test pits 5 and 6 particle size evidence shows a distinct peak in the Ap-1 horizon between 100 – 400µm which suggests that sanding is being conducted in this particular area. By contrast the furthest test pit from the farm (7) contains an organic soil with much coarser inclusions more akin to the natural soils and this suggest minimal input from sanding. However, manuring in the outfield generally appears to have been conducted until fairly recently as the lower amended soils in test pits 5 and 6 contain particle sizes very similar to the natural alongside minimal evidence of settlement material added. Compared to the inner arable area the level of fine grained silt and clay has also decreased suggesting considerably less input from organic peat and turf and only minimal manuring.

5.4.10 DISCUSSION OF PARTICLE SIZE RESULTS FROM THE THREE FARMS

The particle size results from the three sites show that the area closest to the farm centres (kaleyards and gardens), (Figs 96, 97, 98, 101 and 104) are dominated by similar range of particle size (100 – 1000µm) which is very closely linked to the particle size of the natural soils and indicates that the addition is derived either from the addition of mineral rich organic turf and peat fragments or from heavy mixing from ploughing or spade delling. Overall the fine grained clay and silts, in the soils (100µm), decrease with distance from the centre of the farms outwards indicating less manuring with fine grained organic material and an increase of post burial decomposition (Figs 95 to 106). The fine components (<100µm) also decrease with depth as a result of post burial decomposition of organic manuring components but there are distinctive local variations.

At Shirva and Caheratrant the fine grained clay and silt fractions may derive from turf and peat organics extracted from upland areas but the fine grained material may also come from sediment movement from the other landuse areas. Evidence for anthropogenic additions to the organic soils was

evident at Shirva and Caheratrant through the identification of coarser particles, which could be interpreted as deriving from the addition of human waste material in the form of bone, pottery and carbonised particles (Figs 96 & 102). In contrast at Olthof the fine grained (<100µm) component is very low and illustrates a lack of clay and silt in heathland soils used in the development of the black plaggen soils. Heavy leaching and post burial decomposition has also removed fine grained soil components in the brown plaggen soil which was developed with the meadowland turf. The uniform results from Olthof indicate a very different manuring process and post burial decomposition to the other sites but small differences in the particle size data show that there are similar patterns of organic and anthropogenic inputs to the soils (Figs 101 to 103).

5.4.11 DISCUSSION AND COMPARISON OF PARTICLE SIZE RESULTS WITH PAST WORK

Analysis of the particle size of anthropogenic soils has revealed a very high sand component with smaller amounts of fine mineral components. Pape's analysis in the Netherlands showed that the particle size of the deep stratigraphies varied very little between horizons (0-450mm 5.0-6.0-89%, 450-750mm 6.0-6.5-87.5%, 750-1100mm 6.0-9.0-85%) and also between the black and brown plaggen soils (Pape, 1970), a pattern which has also been observed in the analysis of plaggen soils in northwest Germany (Eckelmann, 1980; Blume and Kalk, 1986 and Elwert and Finner, 1993), although it was also suggested that in places the silt levels were typically higher, between 10-20% with practically no clay (de Bakker, 1980). The particle size analysis in Ireland was conducted in order to identify and quantify the level of calcareous sand addition (Conry, 1971). The anthropogenic soils at Donoure, Pillmore and Ballydavid all contained relatively high sand percentages between 72-78.5% which are just comparable with the levels identified in this analysis, however, more detailed comparison may not be drawn as the context of Conry's sample pits is not known. At Castlegregory, Conry compared a considerably higher percentage sanded anthropogenic soil in close proximity

to a farm building (89%) and an unsanded arable soil (68.5%) and the results fit closely with the kaleyard results (72.4 – 89.4%) found here.

In Scotland particle size analysis was conducted on the anthropogenic soils identified at Quinni on the Mainland of Orkney (Davidson and Simpson, 1985). The results included higher levels of clay and silt (26.0 – 27.2% and 64.5 – 65.9%) with sand increasing slightly towards the base of the sequence. This may occur as a result of the addition of organic turf and peat manures to the soil profile or more likely as a direct result of the influence of the natural sandy parent material. The sand results were, however, much higher in all three landuse areas and may point towards the possible use of beach sand as part of the manuring process. Higher sand levels were found at Marwick, West Mainland, Orkney where detailed particle size analysis was conducted at 100mm intervals (Simpson, 1997). The results showed an overall increase in sand component (32.0 – 43.1%), possibly because of the sites proximity to the sea and use of sea sand. However, the clay and silt levels remained high, indicating the continued use of highly organic turf and peat in the formation of the deep topsoils. Larger sand percentages were identified in the anthropogenic soils on Papa Stour, Shetland where results ranged from 15 – 40% clay and silt to 45 – 80% sand (Carter and Davidson, 1998). Like Fair Isle, Papa Stour also had a limited quantity of organic manure components and may have needed to use a large range of materials to maintain the arable soils. At Papa Stour, however, Carter and Davidson (1998) used particle size analysis to show that the anthropogenic soils can contain high sand levels from natural wind-blown sand. Particle size analysis across a number of modern landuse areas was conducted at Olthof, the Netherlands and Nairn, Scotland and both sites revealed high sand levels (78 – 90% Olthof) and (83 – 87% Nairn) (Dercon, et al., 2005), possibly through the use of fine sand as a component to absorb fluids in byres (Pape, 1970).

5.5 MAGNETIC SUSCEPTIBILITY RESULTS FROM FAIR ISLE, THE NETHERLANDS & IRELAND

Magnetic susceptibility can be used by a large range of disciplines from geologists to hydrologists to answer a number of analytical questions from simple individual identification, concentration and total volume to interpretation of formation, transportation and sediment signaturing. In geoarchaeology, magnetic susceptibility has been utilised to identify subtle biological formations of maghaematite in topsoils illustrating slight environmental changes (Longworth, et al., 1979). More common uses of magnetic susceptibility involve archaeological soils which have either been subjected to burning or heating (Tite and Mullins, 1971) and this has been utilised to determine form and function of anthropogenic and natural fires (Bellomo, 1993). Batt and Dockrill (1998) and Peters, et al., (2000) combined magnetic susceptibility with other analytical methods to interpret multiperiod sites at Old Scatness, Shetland and Galson, Isle of Lewis as well as to show distinctive differences between domestic and arable landuse areas. Magnetic susceptibility has also been used to analyse domestic “dark earth” soils (Crowther and Barker, 1995; Crowther, 2003) and “urban garden soils” used in the identification of anthropogenic additions to arable farmland from settlement centres (Carter, 2001; Davidson, et al., 2006).

Magnetic susceptibility was conducted and analysed using the methods outlined by Dearing, 1999 and the methodology is described in chapter 1; section 1:13. The full list of data is displayed in (appendix 11) and the data is analysed firstly by site; Fair Isle (section 5.5.1), the Netherlands (section 5.5.2) and Ireland (section 5.5.3) and then discussed in section 5.5.4.

5.5.1 MAGNETIC SUSCEPTIBILITY RESULTS FROM FAIR ISLE

The magnetic susceptibility results from the three kaleyard areas have three very different patterns which represent distinctive variations in the organic and inorganic material added (Fig 107). At Shirva the Ap-1 and Ap-2 horizons contain considerably higher results than the natural soils ($255 \pm 9.02 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$ to $277 \pm 11.72 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$). This shows that

amendment may have included larger amounts of hearth residue, carbonised particles and anthropogenic waste. There is a distinctive difference between the upper horizons and the Ap-3 horizon which has a considerably lower magnetic susceptibility ($88.14 \pm 7.21 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$) and may represent the post burial breakdown of anthropogenic additions. The results are still considerably higher than the natural and the results from Leogh and may represent a focus on the addition of organic material and less addition from settlement centres.

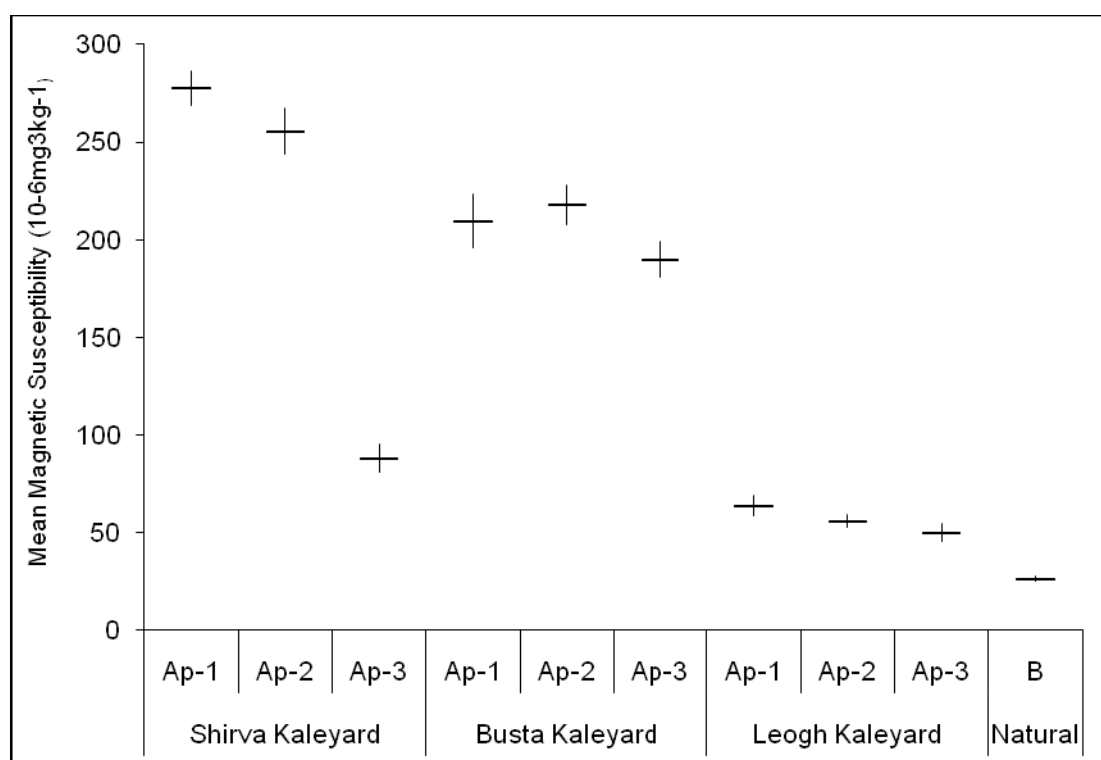


Figure 107, Mean magnetic susceptibility results at three kaleyard areas on Fair Isle

The results from Busta are more consistent and show very little change with depth between the Ap-1 and Ap-2 horizons (209.81 ± 13.95 to 218.74 ± 10.16) and the Ap-3 horizon (189.77 ± 9.07) this illustrates that a similar strategy of addition has been conducted throughout the history of the kaleyard possibly because of the sites location on the east of the island and the focus upon the use of domestic waste residue. In contrast to the results from Shirva and Busta are the magnetic susceptibility figures from Leogh. Overall the soils illustrate a subtle increase compared to the natural soils with a very slight decrease with depth (63.81 ± 5.38 to 49.82 ± 4.63). The results

show that at Leogh there appears to be an emphasis on organic amendment with peat and turf (section 5.3.1) but considerably less material from hearth material and carbonised material from settlement centres. The results gathered from Fair Isle may illustrate the addition of ferrimagnetic minerals rather than anthropogenic material. Dearing, 1999 suggests that results over $100 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$ are likely to originate from this source and carbonised particles and topsoils have lower results.

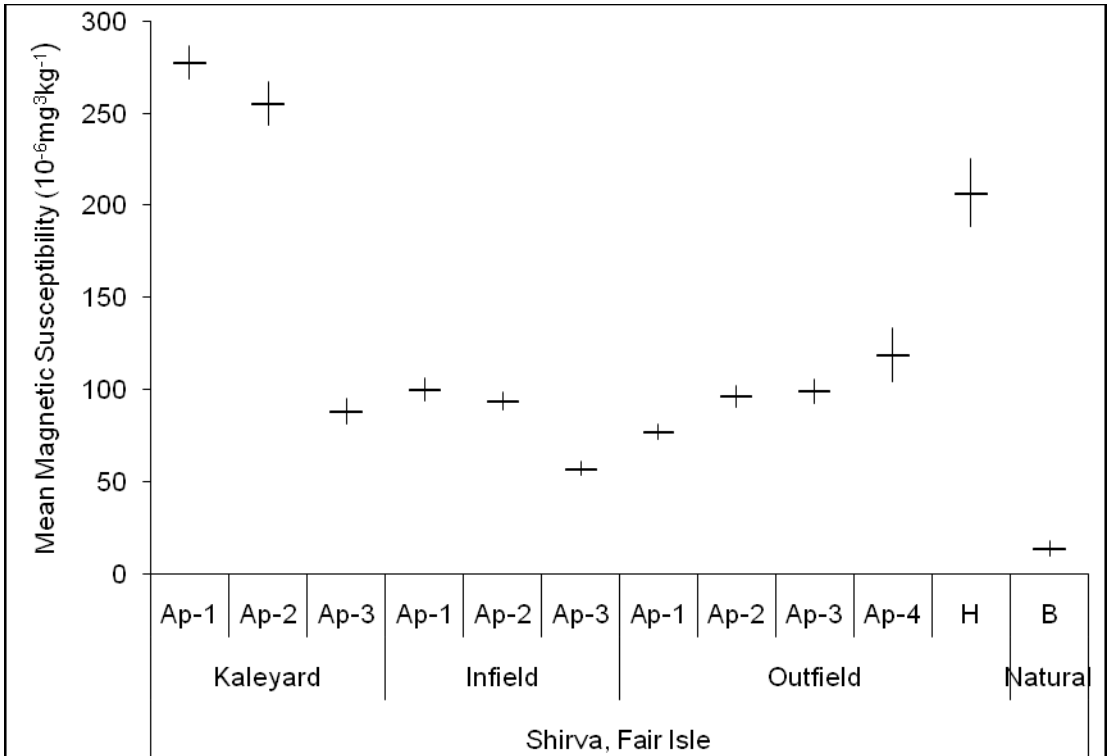


Figure 108, Mean magnetic susceptibility at three landuse areas at Shirva, Fair Isle

The results from the three landuse areas at Shirva illustrate key variations (Fig 108). As discussed in the kaleyard the upper two soil horizons contain considerably higher results and suggest a focus of the addition of anthropogenic waste and carbonised material. The results in the upper horizons of the infield have similar results to the Ap-3 horizon of the kaleyard ($100.22 \pm 6.19 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$ and $93.75 \pm 5.15 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$) suggesting a similar level of addition with time. Results from the outfield however are very different and suggest a different pattern of addition. Unlike the other landuse areas there is an increase in mean magnetic susceptibility with depth. In the Ap-1 to

Ap-3 horizons there is an increase from $77.14 \pm 4.05 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$ to $99.18 \pm 6.52 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$ a pattern similar to the infield and lower kaleyard horizons. In the Ap-4 and H horizon there is a distinctive increase of magnetic susceptibility and this is a result of the increased addition of anthropogenic material in order to increase the nutrient of the main arable soils. The results may also have been increased by the process of paring and burning of the remnant H horizon and then mixed into the Ap-4 horizon.

5.5.2 MAGNETIC SUSCEPTIBILITY RESULTS FROM OLT Hof, THE NETHERLANDS

Overall the magnetic susceptibility results from Olthof illustrate distinctive decreases with depth in each landuse area (Fig 109). In the garden area the black plaggen soil in the Ap-1 and Ap-2 horizons have similar results ranging from 44.97 ± 6.68 to 46.08 ± 3.73 and suggest that there has been a larger input of domestic material and carbonised particles.

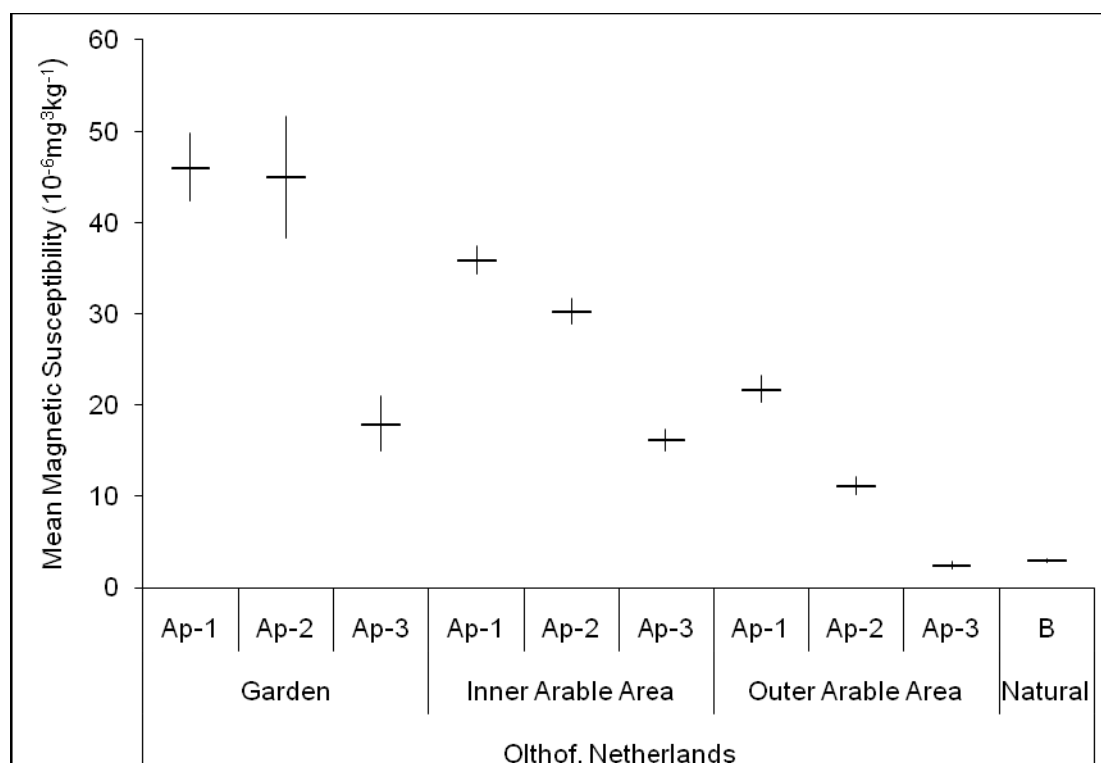


Figure 109, Mean magnetic susceptibility at three landuse areas at Olthof, the Netherlands

In comparison the brown plaggen soils contain much lower amendment but there does appear to be a comparable input with the Ap-3 horizon in the inner arable area. The black plaggen soil in the inner arable area contains lower magnetic susceptibility results ($30.27 \pm 1.43 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$ to $35.86 \pm 1.54 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$) indicating less domestic input. The lowest results at Olhof are present in the outer arable area. In the black plaggen soil there is a small increase compared to the natural soils and this might represent the distribution of carbonised heathland turves since the increase in farming. In contrast the brown plaggen soils contain comparable results with the natural and this suggests very little to no addition with domestic waste or carbonised inclusions.

5.5.3 MAGNETIC SUSCEPTIBILITY RESULTS FROM CAHERATRANT, IRELAND

The magnetic susceptibility results from Caheratrant, Ireland show a very different pattern to the sites on Fair Isle and Olhof (Fig 110). In all three landuse areas there is an increase in mean magnetic susceptibility with depth and considerably less distinctive results between the kaleyard and outer arable area. In the kaleyard the Ap-1 and Ap-2 horizons have very similar results ranging from 77.35 ± 3.55 to $93.31 \pm 7.13 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$ and the results in the neighbouring kaleyard illustrate similar figures. The Ap-3 horizon has a considerably higher magnetic susceptibility result ($184.90 \pm 13.73 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$) and suggests a larger input of domestic waste, hearth ash and carbonised particles possibly as a result to increase the nutrice of the kaleyard. The distinctive calcareous sand horizons (CaCO_3) also have variable results suggesting different levels of mixing with farmyard manure and hearth residue. The upper horizon has a figure of $48.02 \pm 6.19 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$ and was not found with any organic or carbonised material in the field. This therefore most likely represents material added directly to the kaleyard soil. In comparison the lower sand horizon was found with a considerably higher magnetic susceptibility result ($109.11 \pm 12.13 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$) and organic inclusions found in the field show that mixing with farmyard manure and carbonised material is more likely.

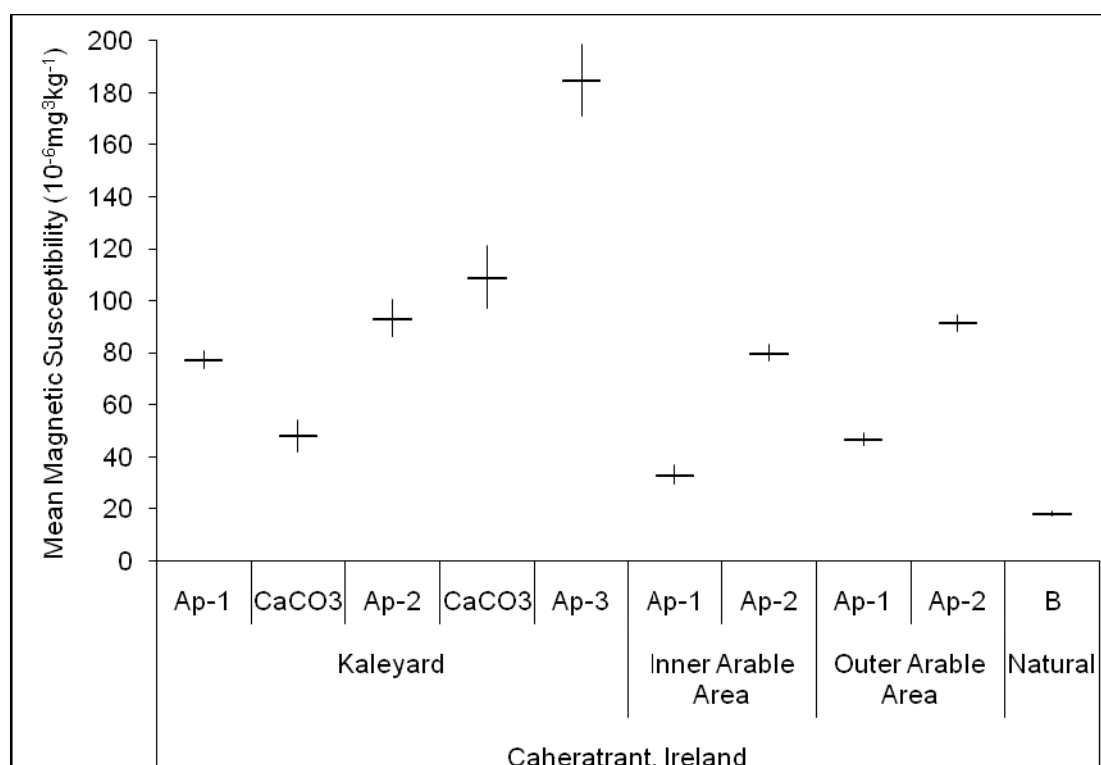


Figure 110, Mean magnetic susceptibility results at three landuse areas at Caheratrant, Ireland

In comparison to the kaleyard the inner arable (33.08 to 79.98x10⁻⁶mg³kg⁻¹) and outer arable areas (46.71 to 91.57x10⁻⁶mg³kg⁻¹) have a very different pattern of magnetic susceptibility results. Both show an increase with depth and indicate a higher input of anthropogenic material during the development of the arable soils. The reduction in results into the Ap-1 horizon must represent a change in manuring strategy perhaps as the landuse changed from arable to pastoral. The results across all the landuse areas might also represent the input of ultra/basic and ferrimagnetic minerals from the natural and beach sand material. This site has the greatest variation in lithologies and is the only site to use a mineragenic form of manure both of which could affect the magnetic susceptibility results.

5.5.4 DISCUSSION OF THE MAGNETIC SUSCEPTIBILITY RESULTS FROM THE THREE FARMS

The results from the magnetic susceptibility analysis from the different landuse areas of the three sites can be compared in order to try and determine the level of anthropogenic addition to the soils. Overall the results show distinctive variations between the landuse areas and sites. The highest results were identified at Shirva ($277 \pm 11.72 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$) (Figs 107 and 108) and Caheratrant ($184.90 \pm 13.73 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$) (Fig 110) and indicate the significant input of settlement material including hearth residue, carbonised material and household waste. Both sites also have very similar soil chemistry including soil pH (section 5.2) soil organic content (section 5.3) and particle size (section 5.4). In contrast the results from Olthof are considerably lower (46.09 ± 3.73) (Fig 109) but these results are still considerably higher than the natural soil horizons and indicate that the areas adjacent to the farm nuclei all have distinctive enhancement with anthropogenic material. The distinctive variations between the sites must occur as a result of different manuring regimes and possibly as a result of higher ferrimagnetic minerals including iron and manganese identified in high levels during the fieldwork.

Across each of the sites there is however, a decline in the mean magnetic susceptibility results from the settlements outwards as was hypothesised, according with the idea that most domestic addition occurred closest to the farmstead. At Shirva and Caheratrant the infield and inner arable results from the amended soils are still considerably higher than Olthof and have only declined by a small amount. At Olthof there is a larger variation between the black and brown plaggen soil and almost certainly derives from the natural parent material. This pattern continues in the outer arable area and in each of the anthropogenic soil horizon mirror results in the natural soils, but at the other sites different processes appear to be occurring. At Caheratrant the upper amended soils in the outer arable area have lower magnetic susceptibility results compared to the Ap-2, indicating considerably higher input from the centre of farms. At Shirva though, there is a slight increase in mean results between the Ap-1 and Ap-4 horizons and the values are similar to the infield area. These higher results are extremely interesting

as it suggests that the outfield area is receiving a large amount of material from the farm a process unusual to outfield area in the northern isles of Scotland. An alternative explanation to the irregular magnetic susceptibility results is that carbonised particles have been added to the soil in the past by stubble burning or through the process of paring and burning (Fenton, 1978).

5.5.5 DISCUSSION OF MAGNETIC SUSCEPTIBILITY RESULTS WITH PAST WORK

The magnetic susceptibility analysis in this thesis is the first to have been done at the three sites sampled therefore a direct comparative analyses cannot be conducted. However the extensive use in archaeological projects in similar contexts may help to interpret the results. Dearing (1999) showed that different composite materials had a range of results (Fig 111). Of particular relevance to this project are the results from topsoils ($0.01 - +10 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$) and burned soils ($+0.1 - 100 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$) which have distinctive ranges into which all the results from this project fit, but importantly there is also a significant number of geological materials which might also affect the results (sections 5.5.1 to 5.5.3).

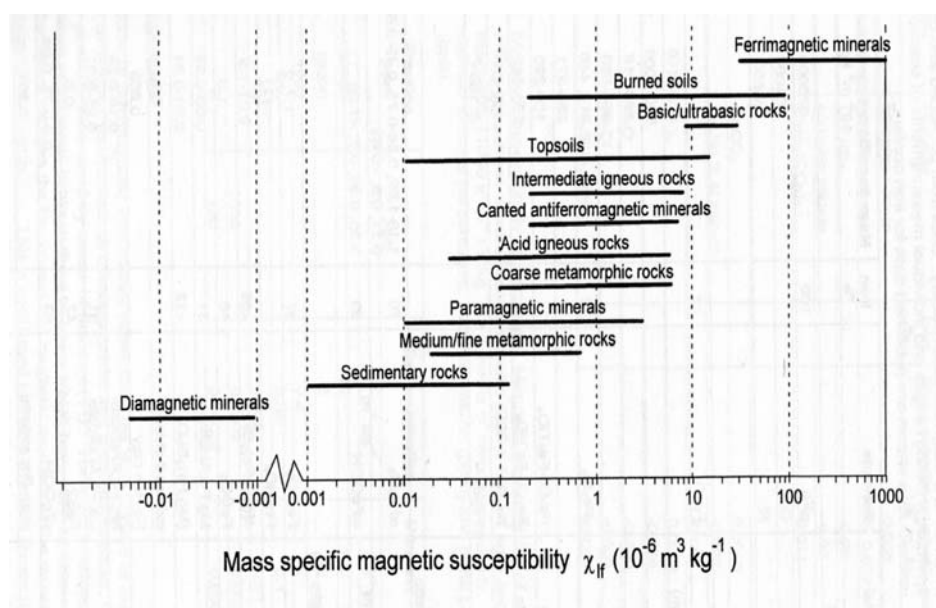


Figure 111, Range of magnetic susceptibility results from soils and rocks (Dearing, 1999)

Across each of the sites the magnetic susceptibility results are surprisingly high especially when compared to results gathered from the heart of domestic areas, for example Roman and Saxon 'beaten floors' from London have revealed magnetic susceptibility results of over $3000 \times 10^{-8} \text{SI kg}^{-1}$ (Macphail, et al., 2003). However other more detailed, systematic field studies of pits and middens have revealed a much more variable pattern dependent upon materials added and levels of preservation. Iron Age and Pictish middens tested every 20mm at Old Scatness, Shetland revealed a subtle down profile increase in results ranging from $3.0 - 9.0 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$ (Pictish) and $4.0 - 8.0 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$ (Iron Age) with distinctive bands of $15 - 26 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$ from dark red burnt laminations (Dewar, et al., 2002). At the same site results from the domestic horizons were compared to the results from the anthropogenic soils in the fields and this showed that midden material was being added to the soils due to infrequent peaks in the magnetic susceptibility results (Dockrill and Simpson, 1994 and Batt and Dockrill, 1998).

5.6 SOIL MULTI-ELEMENT ANALYSIS FROM FAIR ISLE, THE NETHERLANDS & IRELAND

The occupation of sites with time will affect the local landscape in a number of physical and chemical ways. One of the most direct ways is by the accidental or deliberate creation of anthropogenic waste and its distribution as manure upon arable farmland areas. This occupation waste typically consists of a mixture of organic and inorganic components including decomposed and carbonised organic material (peat and turf), mineral material, food waste (animal bone), animal faeces and human nightsoil and domestic waste especially ceramics and industrial debris. The addition of these components can therefore significantly enhance the elemental concentrations in the soils and their analysis and interpretation can be a very useful tool in the determination of source manuring material, settlement distribution and past landuse.

Multi elemental analysis was therefore conducted upon the anthropogenic and amended soil horizons found on Fair Isle, the Netherlands and Ireland were examined in order to determine whether the soils contained

characteristic elemental signatures which might aid provenance of manuring materials. The analysis also aimed to highlight distinctive patterns of elemental concentrations in the areas closest to the settlement centres and compare them to the furthest arable areas. Finally the multi-elemental analysis hoped to define a clear chemical relationship between the soil and the black carbon particles (chapter 7) in order to more clearly understand the physio-chemical relationship between the two. In total the soil samples were analysed for 21 elements and the results are discussed on a site by site basis between Shirva (section 5.6.1), Olthof (section 5.6.2) and Caheratrant (section 5.6.3). There is then a summary of the results from the three sites (section 5.6.4) and a discussion of the results with multi-element results from previous analyses (section 5.6.5). The methodology for the multi-elemental analysis is described in chapter 1; section 1:13 and raw data in appendix 12.

5.6.1 SOIL MULTI-ELEMENT RESULTS FROM SHIRVA, FAIR ISLE

The soil multi-elemental results from Shirva illustrate that in each of the landuse areas there are a range of similar elements deriving from anthropogenic and natural sources (Fig 112). In the kaleyard there are specifically high mean concentrations of Ca (167.54 ± 10.60 ppm) and P (121.90 ± 8.37 ppm) suggesting significant input through manuring with organic and carbonised material a result which mirrors the other geochemical analyses. The specifically high Ca results may also indicate the use of calcareous sea sand in the manuring process. The results are not as dramatic as the Ca results from Caheratrant suggesting that it was not placed directly onto the fields but most likely derives from inorganic material attached to seaweed and added periodically. The Ca results in the kaleyard are considerably higher than the infield (50.07 ± 16.94 ppm) and outfield (43.10 ± 2.07 ppm) and suggest that the kaleyard received more manure but the similar results indicate a similar manuring regime. The results are very similar to the natural B horizon (48.24 ± 3.84 ppm) which indicates that the Ca derives from the underlying soil and not from manuring. There a number of other elemental concentrations which are higher in the natural than in the

amended arable soils and also indicate an origin from the underlying soil horizons.

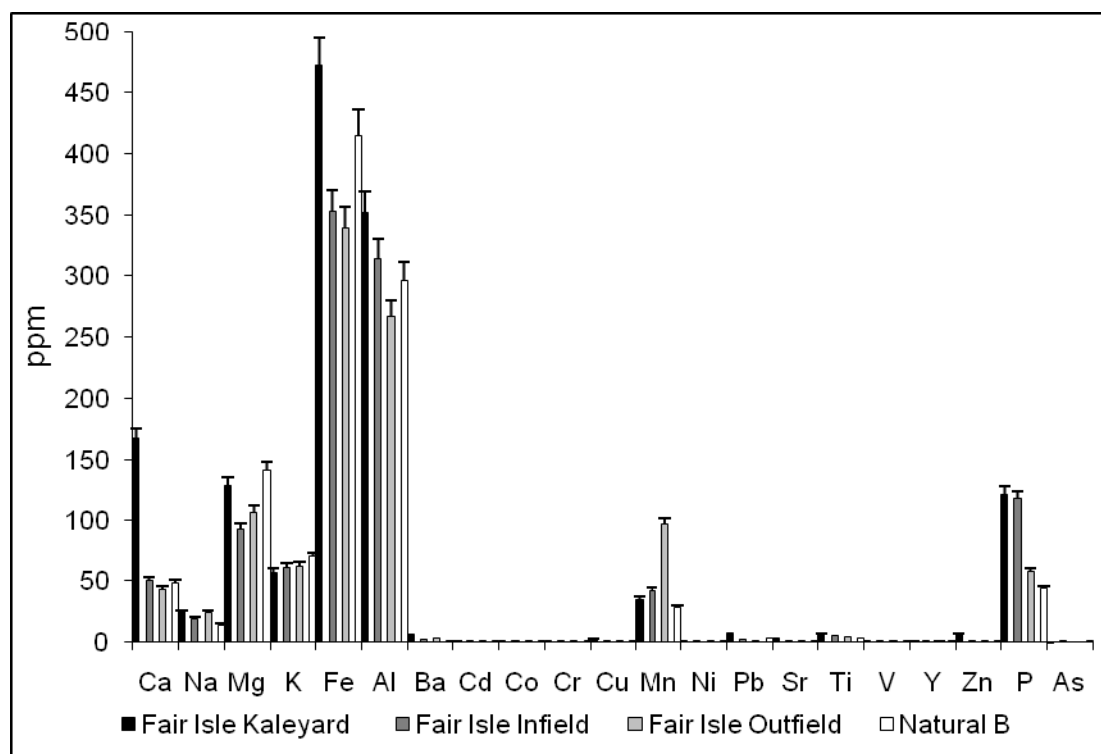


Figure 112, Soil multi-elemental results from three landuse areas at Shirva, Fair Isle (Error bars show 95% confidence interval of the mean)

The concentrations of Mg (141.21 ± 8.21 ppm) and K (69.90 ± 6.17 ppm) are higher in the natural soils and therefore the values in the amended soils may be due to an increase in mixing by biological and physical processes between the horizons, however they may also derive from the addition of turf and peat organic manures which contain mineragenic material. The addition of organic material in the infield and outfield areas can be inferred from the concentration of P. The infield area (118.74 ± 7.33 ppm) contains a concentration akin to the kaleyard and indicates a similar addition of organic material. The outfield however contains only a slightly higher concentration (57.59 ± 3.22 ppm) than the natural soil (43.69 ± 2.87 ppm) and suggests minimal organic addition however it is more likely illustrating an increased concentration in the B horizon because of heavy mixing between the amended arable soils, natural soils and buried H horizon. Mixing between all the horizons in the kaleyard probably explains the high Fe (471.50 ± 9.22 ppm) and Al (351.25 ± 18.10 ppm) results. However, the results are considerably

higher than in the B horizon and may indicate input of organic peat and turf material.

The distinctive elemental concentrations of K and Mg in the amended soil horizons may also be derived from the influence of sea-spray and indeed the concentration of Na is fairly uniform throughout (19.31 ± 2.86 ppm – 25.04 ± 2.04 ppm) and higher than in the natural soils. Importantly the high concentration of Fe and Mn may also be derived from the input of elements in sea spray and there can be increased precipitation of these elements into the soil profile.

Interestingly, although the concentrations of Ba (6.66 ± 1.13 ppm), Pb (7.99 ± 2.32 ppm), Sr (2.85 ± 0.34 ppm) and Zn (6.28 ± 1.10 ppm) are very low there are distinctively higher concentrations in the kaleyard compared with the outfield and the natural soils. This indicates that alongside organic manure, domestic waste, carbonised particles and hearth residues are also being added to the soils but have been seriously depleted by post burial mixing and leaching since the cessation of manuring in this area.

5.6.2 SOIL MULTI-ELEMENT RESULTS FROM OLTHOF, NETHERLANDS

The multi-element results from the anthropogenic soils at Olthof illustrate an interesting distribution between the three landuse areas (Fig 113). The plaggen soils in the garden area contain distinctive concentrations of Ca (49.27 ± 4.81 ppm) and P (38.02 ± 5.41 ppm) which illustrates distinctive amendment with organic manure including turf and domestic waste material including hearth waste and carbonised particles. In the inner arable (73.79 ± 5.44 ppm) and outer arable areas (28.18 ± 3.67 ppm) however the results suggest that manuring has been conducted using organic material only as the concentrations of P decrease gradually and are considerably higher than the natural soils. The concentrations of Ca however in the inner (19.82 ± 1.84 ppm) and outer arable (6.99 ± 4.63 ppm) areas are more consistent with the natural soils. Alongside Ca and P the anthropogenic soils also include distinctive concentrations of Fe (428.38 ± 16.56 ppm to 488.44 ± 12.04 ppm) and Al (334.87 ± 3.91 ppm to 408.94 ± 8.21 ppm), in the garden and inner arable

areas. These most likely represents the addition of the natural heathland and meadowland soils which contain large quantities of these elements.

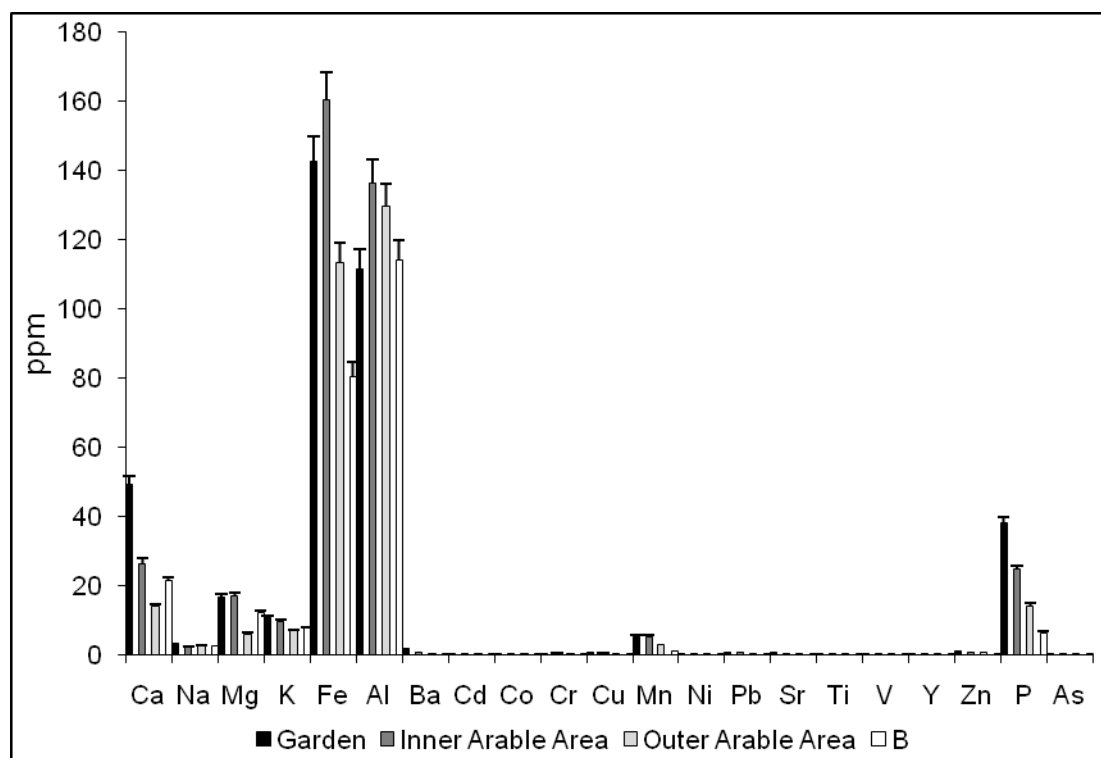


Figure 113, Soil multi-elemental results from three landuse areas at Olthof, the Netherlands (Error bars show 95% confidence interval of the mean)

Evidence for the addition of organic and inorganic material from a domestic source is scant and the elemental record in the soils suggests that no anthropogenic material was added. Apart from only trace levels of Ba and Zn there is no concentrations of elements such as Pb, Cd, Cu, Mn, Sr, and As which might be interpreted as deriving from a domestic source. Instead the elemental record of Na, Mg, K and Mn all suggest the primary addition of organic manure heavily mixed with the natural soils alongside distinctive post burial leaching. Intensive leaching of the Dutch anthropogenic soils appears to have even removed the evidence of modern farming as chemical fertilisers rich in K, P and N which are used in the inner and outer arable areas do not appear to have registered in the analysis. The results gathered here bear far similar resemblance to the natural turf manures used in the production of the brown and black plaggen soils.

5.6.3 SOIL MULTI-ELEMENT RESULTS FROM CAHERATRANT, IRELAND

The multi-elemental results from Caheratrant are illustrated in figure 114. The results show very clearly that Ca amendment has occurred on a huge scale within all the kaleyards analysed with results regularly exceeding 800ppm. Interestingly however the Ca results from the inner arable and outer arable are considerably lower than the natural soil horizons (91.46 ± 8.27 ppm).

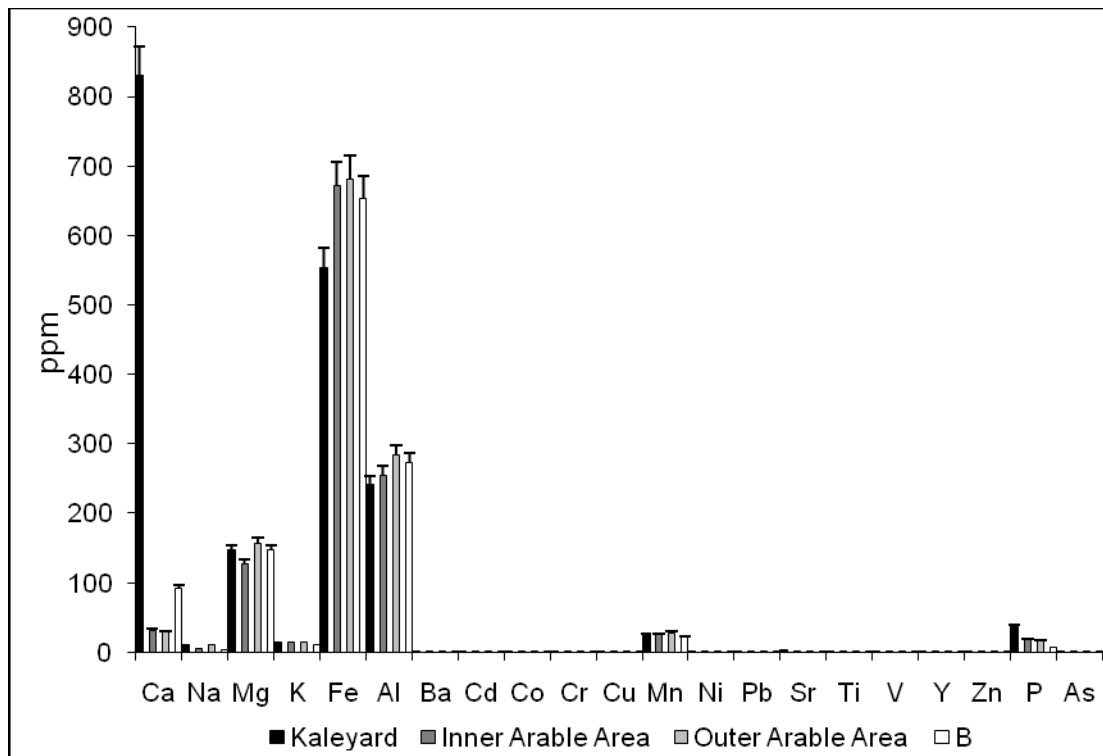


Figure 114, Soil multi-elemental results from three landuse areas at Caheratrant, Ireland (Error bars show 95% confidence interval of the mean)

There is clear evidence from the historical and geoarchaeological work conducted on the Dingle Peninsula that sanding was occurring regularly the low results demonstrated here however seem to suggest that it was concentrated in the kaleyard areas. Further spot analysis of inner arable areas have illustrated that sanding was occurring with results ranging between 300 – 500ppm. This suggests that at Caheratrant sanding was conducted in very specific areas and that the areas sampled in this project are examples of inner arable areas that were not sanded. In the kaleyard areas there is no doubt that sanding took place as the CaCO_3 horizons contain

between 1917.70ppm to 3334.90ppm. The kaleyard areas also contain the highest concentrations of P (45.84 ± 8.12 ppm) suggesting it also received the largest quantity of organic manure with the calcareous sand. There is however also evidence that the inner (17.83 ± 6.17 ppm) and outer arable areas (15.49 ± 4.54 ppm) also received some organic manure as the results are considerably higher than the underlying natural soil horizons (7.37 ± 1.84 ppm). Like the other two sites the amended soils at Caheratrant also contain high concentrations of Fe, Al, Mg and small amounts of K and Mn which probably derive from the addition of organic turf and peat manure mixed with the natural soils and sea spray which, like Fair Isle, is highly prevalent in the coastal environment. In each of the cases the concentrations of the elements are very similar between the different landuse areas and suggest that no major enhancement has been conducted outside the central nucleus of the farm. The lack of Ba, Pb, Cd, Cu, Mn, Sr, Zn and As also indicate a distinctive lack of domestic waste material added to any of the landuse areas and if it was it has not left any evidence of an elemental signature or significant leaching has removed any elemental evidence that was present.

5.6.4 DISCUSSION OF THE MULTI-ELEMENT RESULTS FROM THE THREE SITES

Overall the results from the three sites contain relatively disappointing multi-element signatures however there are a number of distinctive relationships between the results and the other geochemical analyses conducted. Figure 115 shows the concentrations of P, Ca, K and Mg in amended arable soils and anthropogenic horizons from the three sites. The results clearly illustrate that the calcareous sand added at Caheratrant has increased the soil pH above 7.0 but other key elements including P, K and Mg have not been so dramatically increased perhaps as a result of the direct application of the sand. At Shirva the majority of the soils with higher pH contain slightly higher concentrations of P, Ca, K and Mg possibly because of the addition of organic manure or because of heavy mixing with the natural soils which have pH and elemental results which are more consistent especially away from the kaleyards.

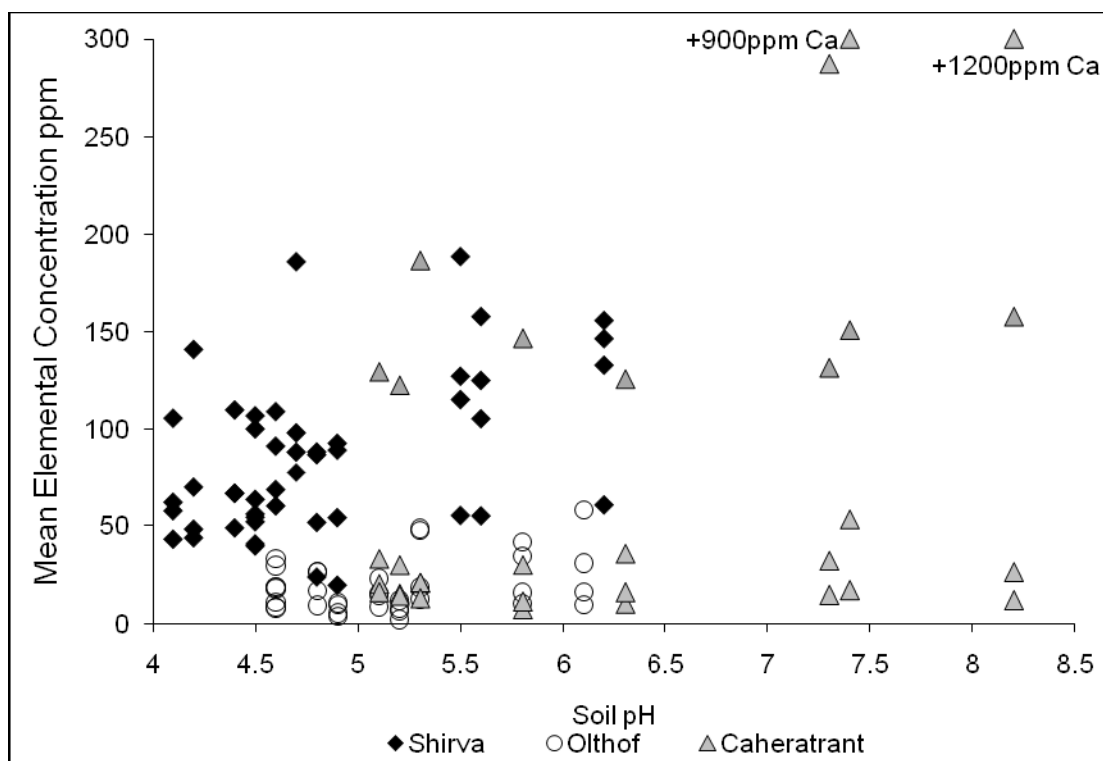


Figure 115, Mean multi-elemental concentrations of P, Ca, K & Mg and soil pH from Shirva, Olthof and Caheratrant

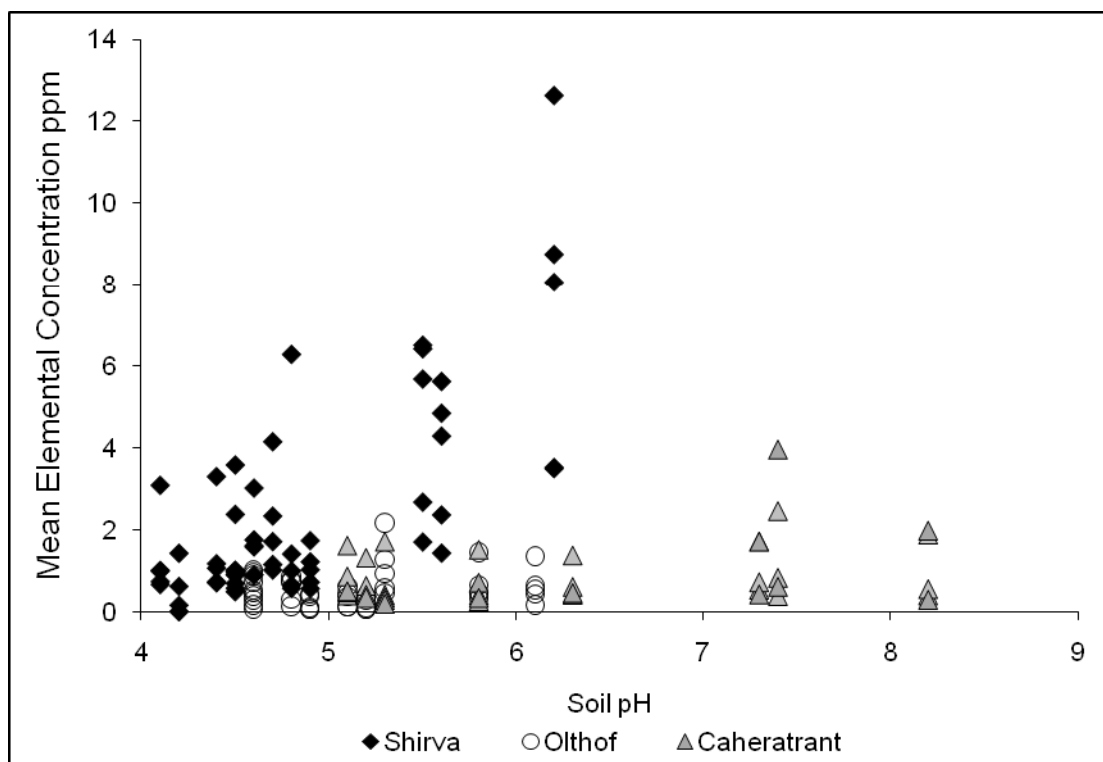


Figure 116, Mean multi-elemental concentrations of Ba, Cu, Pb, Sr & Zn and soil pH from Shirva, Olthof, and Caheratrant

In contrast the results of the concentrations of Ba, Cu, Pb, Sr and Zn (elements associated with the addition of domestic waste and hearth ash) show distinctly higher results at Shirva in moderately acidic soils (pH6.0 – 6.5). The soils at Caheratrant show slightly higher concentrations in the soils around pH7.5 but generally the results are much lower suggesting either leaching or considerably less addition of domestic material. At Olthof the pH and concentrations of all the elements illustrated in figures 115 and 116 are much lower than the other sites and the variations in soil Ph are indistinguishable. This may be because of the sandy nature of the soils and the leaching of elements.

The elemental concentrations from the three sites also illustrate distinct patterns with the loss on ignition data Figs 117 and 118. At Shirva the concentrations of P, Ca, K and Mg are fairly evenly spread throughout the soils and suggest either the addition of organic manure to each landuse area. The results also indicate that the elemental concentrations may derive from mixing with natural soil horizons. The results from the concentrations of Ba, Cu, Pb, Sr and Zn indicate that domestic waste was added frequently to the soils possibly mixed in with organic components. The results illustrate particularly high concentrations of Pb and Zn in the kaleyard soils which might derive from minor industrial activity but also possibly from the residues from fires as the concentrations of Ba, Cu and Sr also range between 3 – 6ppm compared to <1ppm in the natural soils. At Caheratrant there is a clear concentration of P, Ca, K and Mg in the soil horizons in the kaleyard and considerably lower results in the other areas as a result of organic and inorganic manuring with peat, turf and sea sand. Results of Ba, Cu, Pb, Sr and Zn are lower with a slight increase in the kaleyard possibly from the addition from the sand or from waste material. The figures indicate however that if domestic material is added it is reserved for the kaleyard and not for the arable areas which have results akin to the background level. The results from Olthof are considerably lower than the other two sites and suggest the uniform addition of organic material with very little domestic waste and carbonised particles. This pattern is typical of a heavily leached soil which may have had higher soil geochemical results in the past but it has gradually reduced since the end of manuring.

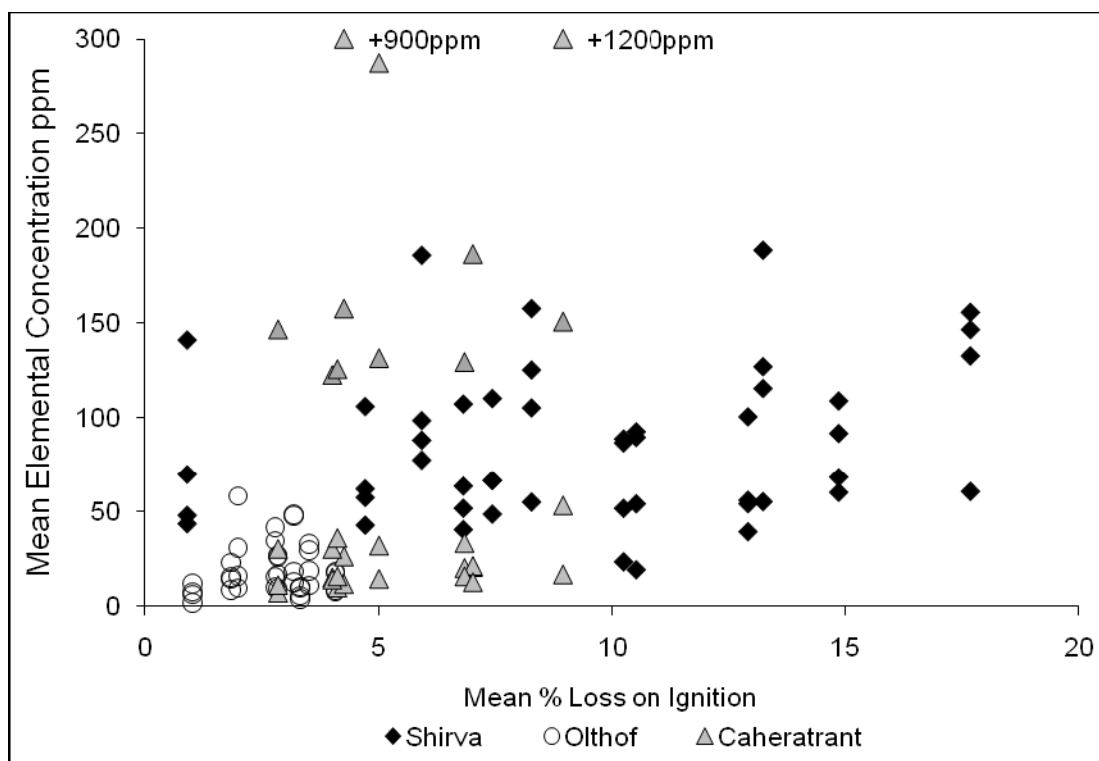


Figure 117, Mean multi-elemental concentrations of P, Ca, K & Mg and mean % loss on ignition from Shirva, Olthof and Caheratrant

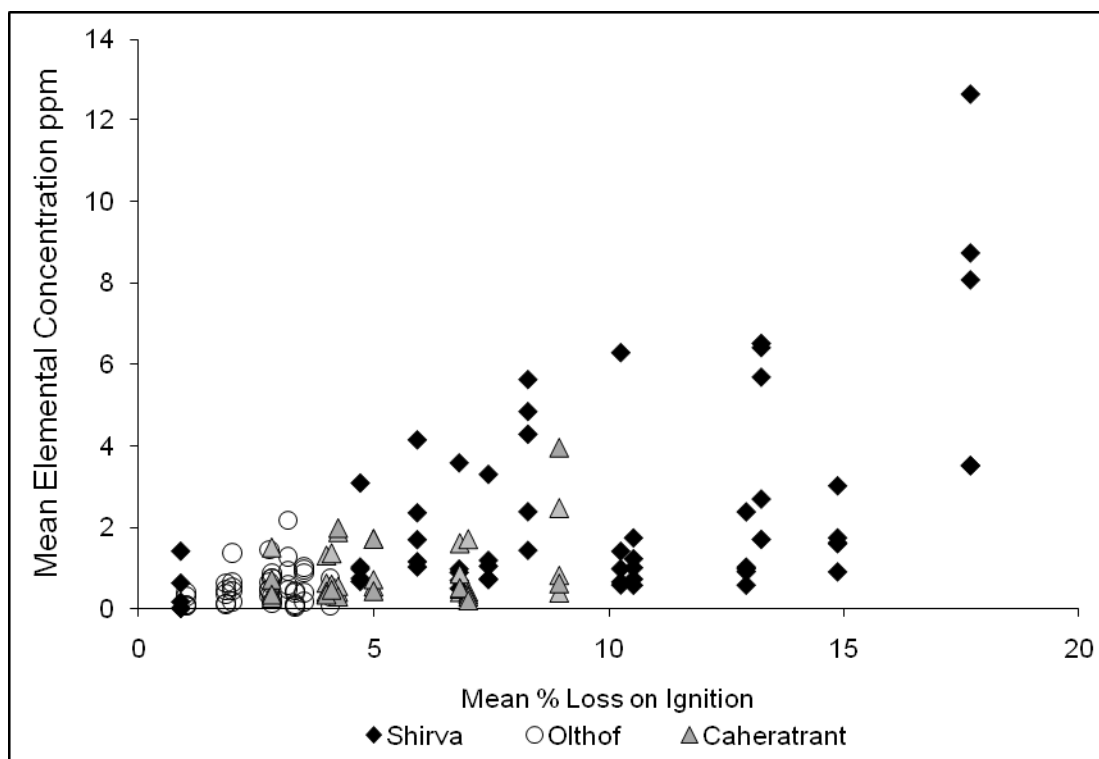


Figure 118, Mean multi-elemental concentrations of Ba, Cu, Pb, Sr & Zn and mean % loss on ignition from Shirva, Olthof and Caheratrant

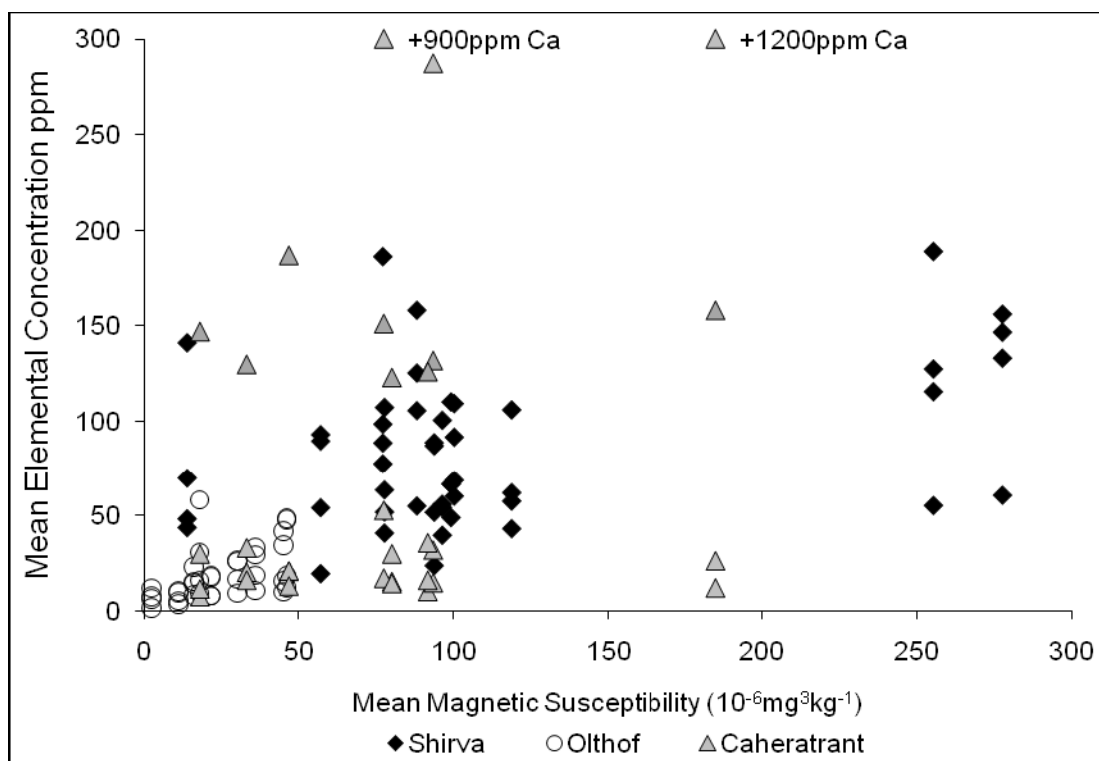


Figure 119, Mean multi-elemental concentrations of P, Ca, K & Mg and mean magnetic susceptibility from Shirva, Olthof and Caheratrant

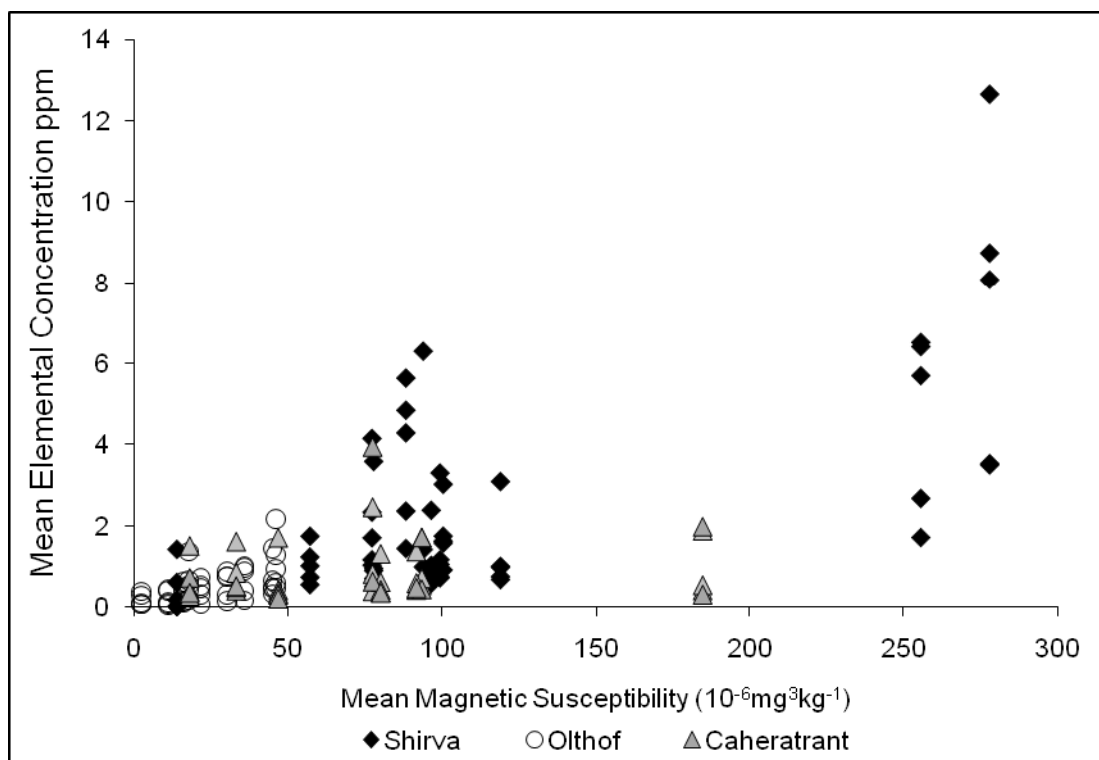


Figure 120, Mean multi-elemental concentrations of Ba, Cu, Pb, Sr and Zn and mean magnetic susceptibility from Shirva, Olthof and Caheratrant

Analysis of the multi elemental results can also be made with the magnetic susceptibility results in order to determine whether there are patterns which illustrate the input of carbonised particles, ash and burnt residues into the soils (Figs 119 and 120). At Shirva there is a distinctive group of elements including P, Ca and Mg from the kaleyard with considerably higher elemental concentrations and magnetic susceptibility than the natural soils and these might derive from manuring. A similar peak is also present in the results of Ba, Cu, Pb, Sr and Zn and like the pH and loss on ignition results illustrates distinctive anthropogenic input throughout the history of the kaleyard. There is also a secondary lower group which corresponds to the infield and outfield areas and shows that some manuring may have occurred in the past possibly when the farm has a higher number of houses.

The results from Caheratrant also mirror those from the comparison with the pH and loss on ignition results. The high Ca results have highly variable magnetic susceptibility ranges possibly mirroring different source areas. There appears to have been minimal mixing with domestic waste and farm material though as the results of Ba, Cu, Pb, Sr and Zn are considerably lower. The organic material also appears to have been rarely mixed with domestic and carbonised material as the group of P, Ca, K and Mg between 125-200ppm and $15-100 \times 10^{-6} \text{mg}^3 \text{kg}^{-1}$ is not replicated in the concentrations of elements in figure 120. Instead the elements have only slightly higher concentrations than the natural soils and are likely to derive from Fe and Al which exceed 400 to 800ppm.

Once again the results from Olthof are considerably lower than the other sites and mirror the results in figures 115 to 118. The concentrations of P, Ca, K and Mg are slightly higher in the upper black plaggen soils but the smooth decrease with depth indicates that there has been a constant leaching of elements with time.

The elemental results gathered in this thesis are just a few of the many projects which have also analysed elemental concentrations and therefore to clearly understand the wider implications of these figures a comparative discussion must be undertaken.

5.6.5 DISCUSSION AND COMPARISON OF MULTI-ELEMENT RESULTS FROM PAST WORK

Multi element analysis has been conducted on a range of anthropogenic soils and archaeological features from across the three assessment areas. In the Netherlands the anthrosols contained high P values typically between 1130 – 1350ppm in the black plaggen soil, and 920 – 2120ppm in the brown plaggen soil (Pape, 1970) these results are considerably higher than the results gathered in this analysis (Figs 112, 113 and 114) suggests either large scale regional variations in results, or the soils at Olthof have gone through extreme leaching possibly as a result of modern agriculture.

Landuse Horizon	P(ppm)					
	Dercon, et al., 2005			Pears, this volume		
	Pasture	Arable	Woodland	Garden	Inner Arable	Outer Arable
Ap-1	670	758	943	49	35	19
Ap-2	863	731	1102	36	29	10
Ap-3	643	880	561	31	/	/
Ap-4	341	837	/	/	/	/
Ap-5	223	/	/	/	/	/
Natural	415	384	318	9	15	3

Table 22, Mean P results in plaggen soils from different landuse areas at Olthof

Total P results from Olthof were also gathered by Dercon, et al., (2005) from a range of modern landuse areas (Table 22). Their results were lower than the values ascertained by Pape but were still considerably higher than values calculated in this work. The difference in results may be due to the different methods used to extract the P values; ICP-AES over sodium hydroxide fusion. Patterns in elemental distribution can still be seen between the soil horizons. The highest P results were identified in the woodland area

which was closest to the kaleyard of the farm but results from the pasture and arable areas are less definable to sample areas. Elemental analysis by Pape and Dercon is focussed on the amount of soils P, which is excellent evidence of anthropogenic manuring but as more recent analyses have demonstrated no one element can be used to determine anthropogenic activity (Wilson, 2008). When compared to the results from the other elements the general trend in concentration is very low but there is a distinctly higher P in the kaleyard area and less in the peripheral areas of the farm suggesting less organic and settlement waste.

Site	Soil Depth	P (ppm)
Valthe-Lienstucken, Infields	Plaggen (0-300mm)	1650
	Plaggen (300-600mm)	1130
	Natural (B horizons 600+mm)	no results
Valthe-Blickackers, Open Fields	Plaggen (0-260mm)	860
	Plaggen (260-480mm)	720
	Natural (B horizons 480+mm)	no results
Valthe-Colckackers, Open fields	Plaggen (0-260mm)	690
	Plaggen (260-380mm)	440
	Natural (B horizons 480+mm)	no results

Table 23, Mean P results from Valthe, Drenthe, the Netherlands (van Smeerdijk, et al., 1995)

Phosphorus values in plaggen soils were also determined from comparative landuse area at Valthe in Drenthe (van Smeerdijk, et al., 1995), (Table 23). The results from Valthe were high and similar to the values found by Pape and Dercon but like the results from Olthof there were clear patterns of distribution with depth and distance from the settlement centres suggesting clear variations in the manuring process across different parts of farm. At both Olthof and Valthe the upper black plaggen soil illustrates a higher P value than the underlying brown plaggen soil, and this may mark the onset of increased organic manuring at the beginning of the post medieval period (van Smeerdijk, et al., 1995).

As well as P the Dutch plaggen soils were also tested for a range of elements (Figs 113) and although the results were generally low they were consistent with the phosphorus results and indicate that manure from settlement centres may have been added to the soils along with organic manures but that the values may have been heavily affected by leaching. Low multi element results were also gathered at the Roman site of Nistelrode (Oonk et al., 2009a) compared to two farms on clay and sandy clay soils the elemental results from sandy soils inside the building were considerably lower than the other sites and indicated large amounts of post burial leaching. Much like the plaggen soils at Olthof the archaeological site at Nistelrode also contained much lower concentrations of Ca, As, Pb, Zn, Ni, Cr, V, Sn, Sr and Ba and the lower results maybe as a result not of less addition but of an inability of sandy soils to retain elements (Oonk, et al., 2009b).

Low multi-element results were also found at Caheratrant, Ireland, however the results from other analysis in Ireland suggest that this is a normal occurrence. In the 1970s the anthropogenic soils from Donoure, Cloghansheskeen, Pillmore and Ballydavid were tested for concentrations of P, K and Mg (Conry 1971), (Table 24) as a direct comparison to the Dutch plaggen soils. Conry's soil chemistry results are highly variable between the four sites because of variable geology, manuring practices and post burial alteration. However, there are distinctly higher concentrations of all the elements in the anthropogenic horizons. The concentration results of P, K, and Mg found at Caheratrant mirror these results and are most closely associated with the sites at Castlegregory and Dingle, a pattern with corresponds with the depth of the soils (chapter 4, section 4.7) and soil pH and loss on ignition results (chapter 5, sections 5.2.3 and 5.3.3). At Castlegregory and Caheratrant there are similar values of P and K indicating organic input but there are considerably higher Mg values which could indicate more input from hearths and fires. Unlike the results found at Olthof the P, K and Mg values from Caheratrant are as low as the results found by Conry and gives validation to the results from the Netherlands.

Author	Site	Horizon	P (ppm)	K (ppm)	Mg (ppm)
Conry, 1971; 1974 and Conry and Mitchell, 1974	Donoure, Ardfield, Klonakilty	Ap-11	104	170	860
		Ap-12	75	170	940
		Ap-13	12	80	1368
		Ap-21b	8	90	1672
		Ap-22b	1	155	215
		natural	1	70	98
	Cloghansheskeen, Castlegregory	Ap-1	52	26	492
		Ap-2	50	20	472
		Apb	29	10	133
		natural	2	37	33
	Pillmore. Youghal	Ap-11	60	203	400
		Ap-12	13	190	540
		Ap-13	16	161	400
		Ap-2b	13	120	292
		natural	3	59	479
	Ballydavid, Dingle	Ap-11	15	50	568
		Ap-12	13	18	684
		Ap-2b	1	22	118
		natural	1	18	50
Pears, this volume	Caheratrant, Dingle	Ap-1	53	17	151
		Ap-2	32	15	138
		Ap-3	26	12	158
		Natural	10	14	171

Table 24, Mean elemental concentrations of P, K and Mg in Irish plaggen soils

More recent work by Conry incorporated the analysis of a larger suit of elements including Ca, Na, Mn, Cu, Zn, B, Se and Co to determine the amount of anthropogenic input into Irish plaggen soils (Conry and MacNaeidhe 1999). The anthropogenic soils from the two sites show very similar values of P, K and Mg and this indicates a similar amount of organic additions to the soils, however the results of other elements associated with anthropogenic input highlight some distinct variations between the two sites (Table 25). The values of Ca at Castlegregory are extremely high in the plaggen soil (22091 – 24625ppm) indicating far more input from calcareous sea sand than at Caheratrant. Results of Cu, Zn and Co are also higher at Castlegregory and suggest that more material from settlement centres has been added to the site. Further evidence of the lack of input from settlement centres comes when the Caheratrant soils are compared to the natural soils

sampled by Conry and MacNaeidhe (1999). The elemental results from Cloghaneanode, Castlegregory include similar amounts of K, Mg, Mn, Zn and Co which may have derived from the natural soils. It seems likely therefore that manuring at the sample areas of Caheratrant consisted of mainly organic manuring with peat and turf and occasional beach sand but less input of anthropogenic waste from settlement centres.

Sites	Horizon	Elemental Concentration (ppm)										
		P	K	Mg	Ca	Na	Mn	Cu	Zn	B	Se	Co
1.	Ap-1	53	17	151	924	13	26	0.63	2.46	/	/	0.27
	Ap-2	32	15	138	337	7	25	0.47	1.80	/	/	0.28
	Ap-3	26	12	158	128	15	25	0.31	1.90	/	/	0.28
	Natural	10	14	172	198	4	24	0.36	1.86	/	/	0.34
2.	Ap-1	60	51	396	22091	36	14	4.46	17.2	1.9	0.45	4.56
	Ap-2	36.8	27	426	24625	19	30	8.40	6.89	1.0	0.30	4.62
	Apb	19.2	21	62.1	5820	26	5	2.40	3.14	2.0	1.00	1.95
	Natural	1.3	12	9.7	900	0	1	0.37	0.52	0.1	0.10	4.48

1. Caheratrant, Dingle (Pears, this volume) 2. Cloghanesheskeen, Dingle (Conry and MacNaeidhe 1999) / - No Data

Table 25, Mean multi-elemental values for two soil horizons from Caheratrant

In Scotland and on the Scottish Islands multi element analysis has been used to identify anthropogenic soils and archaeological features. Indeed the deepened topsoils of Orkney were located partly by identifying total phosphate levels of 438 – 588mg/100g (Davidson and Simpson, 1984). At Olligarth, Papa Stour the deepened topsoils from four landuse areas had high phosphate levels ranging from 216 – 279mg/100g in the kaleyard to as little as 58mg/100g in some infield areas (Bryant and Davidson, 1996). Phosphate results from four farm mounds on Tofts Ness, Sanday ranged from 140 – 500mg/100g and illustrated clear anthropogenic soil and midden horizons associated with human occupation (Simpson, et al., 1998).

The results from Fair Isle are, like the other two sample sites, disappointingly low and at first glance appear to suggest limited anthropogenic input especially when compared to the results collected by Fiona Chrystall in the upland anthropogenic soils. Chrystall's results of P clearly show a pronounced increase of total phosphorus in the anthropogenic soils (205 to 365mgP/100g) indicating high levels of organic manuring (Chrystall, 1994).

	Olligarth, Papa Stour	Shirva, Fair Isle
	Mean P (ppm)	Mean P (ppm)
Landuse area	Bryant and Davidson, (1996)	Pears, (this volume)
Kaleyard	5667	133
Infield	3091	109
Outfield	/	54
Upland	0	4

Table 26, Mean P results from Olligarth, Papa Stour and Shirva, Fair Isle. / = No Data

The multi element results from the three landuse areas at Shirva do mirror the pattern of distribution found at Olligarth, Papa Stour (Table 26). The results of both sites do, show a decrease in phosphorus with distance from the centre of settlement centres indicating less organic manuring in the outer areas of the farmsteads.

Site	Greulin, Isle of Skye			Olligarth, Papa Stour			Nairn		Hirta, St Kilda			Shirva, Fair Isle					
Authors	Entwistle, et al., 1998, 2000			Wilson, et al., 2005, 2008			Davidson, et al., 2006		Meharg, et al., 2006			Pears, (this volume)					
Concentration	µg/g			mg/kg			mg/kg		µg/g			Kaleyard mg/kg		Infield mg/kg		Outfield mg/kg	
Elements	On-field	On-field	Off-field	Garden	Arable	Outfield	Anth	Nat	Anth	Upland	Nat.	Anth	Nat.	Anth	Nat.	Anth	Nat
Ca	3930	4880	1840	1740	930	760	/	/	/	/	/	168	93	49	30	43	22
Mg	24100	25100	16300	/	/	/	/	/	/	/	/	129	162	92.5	20	106	172
K	818	939	430	/	/	/	/	/	/	/	/	57	77	61	50	61	83
P	1440	2691	1010	1980	1320	450	932	440	1000-5000	<1000	1000-2000	122	70	119	47	58	14
V	115	131	140	/	/	/	/	/	/	/	/	0.5	0.7	0.4	0.2	0.2	0.1
Cr	189	196	283	/	/	/	/	/	/	/	/	0.7	1.0	0.5	0.2	0.5	0.8
Co	50.5	46.6	35.1	/	/	/	/	/	/	/	/	0.5	0.4	0.4	0.4	0.3	0.2
Ni	213	187	157	/	/	/	/	/	/	/	/	0.8	0.6	0.4	0.3	0.4	0.5
Cu	102	102	70.3	/	/	/	7	3.5	/	/	/	2.2	0.7	0.9	0.5	0.7	0.5
Zn	126	155	107	71.2	34.2	15.3	17	14	50-500	<50	<50	6.2	2.3	1.4	1.0	1.0	0.9
Rb	6.69	9.7	3.13	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Sr	123	142	43.2	43.6	25.9	14.5	/	/	/	/	/	3.0	0.9	1.3	0.7	3.1	0.3
Y	8.71	8.69	4.3	/	/	/	/	/	/	/	/	0.2	0.1	0.1	0.1	0.2	0.1
Cs	1.12	1.31	0.65	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Ba	115	121	50.2	142	109	19.3	/	/	/	/	/	7.0	2.0	2.6	1.7	3.1	1.1
Pb	7.79	11.05	10.2	/	/	/	11	7	10-100	5-35	0-70	8.0	2.0	1.4	1.0	0.7	0.2

Table 27, Table of mean multi-element data from amended and anthropogenic soils across Scotland and the Scottish Islands

Anthropogenic soils from Quoygrew, Orkney have also been shown to contain very high phosphorus results between 5380 – 5600mg/kg but are much lower than the results from a farm mound (4950 – 10950mg/kg) and smaller fish middens (3310 – 5510mg/kg) (Simpson, et al., 2005).

The low elemental concentrations of phosphorus in the sample soils on Fair Isle also continues in the quantities of other elements associated with anthropogenic input and other analyses in Scotland and the Scottish Islands have revealed much higher values and more conclusive evidence of anthropogenic input from settlement centres (Table 27). At Greulin the values of Ca, Mg, K, P, Cu, Zn, Sr and Ba were considerably higher than at Shirva and suggest a high input of food waste and hearth material (Entwistle, et al., 1998). At Shirva although these elements have the highest values they appear to be much more closely associated with background values. The extensive analysis of the elemental composition of the soils from Olligarth, Papa Stour show much more conclusive differences in concentrations between landuse areas (Wilson, et al., 2005). In the garden, arable and outfield areas (which roughly equate to the kaleyard, infield and outfield used in this project) there are big differences between the concentrations of Ca, P, Zn, Sr and Ba suggesting a longer history of manuring on Papa Stour or better retention of elements by the soils.

The low elemental results from Shirva, Fair Isle may be due to the simple fact that little to no inorganic manure from settlement centres was added to the soils and the main material added was organic which would temporarily raise the fertility of the soil but leaves no lasting elemental signature.

5.7 SUMMARY OF BULK ANALYSES OF SAMPLE SOILS FROM THE THREE FARMS

The bulk physical and chemical analyses conducted on the soils present at the three sites illustrate a number of important factors in their formation. The sandy geologies have typically given the soils sandy textures and moderately acidic soil pH (section 5.2) a pattern seen on other sites with anthropogenic soils (Pape, 1970; Conry, 1971; Dercon, et al., 2005).

However, there is distinct variation in the loss on ignition results (section 5.3) indicating differences in the addition of organic manures between different landuse areas and between the three sites. This variation can be seen most clearly at Shirva and Caheratrant where peat was used predominantly as organic manure. The use of heathland and meadowland turf at Olthof along with increased post burial breakdown has resulted in lower organic results. Evidence of organic and inorganic waste input from settlement centres has been less distinctive especially at Olthof. At this site the magnetic susceptibility and multi-element results (chapter 5, sections 5.5.2 and 5.6.2) suggest very little amendment with midden, hearth or industrial waste, unlike similar sites (Pape, 1970; Bryant and Davidson, 1995; Simpson, et al., 1998; Wilson, et al., 2005). Despite the low results however, distinct patterns in manuring could be determined between different landuse areas and at each of the three sample sites there is a clear reduction in results of loss on ignition, magnetic susceptibility and multi-element with distance from the farm nuclei, indicating less input. This pattern mirrors the results of other sites where anthropogenic soils are present (Bryant and Davidson, 1995; Wilson, et al 2005).

Results from the fieldwork and bulk soil analyses have highlighted a number of important issues. Firstly the deepest anthropogenic soil sequences were found at Olthof (chapter 3, section 3.6.1) but the pH, loss on ignition, magnetic susceptibility and elemental concentrations have been considerably lower than at other sites analysed (Shirva and Caheratrant) and in previous analysis (Pape, 1970; Dercon, et al 2005). Secondly, at Shirva (chapter 2, 2.6.1 and 2.7.2) very shallow, moderately amended soils were found with higher numbers of anthropogenic inclusions and with more evidence of manuring with organic and inorganic material. As indicated previously these differences may be due to variations in the manuring process, post burial removal of elemental evidence by the movement of soil water and ploughing or possibly because elemental concentrations are being withheld in inclusions of carbonised organic and inorganic particles. To understand these soils further, analysis with micromorphology must be undertaken.

6 SOIL MICROMORPHOLOGY & THE QUANTIFICATION OF MANURING INCLUSIONS

6.1 INTRODUCTION

This chapter discusses and interprets the micromorphology of the amended and anthropogenic soils from the three farm sites. The broad aim is to investigate the microscopic detail of the horizons in order to gain information about soil formation and evidence of post depositional soil processes. This will complement the fieldwork (chapters 2 to 4), bulk soil analysis, as discussed in chapter 5, section 5.8 as well as determine the range and diversity of black carbonised particles (chapter 7). Micromorphology allows the identification and detailed analysis of soil and inclusions, which can lead to more detailed interpretation of soil forming processes. Therefore, it is very important to define and describe the different forms of organic, mineral and anthropogenic inclusions, in order to increase understanding of soil forming processes in the soils at the three sites.

Micromorphological analysis can reveal the extent of anthropogenic input into soils, however it is extremely important to understand that there are complex soil processes acting upon different inclusions which may lead to erroneous interpretations of formation processes. In order to maximise micromorphological potential, this chapter analyses the micromorphological description and characterisation of the soil horizons from each landuse area across each site (Fair Isle; section 6.2, the Netherlands; section 6.3 and Ireland; section 6.4) with a particular focus on the organic and inorganic inclusions indicative of the manuring process. There is also a full cross site discussion of these results in section 6.5. The second part of the chapter focuses upon the identification and quantification of black carbonised particles and black amorphous particles by a process of zone counting and image analysis (sections 6.6 and 6.7). The quantitative analysis of identifiable organic and inorganic inclusions was split into nine distinct categories including peat, burnt peat, turf, burnt turf, charcoal, amorphous black and red/brown fragments, mineral inclusions and plant inclusions

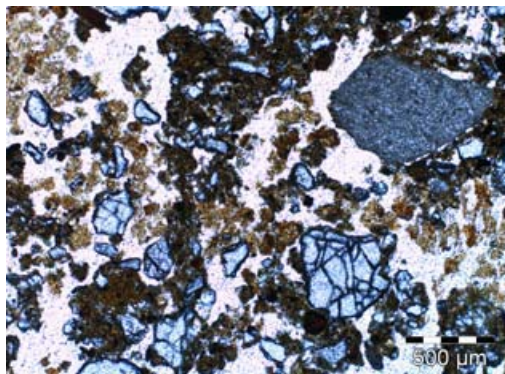
The methodology for the micromorphology and zone counting is described in chapter 1, section 1.13. The raw data from the micromorphology,

zone count and image analysis is illustrated in appendices 13-16 and summary results are displayed within the text alongside key photographs.

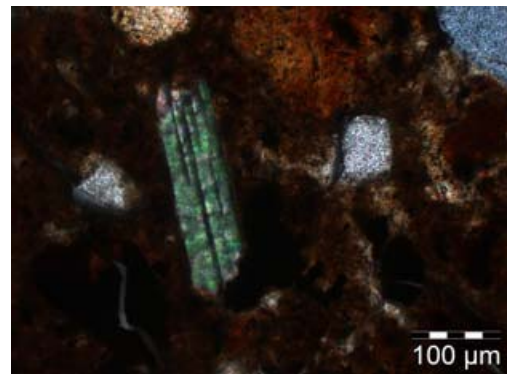
6.2 MICROMORPHOLOGY RESULTS – FAIR ISLE

6.2.1 ROCK AND MINERAL INCLUSIONS

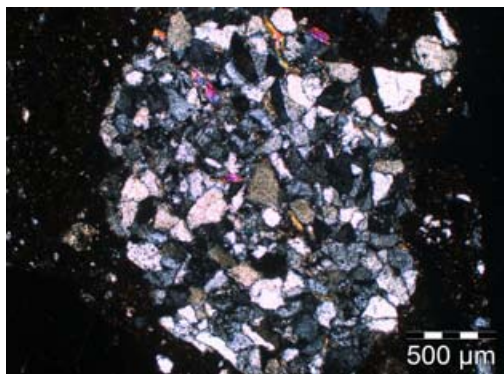
Within each of the kaleyard sequences on Fair Isle there is a large quantity of quartz fragments of varying sizes but mainly sub-rounded to sub-angular shape with no distinctive alteration with depth (Plate 18a). The quartz particles are directly comparable with the quartz fragments found in the C horizon at each of the sites and this suggests that they have a natural origin and are not part of beach sand addition but quantities may have increased accidentally through the addition of turf and peat.



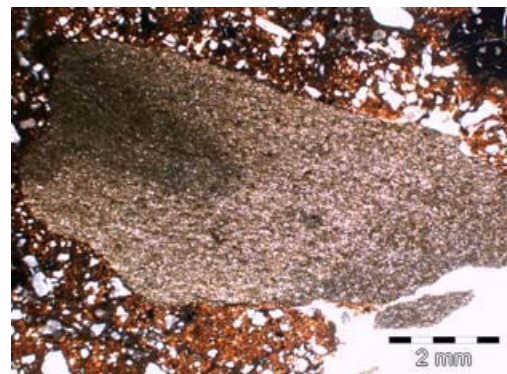
18a, Quartz Fragments 500µm (ppl)



18b, Calcite 100µm (xpl)



18c, Quartzite 500µm (xpl)



18d, Sandstone 2mm (ppl)

Plates 18a-d, Rock and mineral inclusions from the three sites on Fair Isle

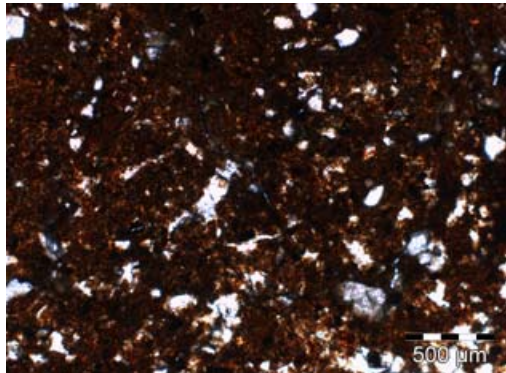
Small calcite fragments are clearly identifiable at the three kaleyards (Plate 18b), typically dark grey, elongate particles with radial mineral structure. At Shirva there is little change in the quantity with depth (Fig 121) but at Busta and Leogh the numbers steadily decrease down profile (Figs 122 and 123). Rock and sediment fragments in the horizons include sandstone and quartzite from which the high quartz quantities derive. Both increase in number with depth at Shirva and Busta but Leogh contains a much lower level. Much rarer inclusions of mudstone and schist are also identifiable in the upper amended soils but the samples are very small and derive from the natural till sediments. Like the kaleyards, the infield and outfield areas are also dominated by quartz (Figs 121 to 125), the inclusions are typically clear to white/yellow colour with a sub-angular to sub-rounded shape.

The quartz may derive from several places, in the infield area (Fig 124) there is a larger quantity of silica based rock materials including quartzite and sandstone from the natural Old Red Sandstone (Plate 18c and 18d), whereas in the outfield there is considerably less sandstone and a lower level of quartzite suggesting that the high quartz level is coming from the deposition of organic manure such as peat and turf and this mirrors the field observations. Both areas have high quantities of iron oxide which are consistent throughout the amended soils and this may derive from the breakdown of iron within the peat and turf manuring components or from the C horizon. This pattern is particularly evident in the Ap-3 horizon of the outfield (Fig 125) where biological mixing and translocation had transported iron from the H and C horizons into the Ap horizons. Manganese inclusions also increase with depth at both landuse areas with slightly higher levels in the outfield sequence, especially in the Ap-2 horizon possibly because of the free movement of water through the soil (Figs 124 and 125). Compared to the kaleyard areas the infield and outfield areas contain almost no inclusions of foreign lithics or softer mudstone fragments, possibly because of the absence of glacial till.

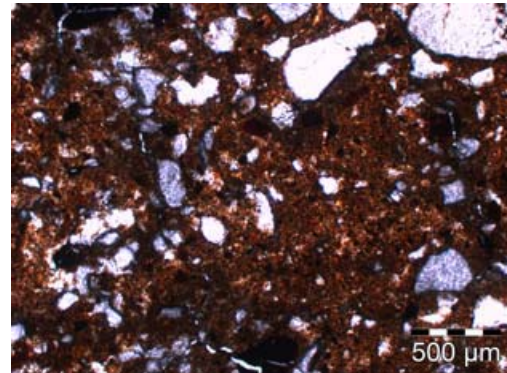
6.2.2. FINE MINERAL STRUCTURE AND ORGANICS

The fine mineral component changes very little across the different contexts and between the three sites (Figs 121 to 123), (Plates 19a, 19b,

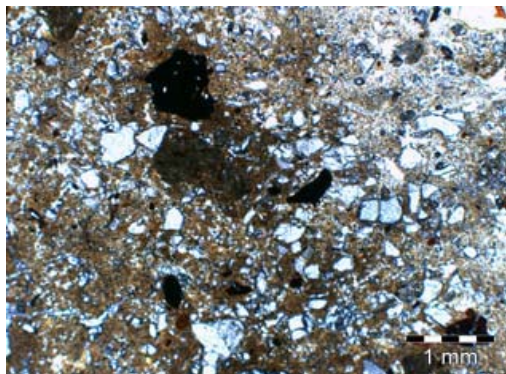
19c). The colour ranges from very dark brown to reddish brown and patches of yellow orange in places which contrasts markedly with the natural soil which has a considerably lighter yellow to orange colour (Plate 19d).



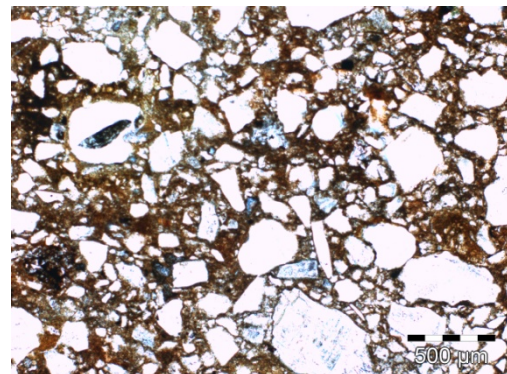
19a, Shirva kaleyard microstructure
500µm (ppl)



19b, Busta kaleyard microstructure
500µm (ppl)



19c, Leogh kaleyard microstructure
1mm (ppl)



19d, Natural microstructure 500µm
(ppl)

Fig 19a-d, Fine organo-mineral microstructures from kaleyards on Fair Isle

The microstructures are all typically intergrain microaggregate but there are variations at Shirva. The Ap-3 horizon has denser patches of vuggy and chamber voids suggesting more biological action and in the Ap-4 horizon there are a number of sub-angular blocky structures, associated with an increase in organic and silty clay particles.

Site - FAIR ISLE, SHIRVA Location - Kaleyad Test Pit - 2			Coarse Rock & Mineral Components ($<10\mu\text{m}$) (1)					Coarse Organics (1)				Fine Organics (1)				Pedofeatures (2)										Microstructure	Coarse Material Arrangement	Groundmass 'b' Fabric	Related Distribution	
Slide No	Depth (mm)	Context	Quartz	Sandstone	Quartzite	Mudstone	Schist	Fine Mineral	Charcoal	Burnt Peat	Peat	Turf	Lignified Tissue	Spores	Amorphous Black	Amorphous Brown	Amorphous Orange	Cell Residue	Silt Infills	Clay Infills	Organic Coatings	Excremental Features	Iron Oxide Nodules	Manganese Nodules	Amorphous Crypto- Crystalline coatings					
1	0 - 80	Ap-1	****	**	**	*	*	Dark Brown to light yellow/orange colour, heterogeneous + spotted limpidity	***	**	***	**	*	*	***	**	**	*	**	**	t	**	**	**	Intergrain micro-aggregate structure	Random, moderately to poorly sorted	Stippled, Flecked	Upper 50mm has a (25-30%) close porphyric distribution with (5-10%) fine monic distribution. From 50 – 80mm (10 -15%) close porphyric distribution and (20-25%) fine monic and open porphyric distribution		
2	60 - 140	Ap-2	****	***	**	*	t	Brown to very dark Brown with patches of yellow/orange, heterogeneous + spotted limpidity	**	**	***	**	*	*	***	**	t	t	***	**	*	*	**	**	Intergrain micro-aggregate structure	Random, moderately to medium sorting	Stippled, Flecked	Open Porphyric (+60%) with patches of Double Porphyric (20%) and Fine Monic (<10%) and Double Spaced Fine Enaulic (<10%) in most of the context towards base the c/f distribution becomes more Double Spaced Fine Enaulic to Close Porphyric.		
3	180 - 260	Ap-3	****	***	*	t	t	Dark Brown, dark orange with very dark reddish/orange patches, heterogeneous + spotted limpidity	**	**	**	**	**	t	**	*	*	*	***	***	t	*	**	**	Intergrain micro-aggregate + patches of dense vughy and occasional chamber structure	Random, medium to well sorted structure	Stippled, Flecked	Double Porphyric (+45) and Open Porphyric (+30) with small areas (<10%) of Fine Monic		
4	240 - 320	Ap-3	****	***	**		t	Dark Brown to reddish-orange colour, heterogeneous + dotted limpidity	*	t	t		t		**	t	t		*	*	t		***	***	Intergrain micro-aggregate + of sub-angular blocky structure	Random, medium to well sorted structure	Stippled, Flecked	Distinctive Double spaced fine enaulic distribution (+40%) with areas of close porphyric (15-20%) and smaller patches of fine monic/open porphyric (<10%)		
5	300 - 380	Ap-3	****	**	**			Dark Brown/red/orange becoming lighter yellow/orange(360-380mm), heterogeneous, spotted limpidity	*	*	*				*				T			***	***	Very blocky structure with some micro-aggregate structure within voids	Random, medium to well sorted structure	Stippled, Flecked	Double spaced fine enaulic distribution across (+40%) of the slide with a more close to single spaced porphyric (15 – 20%) towards base of deposit with small areas of fine monic (<5%)			
(1) Frequency levels for coarse mineral components (Bullock et al (1985)																t trace, * very few, ** few, *** frequent/common, **** dominant/very dominant														
(2) Frequency level for textural pedofeatures (Bullock et al 1985)																t trace, * rare, ** occasional, *** many														

Figure 121, Summary table of micromorphology from a sequence of soils at Shirva kaleyard, Fair Isle

Site - FAIR ISLE,
BUSTA
Location - Kaleyad
Test Pit - 8

Slide No	Depth (mm)	Context	Coarse Rock & Mineral Components (<10µm) (1)						Coarse Organics (1)					Fine Organics (1)					Pedofeatures (2)					Microstructure	Coarse Material Arrangement	Groundmass 'b' Fabric	Related Distribution	
			Quartz	Sandstone	Quartzite	Mudstone	Schist	Fine Mineral	Charcoal	Burnt Peat	Peat	Turf	Lignified Tissue	Spores	Amorphous Black	Amorphous Brown	Amorphous Orange	Cell Residue	Silt Infills	Clay Infills	Organic Coatings	Excremental Features	Manganese Nodules					Iron Oxide Nodules
1	0 - 80	Ap-1	****	**	***	**	Dark brown/reddish orange colour with areas of lighter yellow/orange. Hetrogeneous + spotted limpidity	***	***	**	**	***	**	***	**	**	**	***	**	**	***	***	***		Intergrain micro-aggregate structure	Random, with medium to moderately well sorted microstructure	Stippled, Flecked	Very closely packed double spaced porphyric structure (+40%) with smaller areas of open porphyric (<20%) and more compact single spaced porphyric (10 – 15%)
2	130 - 210	Ap-2	****	***	***	*	Dark brown to orangey/reddish colour. Hetrogeneous + spotted limpidity	***	**	***	*	**	*	***	**	*	*	***	*	**	**	**	***		Intergrain micro-aggregate structure	Random, with medium to moderately well sorted microstructure	Stippled, Flecked	Very closely packed double spaced porphyric structure (+40%) with smaller areas of open porphyric (<20%) and more compact single spaced porphyric (10 – 15%)
3	260 - 340	Ap-3	****	***	***		Light brown with patches of light yellow/orange colour. Hetrogeneous + spotted limpidity	**	**	**	t		t	**	**	t	t	**	t	t	**	**	***		Intergrain micro-aggregate structure	Random, with medium to moderately well sorted microstructure	Stippled, Flecked	Predominantly double spaced fine enaulic (+30%) with areas of double spaced porphyric (+20%) but also small areas of open porphyric (5-10%)
4	390 - 470	Ap-3	****	***	***	t	Brown to light brown, orange grey yellow colour. Hetrogeneous + spotted limpidity	*	*	*	t			**	*	t	t	*	*	*	**	*	****		Intergrain micro-aggregate structure	Random, Medium to moderately well sorted microstructure	Stippled, Flecked	+60% double spaced porphyric with small areas of quartz dominated close porphyric areas towards the bottom of the context

(1) Frequency levels for coarse mineral components (Bullock et al (1985)

(2) Frequency level for textural pedofeatures (Bullock et al 1985)

t trace, * very few, ** few, *** frequent/common, **** dominant/very dominant

t trace, * rare, ** occasional, *** many

Figure 122, Summary table of micromorphology from a sequence of soils at Busta kaleyard, Fair Isle

**Site - FAIR ISLE,
LEOGH
Location - Kaleyad
Test Pit - 9**

Slide No	Depth (mm)	Context	Coarse Rock & Mineral Components (<10µm) (1)							Coarse Organics (1)					Fine Organics (1)					Pedofeatures (2)										Microstructure	Coarse Material Arrangement	Groundmass 'b' Fabric	Related Distribution
			Quartz	Sandstone	Quartzite	Mudstone	Schist	Fine Mineral	Charcoal	Burnt Peat	Peat	Turf	Lignified Tissue	Spores	Anorphous Black	Anorphous Brown	Anorphous Orange	Cell Residue	Silt Infills	Clay Infills	Organic Coatings	Excremental Features	Manganese Nodules	Iron Oxide Nodules	Anorphous Crypto-Crystalline coatings								
1	20 - 70	Ap-1	****	**	**	t	t	Light brown with areas of dark yellow orange colour Hetrogeneous + spotted limpidity	**	*	**	t	t	*	***	**	t	*	**	**	*	*	***	***	Intergrain micro-aggregate structure	Random, Moderately sorted fabric with areas of well sorted fine grained areas	Stippled, Flecked	Areas of closely packed fine monic distribution (10-15%) becoming more open spaced porphyric (20-25%) and double spaced porphyric (20-25%) towards the base of the context					
1	70 - 100	Ap-2	****	*	*			Dark yellow to light brown colour with areas of darker brown orange	**	*	**	t			***	***	t	t	*	***	**	**	***	***	Intergrain micro-aggregate structure	Random, Moderately to poorly sorted fabric with small areas of poorly sorted fabric	Stippled, Flecked	Double spaced porphyric distribution (10-20%) with areas of fine monic distribution (5-10%) and towards the base of the slide increasing areas of coarser double spaced fine enaulic (10-15%)					
2	120 - 200	Ap-2	****	*	**	t		Dark yellow/orange reddish brown colour	**	t	*	*			**	*			*	**	*	**	**	***	Intergrain micro-aggregate structure	Random, Moderately to poorly sorted fabric with small areas of very poorly sorted fabric	Stippled, Flecked	Double spaced porphyric distribution and double spaced fine enaulic predominant (+30%) with areas of single spaced porphyric (5 – 10%)					
3	220 - 300	Ap-3	****	t	***			Dark orangey, reddish brown colour	*	*	*	t			**	t	t		**	***	t	t	*	**	Intergrain micro-aggregate structure	Random, Moderately sorted fabric with small areas (<10%) poorly sorted fabric	Stippled, Flecked	Double spaced porphyric distribution and double spaced fine enaulic predominant (+30%) with areas of single spaced porphyric (5 – 10%)					
4	320 - 380	Ap-3	****	*				Very dark orangey reddish brown colour with patches of very light yellow and darker brown	*	*	**	t	t		*	**			*	*		t	**		Intergrain micro-aggregate structure	Random, Moderately sorted fabric with small areas (<10%) poorly sorted fabric	Stippled, Flecked	Double spaced fine enaulic structure and areas of single spaced porphyric					
4	380 - 400	B	****	**				Light yellow, dark reddish orange colour	n/a						**	**			•				****	Intergrain micro-aggregate structure	Random, Moderately sorted fabric with small areas (<10%) poorly sorted fabric	Mineragenic, Granular	Predominantly Coarse Monic distribution (+40%) with smaller areas of double spaced fine enaulic (10-15%) and (<5%) fine monic						

(1) Frequency levels for coarse mineral components (Bullock et al (1985)

(2) Frequency level for textural pedofeatures (Bullock et al 1985)

t trace, * very few, ** few, *** frequent/common, **** dominant/very dominant

t trace, * rare, ** occasional, *** many

Figure 123, Summary table of micromorphology from a sequence of soils at Leogh kaleyad, Fair Isle

**Site – FAIR ISLE,
SHIRVA
Location - INFIELD
Test Pit - 1**

Site – FAIR ISLE, SHIRVA Location - INFIELD Test Pit - 1			Coarse Rock & Mineral Components (<10µm) (1)					Coarse Organics (1)				Fine Organics (1)				Pedofeatures (2)						Microstructure	Coarse Material Arrangement	Groundmass 'b' Fabric	Related Distribution				
Slide No	Depth (mm)	Context	Quartz	Sandstone	Quartzite	Mudstone	Schist	Fine Mineral	Charcoal	Burnt Peat	Peat	Turf	Lignified Tissue	Spores	Amorphous Black	Amorphous Brown	Amorphous Orange	Cell Residue	Silt Infills	Clay Infills	Organic Coatings					Excremental Features	Manganese Nodules	Iron Oxide Nodules	Amorphous Crypto-Crystalline coatings
1	20 - 100	Ap-1	***	***	**			Dark brown, reddish orange colour with patches of lighter yellow/brown. Hetrogeneous + spotted limpidity	**	**	*		***	**	***	**	**	*	**	**		***	*	***		Intergrain micro-aggregate structure	Random, Moderately to medium sorting with areas of well sorted	Stippled, Flecked	Open Porphyric (+60%) with patches of Double Poryphric (20%) and Fine Monic (<10%) and Double Spaced Fine Enaulic (<10%) in most of the context towards base the c/f distribution becomes more Double Spaced Fine Enaulic to Close Porphyric
2	120 - 200	Ap-2	***	***	***			Dark brown, reddish orange colour with patches of lighter yellow/brown. Hetrogeneous + spotted limpidity	**	*	*		***	*	***	**	**		**	**		**	**	***		Intergrain micro-aggregate structure	Random, Medium to well sorted structure	Stippled, Flecked	Double spaced porphyric structure (+60%) with areas of open porphyric (10-15%) and some close porphyric (<5%)
3	200 - 280	Ap-3	***	***	***			Dark orangey/reddish brown colour with areas of lighter brown yellow/orange, associated with finer grained matrix. Hetrogeneous + spotted limpidity	*	*	t		**	*	**	*	*		**	**		**	**	***		Intergrain micro-aggregate structure	Random, Medium to well sorted structure	Stippled, Flecked	Double spaced porphyric structure (+60%) with areas of open porphyric (10-15%) and some close porphyric (<5%)
4	320 - 400	Ap-3	***	****	****		*	Dark red/brown colour throughout deposit with larger patches of yellow/orange towards base (fragments of C horizon). Hetrogeneous + spotted limpidity	*	t	*		**	t	***	**			t	t		*	**	***		Intergrain micro-aggregate structure	Random, Moderately to medium sorting with areas of well sorted	Stippled, Flecked	Mostly double spaced porphyric structure (+50%) with (10-15%)

(1) Frequency levels for coarse mineral components (Bullock et al (1985)

(2) Frequency level for textural pedofeatures (Bullock et al 1985)

t trace, * very few, ** few, *** frequent/common, **** dominant/very dominant

t trace, * rare, ** occasional, *** many

Figure 124, Summary table of micromorphology from a sequence of soils at Shirva infield, Fair Isle

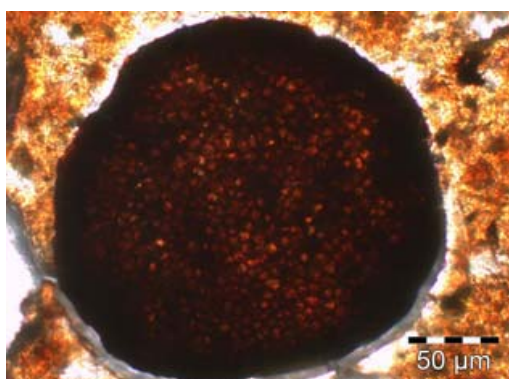
Site – FAIR ISLE, SHIRVA Location - OUTFIELD Test Pit - 5&6			Coarse Rock & Mineral Components ($<10\mu\text{m}$) (1)							Coarse Organics (1)					Fine Organics (1)					Pedofeatures (2)										Microstructure	Coarse Material Arrangement	Groundmass 'b' Fabric	Related Distribution
Slide No	Depth (mm)	Context	Quartz	Sandstone	Quartzite	Mudstone	Schist	Fine Mineral	Charcoal	Burnt Peat	Peat	Turf	Lignified Tissue	Spores	Amorphous Black	Amorphous Brown	Amorphous Orange	Cell Residue	Silt Infills	Clay Infills	Organic Coatings	Excremental Features	Manganese Nodules	Iron Oxide Nodules	Amorphous Crypto-Crystalline coatings								
1	80 - 160	Ap-1	***	**		t		Dark brown/red/orange heterogeneous + spotted limpidity	*	**	***	*	***	**	***	***	**	**	*	*	**	***	**	***		Intergrain micro-aggregate structure	Random, medium to well sorted with $<5\%$ medium to poorly sorted	Stippled, Flecked	Double spaced fine enaulic (+45%) with small areas (15 – 20%) single spaced porphyric structure. The fills of voids has a distinctive double spaced porphyric structure with areas of fine monic structure				
2	200 - 280	Ap-2	***	*	**			Dark brown to brown/reddish colour with areas of lighter brown/orange, Heterogeneous, dotted limpidity	*	**	***		***	**	***	***	**	**	**	**	*	***	**	***		Intergrain micro-aggregate structure	Random, Fine to medium well sorted microstructure across slide with very fine structure around voids	Stippled, Flecked	Double spaced porphyric (30 – 40%) with areas of coarser single spaced porphyric ($<15\%$) and small patches of double spaced fine enaulic ($<5\%$)				
3	320 - 400	Ap-2	***	**				Light reddish/brown to dark brown/orange colour, Homogeneous + dotted limpidity	*	*	*		***	**	**	*	*		**	**	*	***	***	***		Fine microaggregate structure	Random, Fine to medium sorting of microstructure and fining towards voids	Stippled, Flecked	Double spaced fine enaulic (+30%) distribution with areas of finer double spaced porphyric (10 – 15%)				
4	440 - 520	Ap-3	***	t	*		t	Dark orange, brown to dark brown colour, Homogeneous + spotted limpidity	t	*	*		**	*	*	*	*		t	*	*	**	***	***		Fine microaggregate structure	Random, Fine to medium sorting less well sorting towards base	Stippled, Flecked	Double spaced fine enaulic at the top of the slide (+40) with some areas of open porphyric (10 – 15%) and gradually reverts to a single spaced porphyric (+30%) + close porphyric (5-10%)				
5/6	530 - 610	Ap-3	****	*		t		Dark red, dark, dark yellow colour, Homogeneous, spotted limpidity	t	***			***	**	*	*	*		t	*	*	****	**	****		Intergrain micro-aggregate structure	Random, medium to well sorted composition	Stippled	Double spaced porphyric distribution (+30%) with increasing close porphyric towards lower context. Fine matrix has very small areas ($<5\%$) double spaced fine enaulic				
6	610 - 660	H	**	*				Very dark brown, reddish/dark orange colour, hetogenous + spotted limpidity			****		****	**	*	*	*				**	****	**	****		Spongy, microgranular structure	Random, Medium to poorly sorted	Mineragenic, Granular	Distinctive close porphyric (40%) to chitonic (30%) distribution across context with areas of single spaced fine enaulic (+10%) and single spaced porphyric (+10%)				
6	660 - 690	B	****	*	**		*	Light brown to yellow, orange, homogeneous		*		*	t	t	t				t	*	*	*	*	****		Intergrain micro-aggregate structure to semi-single grain structure and some bridged grain structure	Random, Intergrain micro-aggregate structure to semi-single grain structure	Mineragenic, Granular	Sub close porphyric (30%) to sub chitonic (30%) distribution with some single spaced porphyric (20%)				

(1) Frequency levels for coarse mineral components (Bullock et al (1985) t trace, * very few, ** few, *** frequent/common, **** dominant/very dominant

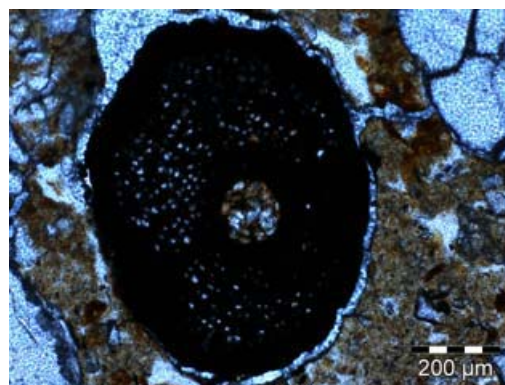
(2) Frequency level for textural pedofeatures (Bullock et al 1985) t trace, * rare, ** occasional, *** many

Figure 125, Summary table of micromorphology from a sequence of soils at Shirva outfield

Towards the natural soil the microstructure becomes almost entirely granular with very occasional intergrain microaggregate areas. The groundmass 'b' fabric in each of the soil horizons is stippled and flecked due to the high level of organic particles present in the fine soil fabric and as a direct result the levels of fine organic material decreases with depth at each of the sequences. The presence of fine organic inclusions varies across the soil horizons (Figs 121 to 125). At all three landuse areas there are a few to frequent number of black, brown and orange amorphous fragments which might be associated with organic additions to the soils but each decrease with depth (Figs 121 to 125). The more delicate cell residues also decrease but are only found in the upper 200mm at Shirva and Leogh with almost none at Leogh, possibly because of post burial consumption by soil organisms (Plate 20a and 20b).



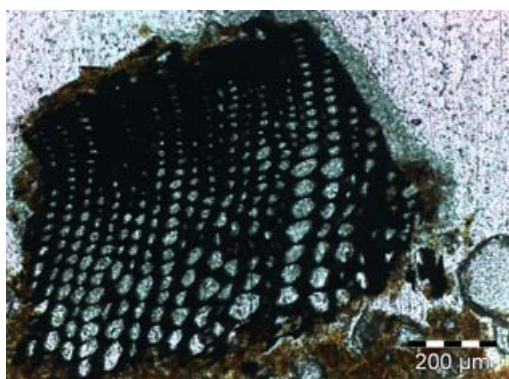
20a, Seed case 50μm (ppl)



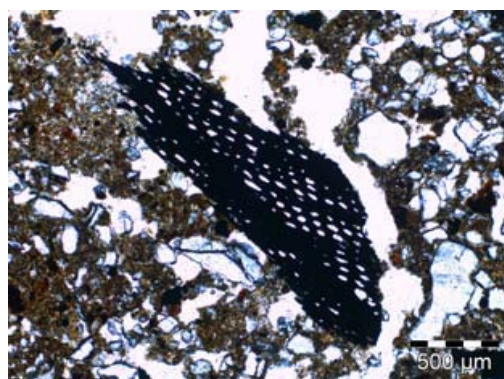
A043 Plant residue 200μm (ppl)

Plate 20a-d, A seed case and plant residue from three kaleyards on Fair Isle

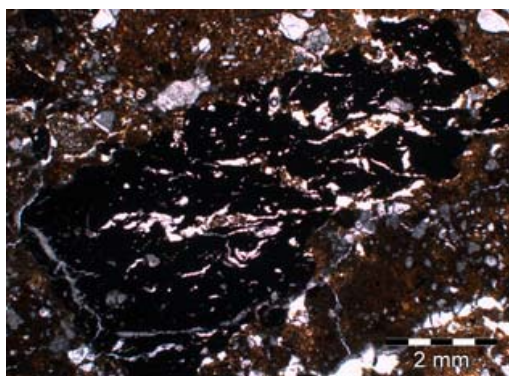
The coarse organic inclusions are considerably easier to identify than the small amorphous fragments and reveal input differences between the amended soils and across the three farms. Charcoal fragments are greatest in the Ap-1 horizon at both Shirva and Busta but at Leogh the numbers are considerably lower, suggesting less input from the farm centre (Figs 121 to 123), (Plate 21a and 21b). At Shirva the Ap-2 and Ap-3 horizons contain less charcoal, but at Busta the level is fairly even, and at Leogh there are also low levels throughout the horizons.



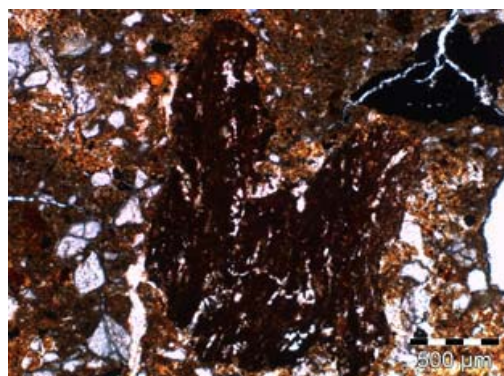
21a, Charcoal 200µm (ppl)



21b, Charcoal 500µm (ppl)



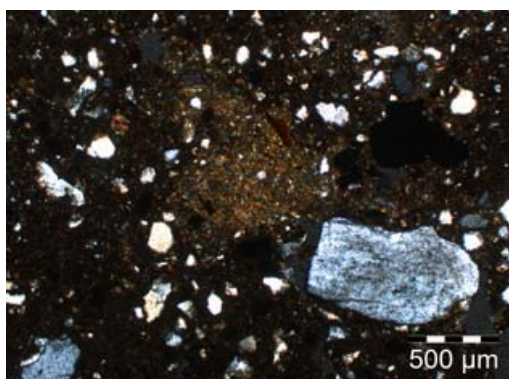
21c, Burnt peat 2mm (ppl)



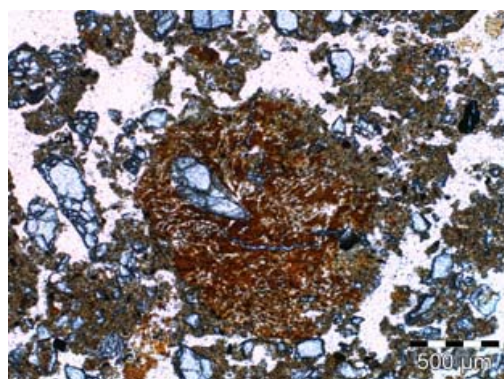
21d, Peat 500µm (ppl)

Fig 21a-d, Large organic inclusions from the three kaleyards on Fair Isle

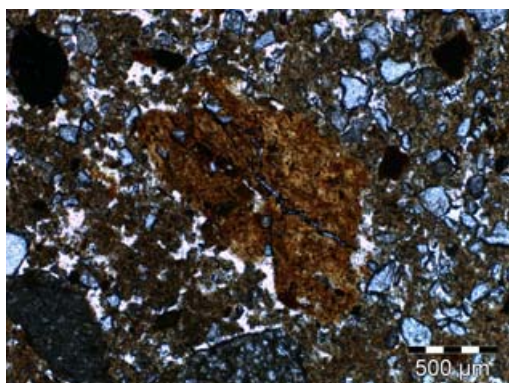
Carbonised peat and turf inclusions are also relatively high at the three sites and especially in the Ap-1 horizon. At Shirva there is a high number in the upper 250mm but a very distinctive decrease in the Ap-3 and natural soils (Fig 121), (Plate 21c, 21d and 22a). At Busta there are very high numbers of peat and burnt peat fragments in all three Ap horizons and less turf and carbonised turf inclusions (Fig 122), (Plate 22c). At Leogh the number of burnt peat and turf fragments is considerably lower throughout the sequence and the horizons have much higher levels of peat and turf fragments (Fig 123), (Plate 22d). This suggests that Leogh kaleyard has much less input from settlement centres than the other sites, and the soil stratigraphy was built up utilising mainly organic components. Delicate lignified tissues and spores are also present in greater abundance at Shirva and Busta in each of the soil horizons than at Leogh.



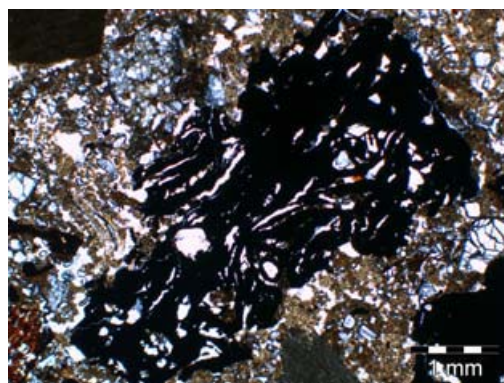
22a, Degraded turf 500µm (xpl)



22b, Turf 500µm (ppl)



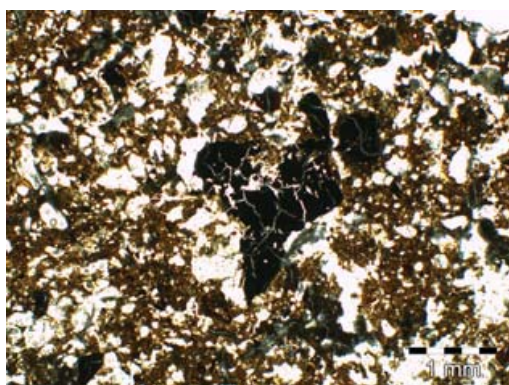
22c, Turf 500µm (ppl)



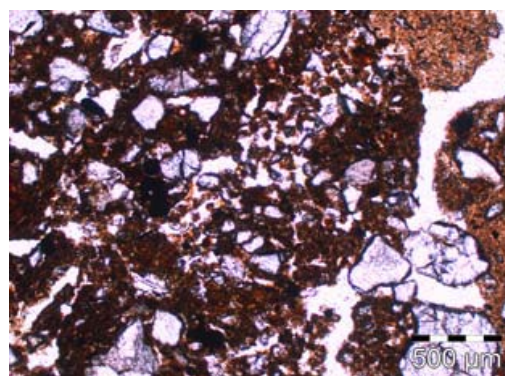
22d, Carbonised peat 1mm (ppl)

Plate 22a-d, Large organic inclusions from the three kaleyards on Fair Isle

The soil horizons in the infield have a dark brown colour with areas of reddish brown and some lighter yellow patches, with an intergrain microaggregate structure throughout and distinctive stippled and flecked groundmass (Plate 23a). The relative distribution of the structure ranges from open porphyric to double porphyric suggesting an increase in pore space, most likely due to the movement of soil organisms and this theory is complemented by the excremental pedofeature evidence (Fig 124). In the outfield area the fine organic material is also dark brown to dark reddish brown with dotted limpidity from the high level of organic and iron translocation (Plate 23b). The microstructure varies from an intergrain microaggregate structure, in the Ap-1 and Ap-2 horizons, to a finer microaggregate in the Ap-3 horizon and a distinctive spongy microgranular structure in the buried H horizon (Fig 125).

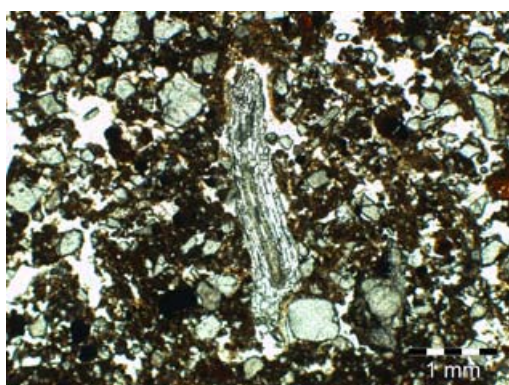


23a Microstructure with carbonised peat 1mm (ppl)

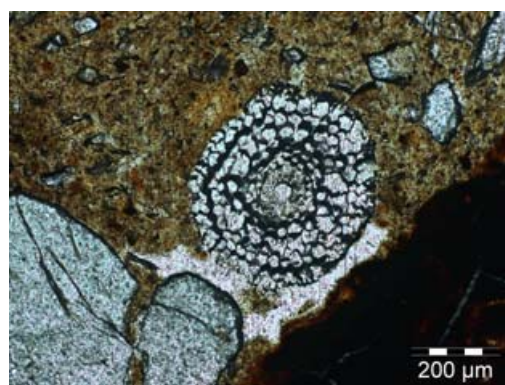


23b Microstructure 500µm (ppl)

Plate 23a-b, Fine organo-microstructures from the infield and outfield at Shirva, Fair Isle



24a, Plant residue 1mm (ppl)

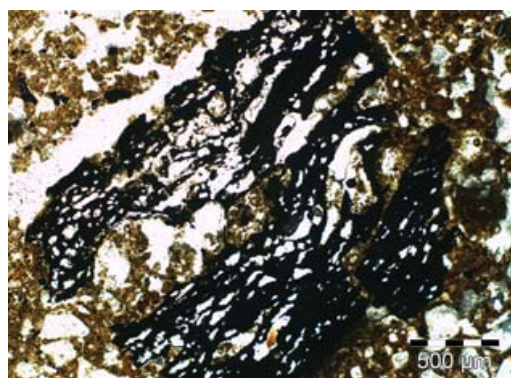


25b, Plant fragment 200µm (ppl)

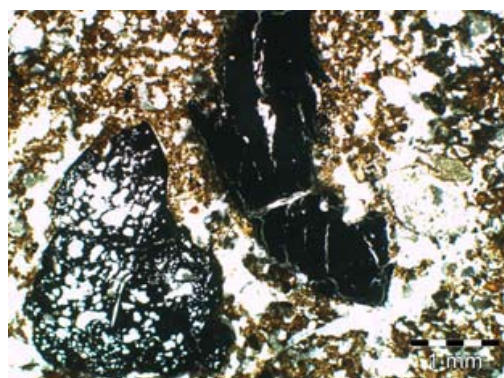
Plate 24a-b Large plant inclusions from Shirva infield & outfield on Fair Isle

The groundmass has a stippled and flecked appearance but towards the base of the sequence there is a larger mineragenic and granular fabric coinciding with the sandy C horizon. As observed in the infield area the upper soil horizons have a distinctive double spaced porphyric to fine enaulic structure indicating an equal if not larger amount of void space from soil microbial activity and plant growth. Fine organic inclusions in the amended soils include amorphous black, brown and orange particles which decrease with depth and at both the infield and outfield areas.

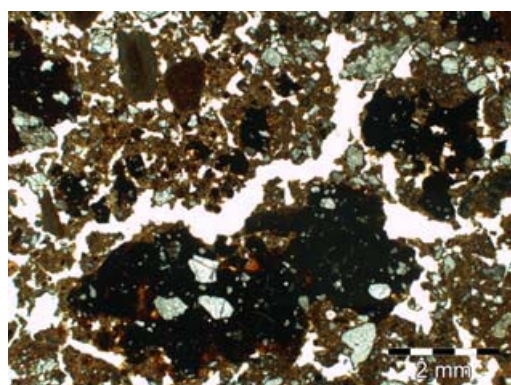
At both landuse areas the Ap-1 and Ap-2 horizons contain the most amorphous inclusions and a small quantity of cell residue usually within small degraded void spaces (Plate 24a and 24b). In the infield area there is a decrease in the number of particles, but a distinctive increase in the Ap-3 horizon possibly due to heavy mixing with the natural which appears to have removed any evidence of organic inclusions.



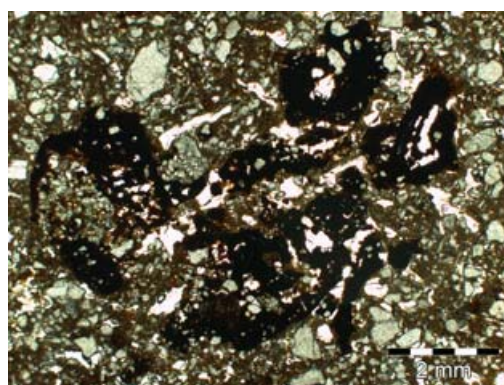
25a, Carbonised peat 500µm (ppl)



25b, Burnt peat & turf 1mm (ppl)



25c, Unburnt peat with degraded edges from H horizon 2mm (ppl)

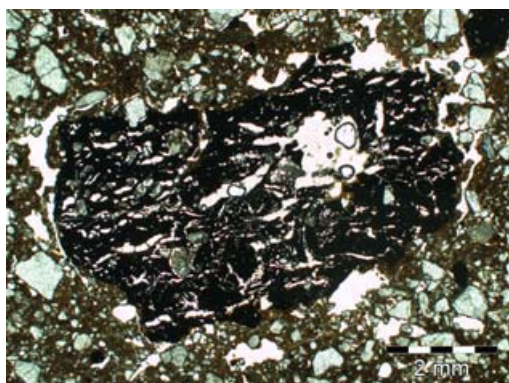


25d, Heavily degraded peat in B

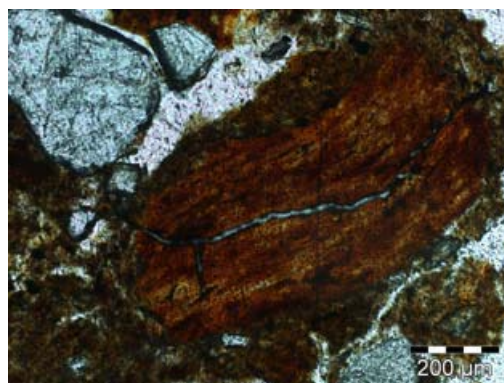
Plate 25a-d Large organic inclusions from Shirva infield & outfield on Fair Isle

The coarse organic inclusions clearly illustrate a reduction in charcoal inclusions between the kaleyard and infield/outfield areas and both areas demonstrate a reduction with depth. The infield area has high numbers of carbonised and uncarbonised peat fragments indicating a specific manuring programme (Fig 124), (Plate 23a, 25a and 26b). By contrast, the outfield area the Ap-1 and Ap-2 horizons are dominated by uncarbonised peat fragments

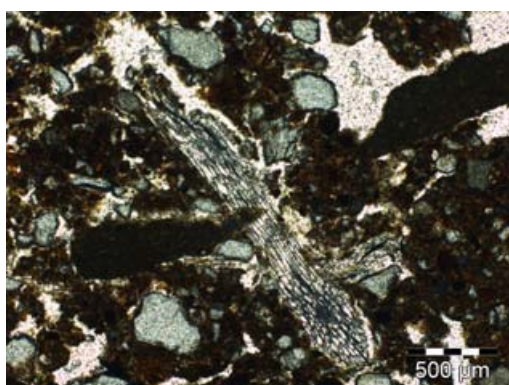
(Plate 25c and 25d), burnt peat fragments (Plate 26a) and minimal turf inclusions (Plate 26b), and indicate a different manuring regime (Fig 125).



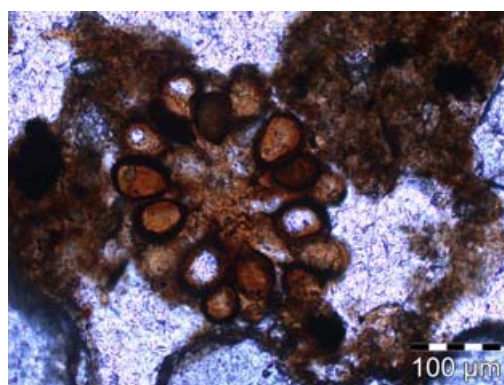
26a, Burnt peat 2mm (ppl)



26b, Turf 200µm (ppl)



26c, Plant fragment 500µm (ppl)



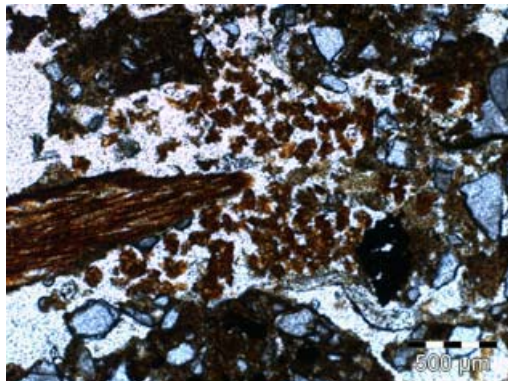
26d, Plant residue 100µm (ppl)

Plate 26a-d Large organic inclusions from Shirva infield & outfield on Fair Isle

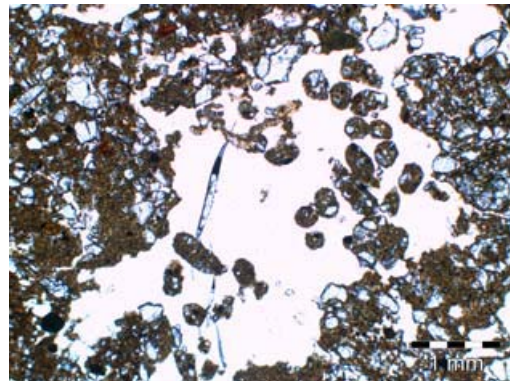
There is a reduction in the amount of peat in the Ap-2 and Ap-3 horizons but an increase in the lower Ap-3 horizon as a result of the breaking up of the buried peat horizon (H), probably by ploughing or spading action. The amount of lignified tissue and plant spores decreases with depth in the infield and reflects the high level of organics from the addition from peat and possibly from the growth of small plants. There is a surprisingly high level of lignified tissue and spores in the outfield area especially in the Ap-1 and Ap-2 horizons, which possibly reflect the growth of crops (Plate 26c and 26d). The quantity of lignified tissue may also derive from the peat as the H horizon contains a dominant level of plant material and spores.

6.2.3 PEDOFEATURES

The soils on Fair Isle contain a range of pedofeatures illustrating post burial processes. At Shirva and Busta the most common form of pedofeatures are excremental, typically small clustered spheroidal and ellipsoidal shaped fragments of digested soil fabric with rounded edges (Plate 27a and 27b).



27a, Excremental pedofeatures
500µm (ppl)

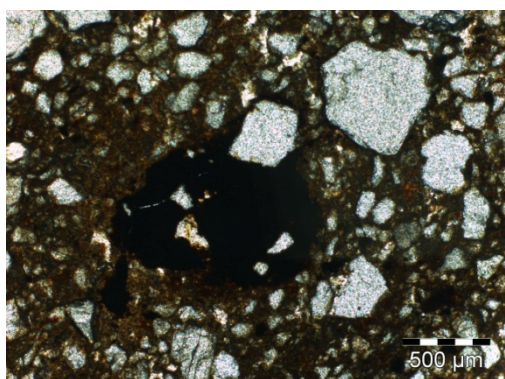


27b, Excremental pedofeatures
1mm (ppl)

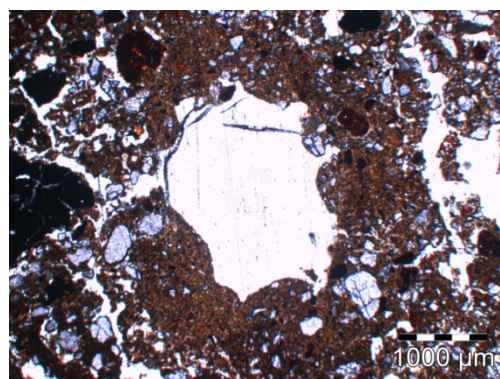
Plate 27a-b Excremental pedofeatures from the three sites on Fair Isle

These features are typical formed by earthworms within small discrete worm casts and are present in each of the kaleyards in large numbers (Figs 121 to 123). At Busta the excremental pedofeatures are prevalent throughout each of the soil horizons but at Shirva and Leogh they are concentrated in the Ap-1 and Ap-2 horizons. The soil horizons also contain a large number of manganese and iron oxide nodules, and at each site inclusions increase with depth (Plate 28a) and are clearly influenced by the natural soils which contain very high numbers (Figs 121 to 123).

Also present in the samples are silt and clay infills associated with the degradation and movement of organics, and clay minerals. At Shirva there is a slight increase between the Ap-1 and Ap-2 horizons but a rapid decrease in the Ap-3 and natural horizon either representing a pattern of less organic input or because the soil horizon has undergone post burial soil processes for a longer period (Plate 28b)(Fig 121).



28a, Fe/Mn nodule 500μm (ppl)



28b, Silty void fill 1mm (ppl)

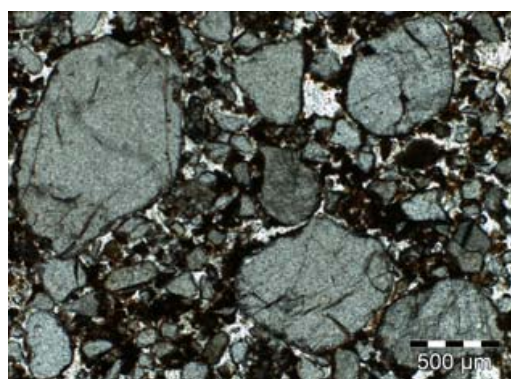
Plate 28a-b Fe/Mn nodules and silty void pedofeatures from Fair Isle

In the infield the excremental pedofeatures are mainly concentrated in the upper Ap-1 horizon which mirrors the majority of the organic microfabric and inclusions. In the Ap-2 horizon there are considerably less excremental features suggesting either a minimal manuring regime or a possible degradation of organic content (Fig 124). In the outfield, where there is still a high organic content, the amount of excremental pedofeatures are much more consistent, with soil microbiological degradation to a depth of over 520mm. In the lower Ap-3 and H horizon there is actually an increase in excremental pedofeatures and the peat fragments illustrate distinctive linear and elongate void spaces (Fig 125). The sandy nature of the soils and frequency of worm casts allows the easy movement of water through the soil and this has developed silt and clay infills in void spaces and in the lee of larger inclusions. The soils in the infield have a consistent level of void infill, suggesting regular movement of material through the profile by mixing and soil water but in the outfield there is far less fine grained infills because there is too much disturbance from mixing. Nevertheless, the Ap-2 horizon does have a larger amount of clay and silt infills (Figs 121 to 125) which suggests that the later manuring process may have been similar to the infield regime.

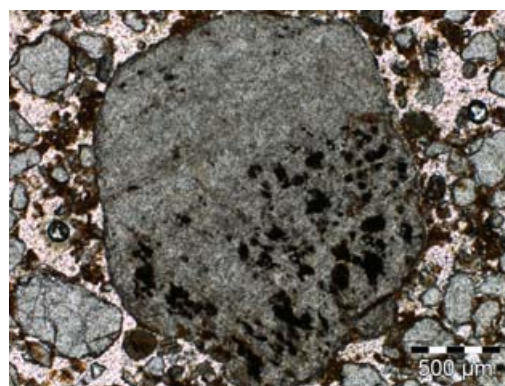
6.3 MICROMORPHOLOGY RESULTS – THE NETHERLANDS

6.3.1. ROCK AND MINERAL INCLUSIONS

In all the landuse areas at Olthof quartz is the dominant mineral present and there is little to no variation in any of the horizons (Plate 29a and 29b). The mineral is typically sub-rounded to sub-angular and derives from the coversand soils. There are, however, some subtle variations in shape between the black and brown plaggen soils (Figs 126 to 128). In the upper Ap-1 and Ap-2 horizons the quartz is more sub-angular shaped and mainly clear to grey coloured under plane polarised light. In the Ap-3 horizon there is more of a mixture of sub-rounded and sub-angular fragments and the grains are more frequently iron stained and have thin dark coloured cementations. The variety in form may indicate the different types of organic additions being added to the soils as particle size and micromorphological analysis of the heathland and meadowland soils show very interesting similarities to the black and brown plaggen soils. Alongside the quartz there is also a small level of quartzite most prevalent in the Ap-1 and Ap-2 horizons of the inner arable area (Fig 127) and this may derive from either the heathland or meadowland turves.



29a, Quartz grains 500µm (ppl)



29b, Large quartz grains 500µm (ppl)

Plate 29a-b Quartz minerals from the plaggen soils from Olthof, Netherlands

Site – NETHERLANDS, OLTHOF Location – Garden Test Pit - 8			Coarse Rock & Mineral Components ($<10\mu\text{m}$) (1)					Coarse Organics (1)					Fine Organics (1)					Pedofeatures (2)					Microstructure	Coarse Material Arrangement	Groundmass 'b' Fabric	Related Distribution				
Slide No	Depth (mm)	Context	Quartz	Sandstone	Quartzite	Mudstone	Schist	Fine Mineral	Charcoal	Burnt Peat	Peat	Turf	Lignified Tissue	Spores	Amorphous Black	Amorphous Brown	Amorphous Orange	Cell Residue	Silt Infills	Clay Infills	Organic Coatings	Excremental Features					Manganese Nodules	Iron Oxide Nodules	Amorphous Crypto- Crystalline coatings	
1	120-200	Ap-1	****	*				Dark brown coloured with areas of very dark orangey/reddish brown + lighter yellow orange deposits. Spotted Limpidity	**			*	*	t	***	**	*	***	*	**		**	**	**		Mostly intergrain microaggregate structure	Random, with well sorted microstructure	Stippled, Flecked	+60% single spaced porphyric structure with <20% close porphyric and smaller areas of close monic (<5%)	
2	350-430	Ap-1	****	*				Brown to dark brown coloured microstructure with areas of yellow/grey	**			t	t	t	***	**	*	**		**	**		**	**	**		Intergrain microaggregate structure	Random, with well sorted microstructure	Stippled, Flecked	Single spaced porphyric structure (+30%) with <20% close porphyric
3	580-660	Ap-1	****	*				Dark brown to reddish/orange with dark yellow patches	*				t	t	**	**	*	*		**	**		**	**	***		Intergrain microaggregate structure	Random, with well sorted microstructure	Stippled, Flecked	Distinct single spaced porphyric structure with areas of close porphyric structure
4	860-940	Ap-2	****	t				Very dark brown and large areas of dark reddish/orange grey colour	*			t			**	t	t	t		**	**		**	**	**		Intergrain microaggregate structure	Random, with well sorted microstructure	Stippled, Flecked	Mostly single spaced porphyric structure (+45%) with areas of close porphyric structure (10 -15%) and some double spaced porphyric structure (<5%)
5	1170-1250	Ap-2	****	t				Dark orange, with large areas of light orange, dark yellow and darker brown	*			*	t		**	t	t	t		**	**		**	**	**		Intergrain microaggregate structure	Random, with well to very well sorted microstructure	Stippled, Flecked	+60% single spaced porphyric structure with 5-10% close porphyric structure and <5% coarse monic structure
6	1350-1430	Ap-3	****	t				Light orange/brown/reddish yellow colour	*			*	t	t	*	*	*			*		**	t	***		Mainly intergrain microaggregate structure with areas of bridged grain structure and between quartz grains and organic material together with areas of single grain structure <5%.	Random, with well to very well sorted microstructure	Stippled, Flecked + Mineragenic & Granular	Double spaced porphyric structure +40% but also single spaced porphyric structure towards the bottom of the deposit (30%) with areas of coarse monic structure	
7	1470-1550	Ap-3	****					Dark orange/dark yellow,red colour	t			t	t		t	*			t	t		*	t	***		Intergrain microaggregate structure with areas of bridged grain structure and single grain structure	Random, with well to very well sorted microstructure with clear fibrous structure typical of grassland soils	Stippled, Flecked + Mineragenic & Granular	Mainly single spaced porphyric structure +40% with large areas of double spaced porphyric and some close porphyric structure	
8	1630-1771	B	****					Light yellow, grey/orange colour								t						t	*	****		Bridged grain structure and single grain structure with very small areas of intergrain microaggregate structure	Random, with very well sorted microstructure	Mineragenic & Granular	Close porphyric structure with areas of coarse monic structure	
(1) Frequency levels for coarse mineral components (Bullock et al (1985))																				t trace, * very few, ** few, *** frequent/common, **** dominant/very dominant										
(2) Frequency level for textural pedofeatures (Bullock et al 1985)																				t trace, * rare, ** occasional, *** many										

Figure 126, Summary table of micromorphology from a section of soils at Olthof garden, the Netherlands

**Site – NETHERLANDS,
OLTHOF
Location - INFIELD
Test Pit -
Archaeological Section**

Site – NETHERLANDS, OLTHOF Location - INFIELD Test Pit - Archaeological Section			Coarse Rock & Mineral Components ($<10\mu\text{m}$) (1)					Coarse Organics (1)			Fine Organics (1)			Pedofeatures (2)							Microstructure	Coarse Material Arrangement	Groundmass ^b Fabric	Related Distribution					
Slide No	Depth (mm)	Context	Quartz	Sandstone	Quartzite	Mudstone	Schist	Fine Mineral	Charcoal	Burnt Peat	Peat	Turf	Lignified Tissue	Spores	Amorphous Black	Amorphous Brown	Amorphous Orange	Cell Residue	Silt Infills	Clay Infills					Organic Coatings	Excremental Features	Manganese Nodules	Iron Oxide Nodules	Amorphous Crypto-Crystalline coatings
1	400 - 480	Ap-1	****	*	*			Dark brown colour with large areas of reddish orange and yellow as well as light yellow grey colour. Spotted Limpidity	**			**	**	*	***	**	*	*	t	*	*	**	*	**		Microaggregate but there are very small patches ($<5\%$) bridged granular structure	Random, with medium to well sorted microstructure	Stippled, Flecked	Mostly double spaced fine enaulic (+40%) and double spaced porphyric (40%) with a small quantity of single spaced porphyric structure
2	560 - 660	Ap-2	****	*	**			Dark brown/red colour with areas of brown/orange and lighter yellow. Spotted Limpidity	**			*	*	*	**	*	*		t	*	*	**	t	**		Intergrain micro-aggregate structure	Random, with medium to well sorted microstructure	Stippled, Flecked	Double spaced porphric structure (35 – 45%) with areas of open porphyric ($<10\%$) and more compact single spaced porphyric (+20%)
3	710 - 790	Ap-3	****		*			Brown to dark orange/yellow colour. Spotted Limpidity	*			*	*	t	*	t	t	t	t	*	*	**		**		Intergrain micro-aggregate structure	Random, with medium to well sorted microstructure	Stippled, Flecked	Double spaced porphric structure (35 – 45%) with areas of open porphyric ($<10\%$) and more compact single spaced porphyric (+20%)
4	910 - 960	BS	***		t			Brown to dark orange/yellow colour. Spotted Limpidity	t			t	*		*	t			t	t		t		**		Intergrain micro-aggregate structure + Single grain structure	Random, with medium to well sorted microstructure	Stippled, Flecked	Double spaced porphric structure (35 – 45%) with areas of open porphyric ($<10\%$) and more compact single spaced porphyric (+20%)
4	960 - 990	B	****		t			Light yellow to light orange colour														t		***		Single grain structure throughout	Random, with medium to well sorted microstructure	Mineragenic, Granular	Close porphyric structure (+40%) with areas of close monic structure (20%) and ($<5\%$) chitonic structure with the movement of iron around quartz particles

(1) Frequency levels for coarse mineral components (Bullock et al (1985)

(2) Frequency level for textural pedofeatures (Bullock et al 1985)

t trace, * very few, ** few, *** frequent/common, **** dominant/very dominant

t trace, * rare, ** occasional, *** many

Figure 127, Summary table of micromorphology from a section of soils at Olthof inner arable area, the Netherlands

**Site – NETHERLANDS,
OLTHOF
Location – Outer Arable
Test Pit - 11**

Slide No	Depth (mm)	Context	Quartz	Sandstone	Quartzite	Mudstone	Schist	Fine Mineral																Microstructure	Coarse Material Arrangement	Groundmass 'b' Fabric	Related Distribution	
								Charcoal	Burnt Peat	Peat	Turf	Lignified Tissue	Spores	Amorphous Black	Amorphous Brown	Amorphous Orange	Cell Residue	Silt Infills	Clay Infills	Organic Coatings	Excremental Features	Manganese Nodules	Iron Oxide Nodules					Amorphous Crypto-Crystalline coatings
1	0 - 80	Ap-1	****	*				Dark brown coloured matrix with patches of lighter orange/yellow/red areas. Spotted Limpidity	*			*	**	*	**	**	*	t	*	*	t	**	**	***	Intergrain micro-aggregate structure	Random, with well sorted microstructure	Stippled, Flecked	Majority double spaced fine enaulic (+45%) with large areas of single spaced porphyric (+20) and (5-10%) close porphyric
2	80 - 160	Ap-1	****	*				Dark orange, light brown colour with patches of dark red/brown colour. Spotted Limpidity	*			**	**	*	**	*	*		t	t	t	***	**	***	Intergrain microaggregate structure with very small areas of single grain structure (<5%)	Random, with well sorted microstructure	Stippled, Flecked	+30% double spaced fine enaulic with smaller areas of sinle spaced porpyric (15%) and <5% chitonic where microaggregate structure joins with single grain structure
3	160 - 240	Ap-1	****					Dark brown to reddish/orange colouration. Spotted Limpidity	*			*	*	t	*	t	t			t		*	*	***	Intergrain microaggregate structure with very small areas of single grain structure (<5%)	Random, with well sorted microstructure	Stippled, Flecked	Mainly double spaced fine enaulic structure (+30%) with very small isolated areas of close porphyric (<15%)
4	240 - 270	Ap-1	****					Dark brown to reddish/orange colouration. Spotted Limpidity	t		t	t			t	t			t		*	t	****	Intergrain microaggregate structure with very small areas of single grain structure (<5%)	Random, with well to very well sorted microstructure	Stippled, Flecked	Mainly double spaced fine enaulic structure (+30%) with very small isolated areas of close porphyric (<15%)	
4	270 - 320	B	****					Clear to yellow/orange colour with patches of dark red. Spotted Limpidity							*								t	****	Single grain structure throughout	Random, with well to very well sorted microstructure	Mineragenic, Granular	Almost entirely close porphyric (+80%) with smaller areas 10 – 15% coarse monic fabric
5	320 - 400	B	****					Clear to yellow/orange colour with patches of dark red							*								t	****	Single grain structure throughout	Random, with well to very well sorted microstructure	Mineragenic, Granular	Almost entirely close porphyric (+80%) with smaller areas 10 – 15% coarse monic fabric

(1) Frequency levels for coarse mineral components (Bullock et al (1985)

(2) Frequency level for textural pedofeatures (Bullock et al 1985)

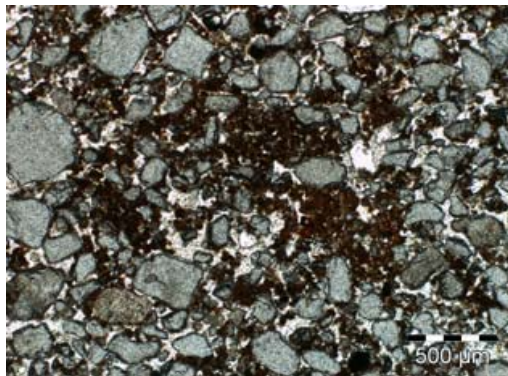
t trace, * very few, ** few, *** frequent/common, **** dominant/very dominant

t trace, * rare, ** occasional, *** many

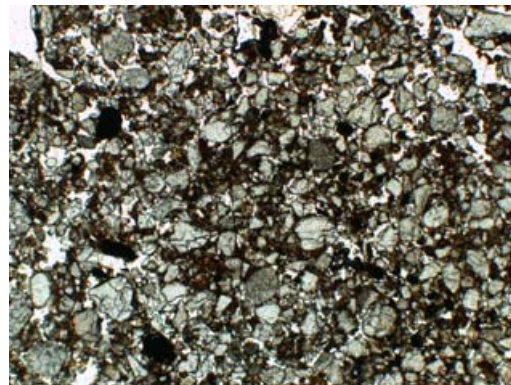
Figure 128, Summary table of micromorphology from a section of soils at Olthof outer arable area, the Netherlands

6.3.2 FINE MINERAL STRUCTURE AND ORGANICS

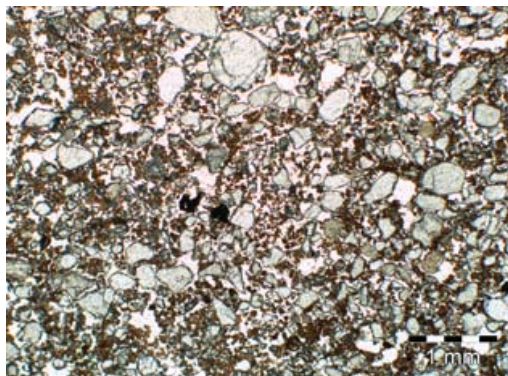
The fine mineral structure has a number of variations between horizons and landuse areas. Overall the black plaggen soil (Ap-1 and Ap-2), (Plate 30a and 30b) is considerably darker in colour than the brown plaggen soil (Ap-3), (Plate 30c and 30d) presumably because of the different input material and level of post burial pedogenesis, but there are distinct variations between the different landuse areas.



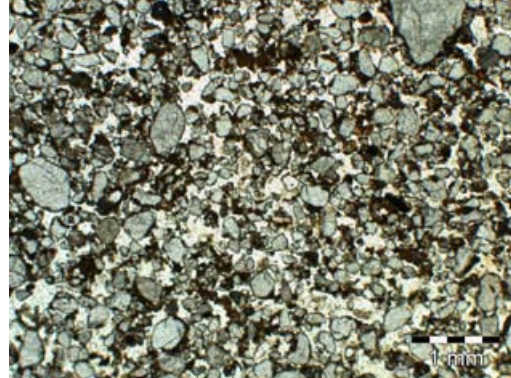
30a, Black plaggen microstructure
500µm (ppl)



30b, Black plaggen microstructure
1mm (ppl)



30c, Brown plaggen microstructure
1mm (ppl)

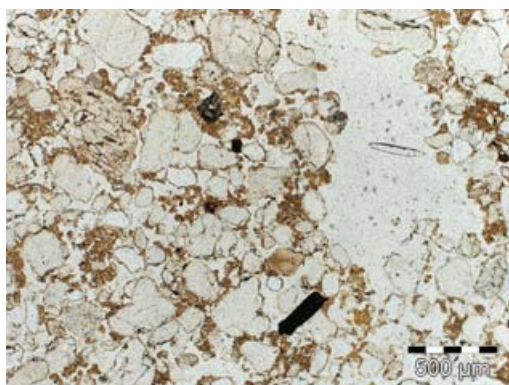


30d, Brown plaggen microstructure
1mm (ppl)

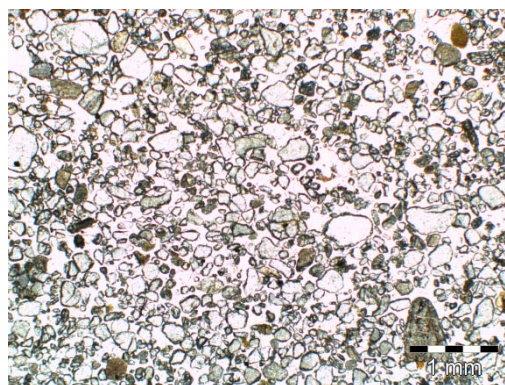
Plate 30a-d Fine organo-mineral microstructures from Olthof, Netherlands

In the garden and inner arable areas the upper soil horizons (Ap-1 and Ap-2) have a dark brown coloured soil with areas of orange and red. In the outer arable areas the black plaggen soil is a slightly lighter colour, typically brown, orange with some darker areas (Fig 128), (Plate 31a). In the lower Ap-3 horizon the soil is a considerably lighter colour, ranging from light orange to

dark yellow in the garden soils, dark orange/brown in the inner arable soils and dark orange to dark yellow in the outer arable soils. The microstructure of the majority of the soil horizons show a distinctive intergrain microaggregate structure, but there are areas of bridged granular structure particularly in the Ap-3 horizon due to extensive leaching of organic material (Plate 31b).

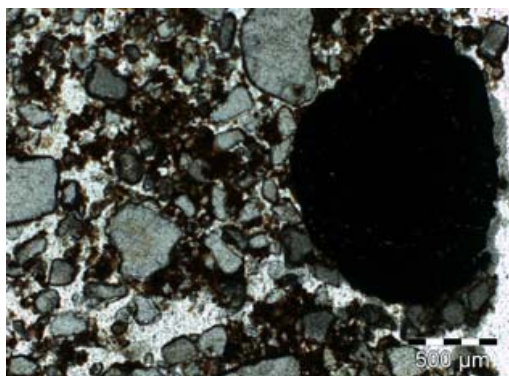


31a, Microstructure 500µm (ppl)

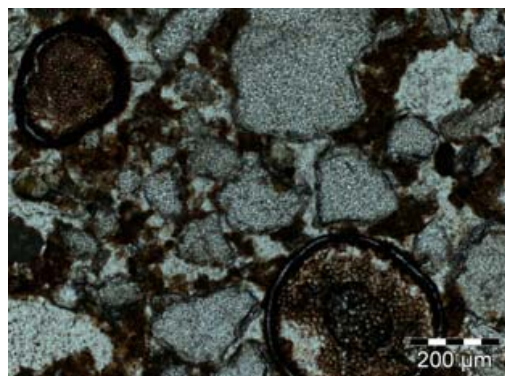


31b, Natural microstructure 1mm (ppl)

Plate 31a-b Fine organo-mineral microstructures from Olthof, Netherlands



32a, Black amorphous particle 500µm (ppl)

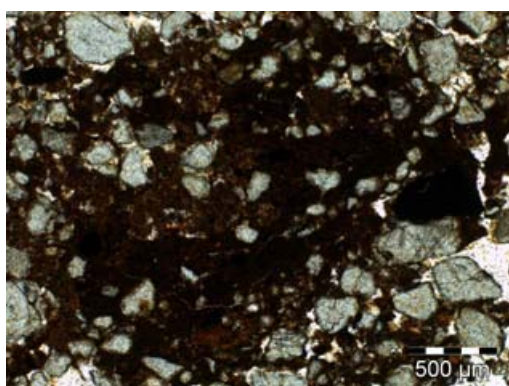


32b, Plant material 200µm (ppl)

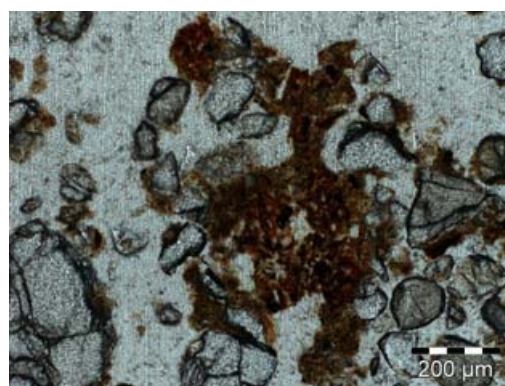
Plate 32a-b Black amorphous and plant material from Olthof, Netherlands

The natural soil has a bridged grain to single grain structure. The groundmass of the soils is also very similar throughout with the majority of horizons demonstrating a stippled, flecked fabric with a random, well sorted microstructure and mainly single to double spaced porphyric distribution (Figs 126 to 128). This indicates that the soils were more organic in the past and

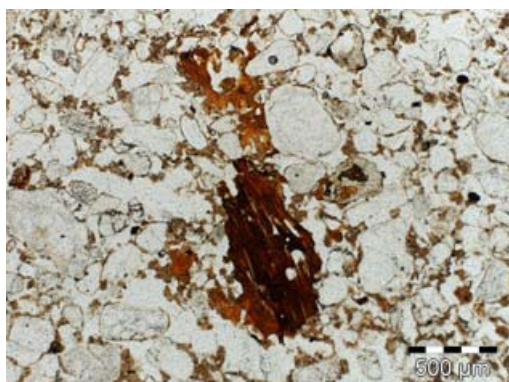
the large number of void space derive from post burial decomposition of organic material by soil organisms and leaching from the movement of soil water. Inclusions of fine organic particles vary across the different landuse areas and indicate variations in manuring materials. In the garden there is a frequent amount of black amorphous particles (Fig 126), (Plate 32a) in the upper Ap-1 horizon alongside a slightly lower amount of amorphous brown, orange particles and cell residue (Plate 32b). But levels of fine organics decrease with depth in the Ap-2 and Ap-3 horizons suggesting less input of carbonised and organic particles from burning/ash residues.



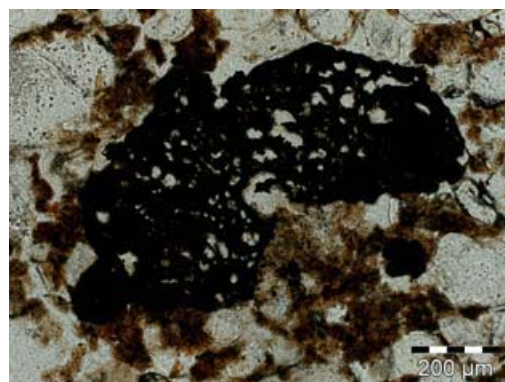
33a, Turf 500µm (ppl)



33b, Degraded turf fragment A088
200µm (ppl)



33c, Degraded turf fragment 200µm (ppl)

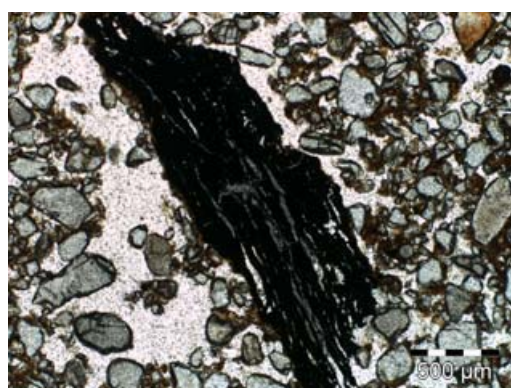


33d, Burnt turf 500µm (ppl)

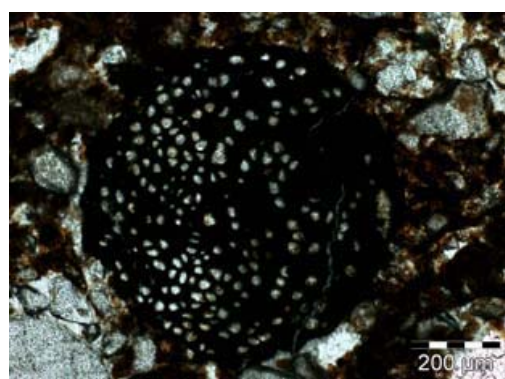
Plate 33a-d Large organic inclusions from Olthof, Netherlands

In the inner arable area there is a very similar pattern with the amorphous black particles dominant in the black plaggen soils but less in the brown plaggen soil, and a much lower amount of cell residue, possibly

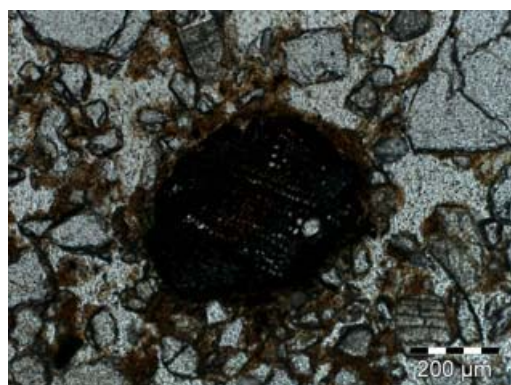
because of damage by plough action (Fig 127). In the outer arable area the Ap-1 horizon has the largest concentration of fine grained particles but the numbers quickly decrease with depth and the reclaimed outfield area has an even lower level of fine organic particles. Coarse organic inclusions consist of very small charcoal, turf and plant residue fragments, but remarkably the numbers of inclusions are very low in each of the areas sampled because of post burial degradation (Fig 128).



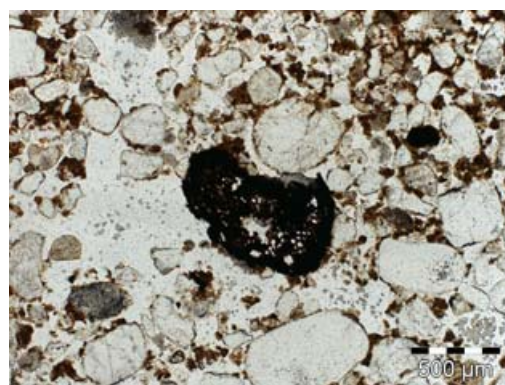
34a, Burnt turf 500µm (ppl)



34b, Charcoal 200µm (ppl)



34c, Charcoal 200µm (ppl)



34d, Charcoal 500µm (ppl)

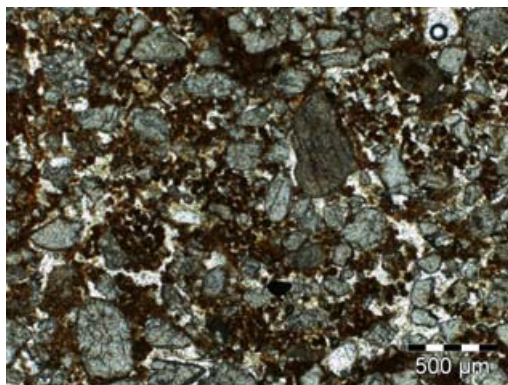
Plate 34a-d Large organic inclusions from Olthof, Netherlands

Turf fragments are lowest in the garden area with minimal evidence whereas in the inner and outer arable areas there is a clear reduction in organics with depth (Plate 33a, 33b, 33c and 33d). This inverse relationship may exist because although the manuring process occurred in all the landuse areas, manuring continued long after the garden had been abandoned and the soft turf fragments would have been easily degraded and consumed by

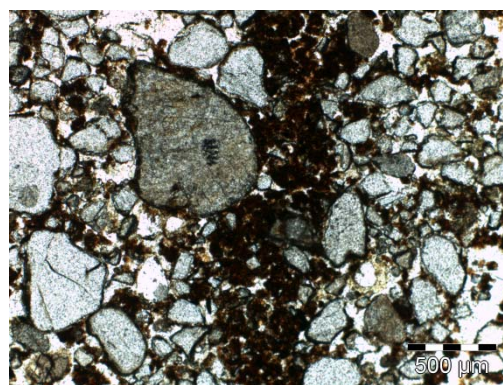
soil organisms. The best evidence for higher levels of organics in the garden comes from the presence of the more resistant carbonised inclusions of charcoal (Plate 34b, 34c and 34d) and infrequent burnt turf (Plate 33d and 34a). The garden has particularly high results in the Ap-1 horizon and a slightly lower level in the Ap-2 and Ap-3 horizons (Fig 126). There is a similar level of charcoal in the inner and outer arable areas (Figs 127 and 128) but a considerably lower level in the reclaimed arable land, suggesting little to no input from settlement centres.

6.3.3 PEDOFEATURES

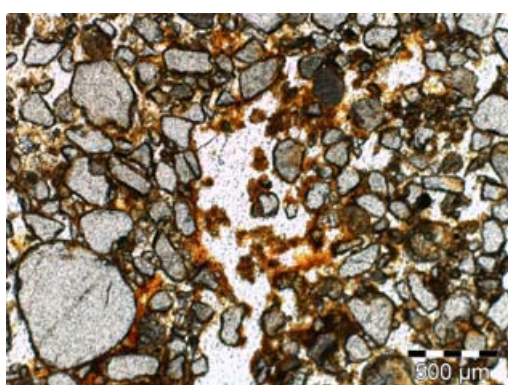
By far the most common pedofeatures present in the plaggen soils from Olthof are the distinctive clusters of excremental material. In the garden there is a consistent level of excremental evidence from the Ap-1 to the Ap-3 horizon, indicating a high level of biological activity and organic mixing (Plate 35a and 35b). The lower brown plaggen soil and natural C horizon, however, contain much less evidence of biological activity (Fig 126). The black plaggen soil in the inner arable area contains slightly less excremental clusters but the quantity is relatively consistent with depth and there is a definite difference between the black and brown plaggen soils (Fig 127). The two comparative outer arable areas have contradictory results and this is possibly due to the continued use of the reclaimed outfield providing a higher level of organic input and encouraging more biological activity (Fig 128). Other, less frequent pedofeatures include silt and clay infills washed into voids by the movement of water through the soil profile (Plate 35c, 35d). At the other landuse areas there are a much lower number of silt and clay infills possibly because of the continuation of ploughing in these areas increasing void space and allowing more infiltration. Iron and manganese inclusions are also present in large numbers in the anthropogenic soils in the garden (Fig 126) and these may derive from the increased addition of turves compared to the inner and outer arable areas (Fig 127 and 128).



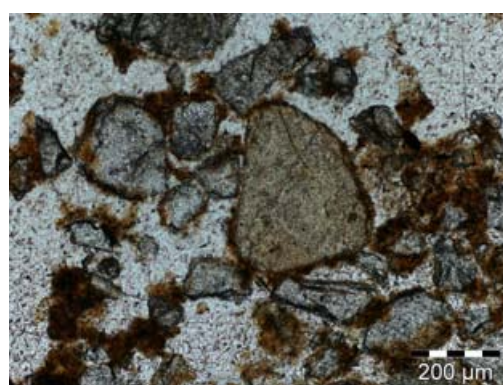
35a, Excremental pedofeatures
500μm (ppl)



35b, Excremental pedofeatures
500μm (ppl)



35c, Iron rich organic void coating
500μm (ppl)



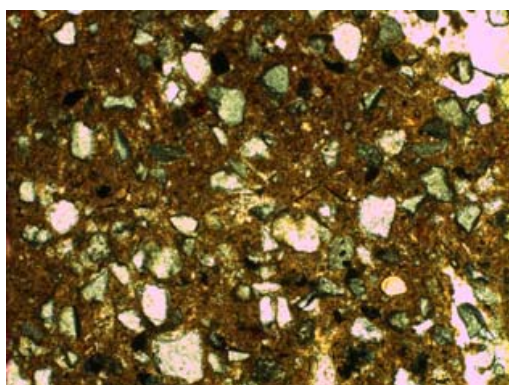
35d, Grain coatings 200μm (ppl)

35a-d Soil pedofeatures from Olthof, Netherlands

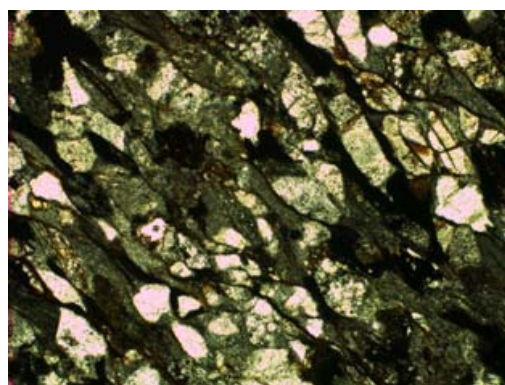
6.4 **MICROMORPHOLOGY RESULTS – IRELAND**

6.4.1 **ROCK AND MINERAL COMPONENTS**

Of all the areas sampled, the Irish amended arable soils have the greatest range of mineralogies present (Figs 129 to 132) and, like the other sites, quartz is in abundance in all the soils derived from the natural sandstone geology or added from beach sands or with peat and turf inclusions (Plate 36a and 36b). The quartz is typically white to yellow/grey colour with sub-rounded to rounded shape and is fairly well sorted (500μm – 1.25mm). The next most abundant mineral present, because of its association with shell sand, is calcite (Plate 36c and 36d). It is typically white to yellow in colour under plain polarized light and pinkish red under cross polarized light.



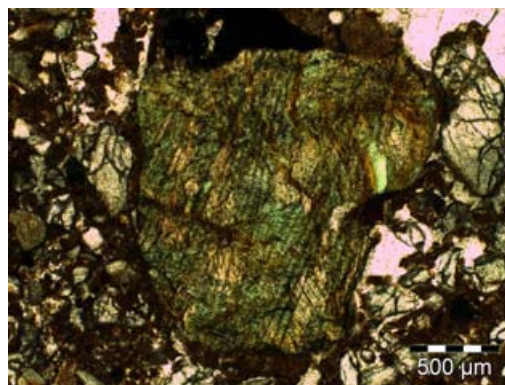
36a, Quartz fragments 500μm (ppl)



36b, Large quartzite particle 500μm (ppl)



36c, Calcite & shell carapace 100μm



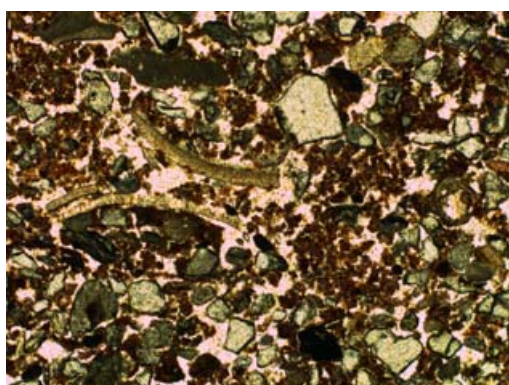
36d, Calcite 500μm (ppl)

Fig 36a-d Rock and mineral inclusions from Caheratrant, Ireland

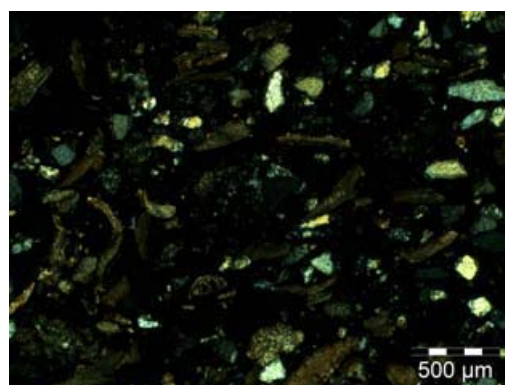
The particles are sub-rectangular in shape and have platy laminar structures throughout. In places the particles retain the shape of shells which indicates a marine origin. Overall the regular distribution of calcite in the three landuse areas shows that its addition to the amended soils was a major contributing factor to their development. In the kaleyards there is a large quantity throughout the Ap-1 to Ap-3 horizons and the inclusions have a distinctive smaller and more angular shape from extensive mixing (Figs 129 and 130). In test pit 10 the soil horizons contain a very similar quantity of calcite but these are two very distinctive calcite rich sand horizons (chapter 4, section 4.5.1). Both these horizons contain larger, more rounded inclusions and appear to have undergone less mixing and also contain larger quantities of other lithic fragments (sandstone, quartzite, and schist) as well as nodules

of iron oxide and manganese than the amended soils. In the inner and outer arable areas there are progressively less and less calcitic inclusions indicating less input from beach sand in the hinterland areas of the farm (Figs 131 and 132). The natural sandy till does contain calcite along with iron oxide and a range of other elemental concentrations as shown in chapter 5, section 5.6.3 and heavy mixing may also be a reason for the high results.

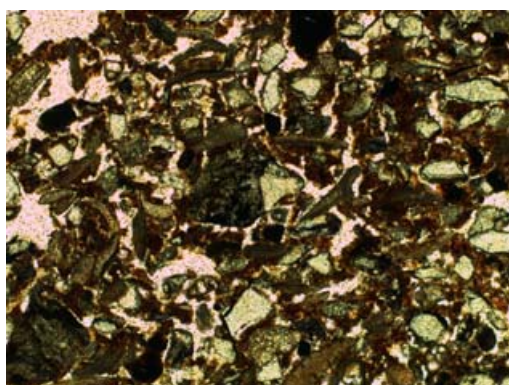
6.4.2 FINE MINERAL STRUCTURE AND ORGANICS



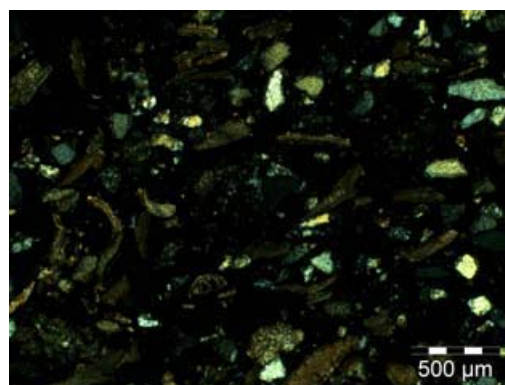
37a, Microstructure 500µm (ppl)



37b, Microstructure 500µm (xpl)



37c, Microstructure 500µm (ppl)

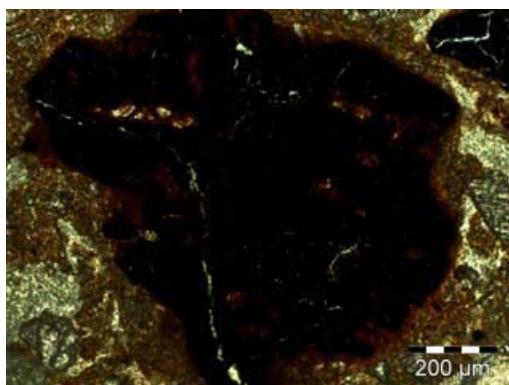


37d, Microstructure 500µm (ppl)

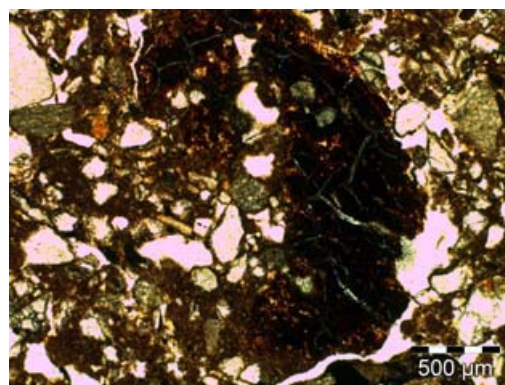
Plate 37a-d Organo-mineral microstructures from Caheratrant, Ireland

The fine mineral structure of the soils is heavily influenced by the amount of iron in the soils. In the kaleyard the soils have a distinctive dark brown/orange to light brown/red colour with some yellowish red patches (Fig 129 to 130), (Plate 37a and 37b). In the inner and outer arable areas however, the soils are dark orange to reddish/grey colour with some orange

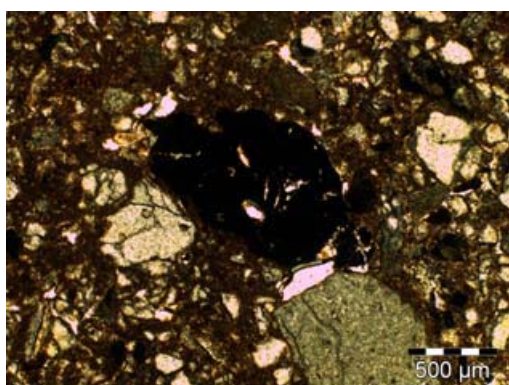
as a result of higher soluble iron levels (Figs 131 and 132), (Plate 37c and 37d). The outer arable area has the shallowest sequence of soils (chapter 4, section 4.5.3) and the colour is greatly influenced by mixing with the much lighter grey/yellow/orange natural soil (C) (Plate 36a).



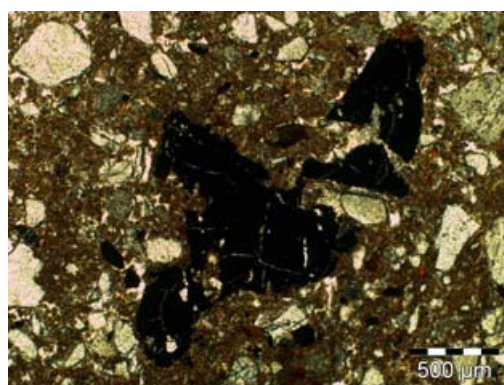
38a, Peat 200µm (ppl)



38b, Degraded peat 500µm (ppl)



38c, Burnt peat 500µm (ppl)



38d, Burnt peat 500µm (ppl)

Plate 38a-d Large organic inclusions from Caheratrant, Ireland

The microstructure of the Ap-1 to Ap-3 horizons are almost all intergrain microaggregate structure except for the highly mineragenic sandy horizons which have a mixture of bridged granular structure and single grain structure (Figs 129 to 132). These horizons indicate that the beach material was not mixed with organics prior to being added to the kaleyard sequence. The soils have a stippled and flecked groundmass whereas in the mineragenic beach sand and natural till soils there is a distinctive mineragenic and granular fabric. The fine organic inclusions present in the soils range from the amorphous black, brown and orange particles to fine grained organics but

there is variability between horizons and across landuse areas, which could be attributed to anthropogenic activity. Black amorphous fragments are very frequent in all the landuse areas especially the upper Ap-1 horizon and in particular the Ap-2 and Ap-3 horizons in the kaleyard sequence in test pit ten (Fig 130). These inclusions are either heavily degraded organic inclusions or possibly mineragenic fragments from sediment collected from the beach, as the mineragenic horizon also has a high number of black amorphous particles. In comparison, the brown and orange amorphous particles are present in much lower numbers in the mineral rich sand horizon, but in the amended soil there is only a slight difference in the quantity of these particles due to post burial degradation of organic fragments or ashy remnants.

Fine plant cell fragments were found most frequently in the lower amended soils of the kaleyard (Figs 129 and 130), but in the inner and outer arable areas far fewer fragments are identifiable and the ones that were had been degraded by soil micro-organisms (Figs 131 and 132). Alongside the fine organic inclusions there are also a large number of larger coarse organic fragments.

In the kaleyards the amended soils contain a mixture of peat (Plate 38a and 38b) and carbonised fragments of peat (Plate 38c and 38d), turf, lignified tissue and fungal spores alongside charcoal fragments. Of the three amended horizons, the Ap-1 contains mainly peat, burnt peat and charcoal with small organic rich turf fragments and these inclusions decrease in size and number with depth. The Ap-2 horizons contained almost no turf or peat especially towards the base of test pit one, however there was a greater quantity of charcoal, peat and turf fragments in test pit ten (Figs 129 and 130). The soils in the inner arable area contain fewer particles of charcoal and burnt peat and some peat fragments but a considerably greater number than in the outer arable soils (Figs 131 and 132).

**Site – IRELAND,
CAHERATRANT I
Location - KALEYARD
Test Pit - 1**

Site – IRELAND, CAHERATRANT I Location - KALEYARD Test Pit - 1			Coarse Rock & Mineral Components (<10µm) (1)							Coarse Organics (1)					Fine Organics (1)				Pedofeatures (2)							Microstructure	Coarse Material Arrangement	Groundmass 'b' Fabric	Related Distribution		
Slide No	Depth (mm)	Context	Quartz	Calcite	Sandstone	Quartzite	Mudstone	Schist	Fine Mineral	Charcoal	Burnt Peat	Peat	Turf	Lignified Tissue	Spores	Amorphous Black	Amorphous Brown	Amorphous Orange	Cell Residue	Silt Infills	Clay Infills	Organic Coatings	Excremental Features	Iron Oxide Nodules	Amorphous Crypto-Crystalline coatings						
1	60-140	Ap-1	***	***	***	**	**	t	Dark orange, light brownish red colour + spotted limpidity	**	**	**	*	**	**	***	**	**	*	*	**	*	***	***	Intergrain microaggregate structure	Random, with moderately sorted microstructure	Stippled, Flecked	Distinctive double spaced porphyric structure (+40%) with areas of compact single spaced porphyric (15-20%) and small areas of open porphyric (5-10%)			
2	170-250	Ap-1	***	***	**	*	*	*	Light orange, dark yellow/reddish brown + spotted limpidity	**	*	**	t	***	**	***	**	*	*	*	*	***	*	***	***	Intergrain microaggregate structure	Random, with well sorted microstructure	Stippled, Flecked	Clear mixtures of fabrics from double spaced porphyric (30-40%) to areas of double spaced fine enaulic (10-15%) and finer semi chitonic structure (5-10%)		
3	280-360	Ap-2	***	***	*	*	t	t	Dark red/orange, yellowy brown colour + spotted limpidity	**	*	*	t	**	*	**	**	*	*	*	*	**	*	**	***	Intergrain microaggregate structure	Random, with moderately sorted microstructure	Stippled, Flecked	Double spaced porphyric (30-40%) with some double spaced fine enaulic (10-15%) and finer semi chitonic structure (5-10%)		
4	390-470	Ap-2	***	**	*	*	t	t	Dark orange, red to brown to dark brown colour + spotted limpidity	**	*	*	t	**	*	**	*	**	*	t	**	t	**	***	Intergrain microaggregate structure	Random, with moderately to well sorted microstructure	Stippled, Flecked	(+30-35%) single spaced porphyric structure with areas of chitonic structure (10-15%) and close porphyric structure (10-15%)			
5	500-580	Ap-2	****	**	t	*	*	*	Dark orange to light yellow/brown colour with large areas of red/brown + spotted limpidity	*	t	t	t	**		**	*	*	t	*	**	*	**	****	Intergrain microaggregate structure	Random, with moderately to well sorted microstructure	Stippled, Flecked	(+30-35%) single spaced porphyric structure with areas of chitonic structure (10-15%) and close porphyric structure (10-15%)			
6	610-680	Ap-2	****	**	t	t	t	**	Dark orange to brown to dark red/orange with yellow patches + spotted limpidity	t	t	t		*		*	**	*	*	t	*		t	****	Intergrain microaggregate structure	Random, with moderately to well sorted microstructure	Stippled, Flecked	Distinctive single spaced porphyric structure (20-25%) with areas of open porphyric (5-10%)			
(1) Frequency levels for coarse mineral components (Bullock et al (1985))																						t trace, * very few, ** few, *** frequent/common, **** dominant/very dominant									
(2) Frequency level for textural pedofeatures (Bullock et al 1985)																						t trace, * rare, ** occasional, ***									

(1) Frequency levels for coarse mineral components (Bullock et al (1985)

(2) Frequency level for textural pedofeatures (Bullock et al 1985)

t trace, * very few, ** few, *** frequent/common, **** dominant/very dominant

t trace, * rare, ** occasional, ***

Figure 129, Summary table of micromorphology from a sequence of soils at Caheratrant kaleyard, Ireland

Site – IRELAND, CAHERATRANT II Location - KALEYARD Test Pit - 10										Coarse Rock & Mineral Components ($<10\mu\text{m}$) (1)					Coarse Organics (1)			Fine Organics (1)		Pedofeatures (2)									
Slide No	Depth (mm)	Context	Quartz	Calcite	Sandstone	Quartzite	Mudstone	Schist	Fine Mineral	Charcoal	Burnt Peat	Peat	Turf	Lignified Tissue	Spores	Amorphous Black	Amorphous Brown	Amorphous Orange	Cell Residue	Silt Infills	Clay Infills	Organic Coatings	Excremental Features	Iron Oxide Nodules	Amorphous Crypto- Crystalline coatings	Microstructure	Coarse Material Arrangement	Groundmass 'b' Fabric	Related Distribution
1	400-460	Ap-2	****	***	*	**		**	Dark brown with areas of dark orange, red and yellow/brown colours + spotted limpidity	***	**	***	**	***	**	***	***	**	**	**	***	*	**	***		Intergrain microaggregate structure	Random, with moderately to well sorted microstructure	Stippled, Flecked	Double spaced porphyric structure (+40%) with areas of compact single spaced porphyric (15-20%) and small areas of open porphyric (5-10%)
1	460-480	CaCO3	****	****	****	****		***	Dark brown with areas of dark orange, red and yellow/brown colours	*	t			*		***	**	**	t			*	***		Mostly bridged grain structure (+50%) with areas of single grain structure (20%) and some intergrain micro-aggregate structure (10-15%) mostly at the boundary with layer above	Random, with moderately to well sorted microstructure	Mineragenic & Granular	A close porphyric and coarse monic structure (40-60%)	
2	520-600	Ap-3	****	****	*	*		**	Dark brown with areas of dark orange, red and yellow/brown colours + spotted limpidity	***	**	***	**	***	**	****	**	**	*	**	***	*	**	****		Intergrain micro-aggregate structure	Random, with moderately to well sorted microstructure	Stippled, Flecked	Double spaced porphyric structure (+40%) with areas of compact single spaced porphyric (15-20%) and small areas of open porphyric (5-10%)
(1) Frequency levels for coarse mineral components (Bullock et al (1985))										t trace, * very few, ** few, *** frequent/common, **** dominant/very dominant																			
(2) Frequency level for textural pedofeatures (Bullock et al 1985)										t trace, * rare, ** occasional, *** many																			

Figure 130, Summary table of micromorphology from a sequence of soils at Caheratrant kaleyard, Ireland

Site – IRELAND, CAHERATRANT Location – Inner Arable Test Pit - 3			Coarse Rock & Mineral Components ($<10\mu\text{m}$) (1)							Coarse Organics (1)				Fine Organics (1)				Pedofeatures (2)										Microstructure	Coarse Material Arrangement	Groundmass 'b' Fabric	Related Distribution
Slide No	Depth (mm)	Context	Quartz	Calcite	Sandstone	Quartzite	Mudstone	Schist	Fine Mineral	Charcoal	Burnt Peat	Peat	Turf	Lignified Tissue	Spores	Amorphous Black	Amorphous Brown	Amorphous Orange	Cell Residue	Silt Infills	Clay Infills	Organic Coatings	Excremental Features	Manganese Nodules	Iron Oxide Nodules	Amorphous Crypto- Crystalline coatings					
1	40-120	Ap-1	****	***		**		t	Dark orange red with brownish, orange red colour patches + spotted limpidity	**	**	*		***	*	***	**	*	*	*	*		***	*	***		Intergrain micro-aggregate structure	Random, with moderately to well sorted microstructure	Stippled, Flecked	Double spaced porphyric (30-35%) with areas of open porphyric (10-15%) and close porphyric (10-20%)	
2	140-220	Ap-1	***	***		**		t	Dark brown colour with areas of dark reddish/orange + spotted limpidity	*	**	*		**	*	**	*	*	*		t	*		***	**	***		Intergrain micro-aggregate structure very small areas of bridged grain structure ($<5\%$)	Random, with well sorted microstructure	Stippled, Flecked	Single spaced porphyric structure throughout deposit (+45%) with areas of double spaced porphyric and close porphyric (15-20%)
3	240-320	Ap-2	***	**	t	*			Dark brown/reddish/orange colour + spotted limpidity	*	*	*		***	*	*	*	*	*		*	**	**	**	****		Intergrain micro-aggregate structure very small areas of bridged grain structure ($<5\%$)	Random, with well sorted microstructure	Stippled, Flecked	Single spaced porphyric structure throughout deposit (+45%) with areas of double spaced porphyric and close porphyric (15-20%)	
4	340-420	Ap-2	****	**	t	*		t	Dark brown colour with areas of dark reddish/orange + spotted limpidity	*	*	*		***	*	*	*	*	*		*	*	*	**	****		Intergrain micro-aggregate structure very small areas of bridged grain structure ($<10\%$)	Random, with well sorted microstructure	Stippled, Flecked	Single spaced porphyric structure throughout deposit (+30%) with areas of double spaced porphyric and close porphyric (25-35%)	
(1) Frequency levels for coarse mineral components (Bullock et al (1985))																				t trace, * very few, ** few, *** frequent/common, **** dominant/very dominant											
(2) Frequency level for textural pedofeatures (Bullock et al 1985)																				t trace, * rare, ** occasional, *** many											

Figure 131, Summary table of micromorphology from a sequence of soils at Caheratrant inner arable area, Ireland

Site – IRELAND, CAHERATRANT Location – Outer Arable Test Pit - 7			Coarse Rock & Mineral Components ($<10\mu\text{m}$) (1)							Coarse Organics (1)					Fine Organics (1)				Pedofeatures (2)											
Slide No	Depth (mm)	Context	Quartz	Calcite	Sandstone	Quartzite	Mudstone	Schist	Fine Mineral	Charcoal	Burnt Peat	Peat	Turf	Lignified Tissue	Spores	Amorphous Black	Amorphous Brown	Amorphous Orange	Cell Residue	Silt Infills	Clay Infills	Organic Coatings	Excremental Features	Manganese Nodules	Iron Oxide Nodules	Amorphous Crypto- Crystalline coatings	Microstructure	Coarse Material Arrangement	Groundmass 'b' Fabric	Related Distribution
1	80-160	Ap-1	***	*		*		*	Dark brown to dark orange, yellow colour	t	t	*	t	*	*	***	**	**	t	**	**	**	t	**		Intergrain microaggregate structure	Random, with medium to well sorted microstructure	Stippled, Flecked	Double spaced porphyric structure (40-45%) with areas of close porphyric (15-20%)	
2	180-260	Ap-2	****	t	t	**		*	Brown to very dark brown and areas of light brown to red/dark red		t			*	t	***	*	**		*	*		*	t	***	Intergrain microaggregate structure	Random, with poor to medium sorted microstructure	Stippled, Flecked	Single spaced porphyric (40-50%) with areas of close porphyric structure (30-35%)	
3	280-360	C	****		**	***	**		Mineral component is grey, dark grey, yellow colour. Matrices yellow, orange with areas of darker red, brown colour					*		*				*	t	*		****	Intergrain micro-aggregate structure	Random, with medium to well sorted microstructure	Mineragenic & Granular	Fine matrices has a single spaced porphyric structure (40-45%) with areas of close porphyric structure (30-35%)		

(1) Frequency levels for coarse mineral components (Bullock et al (1985)

(2) Frequency level for textural pedofeatures (Bullock et al 1985)

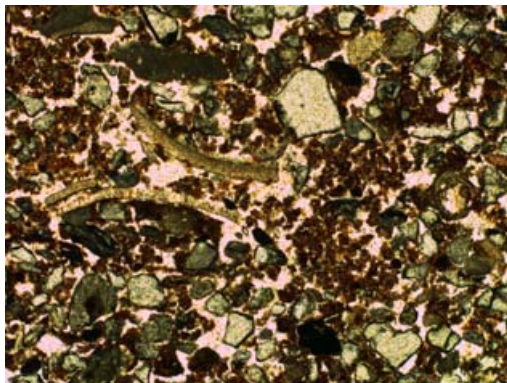
t trace, * very few, ** few, *** frequent/common, **** dominant/very dominant

t trace, * rare, ** occasional, *** many

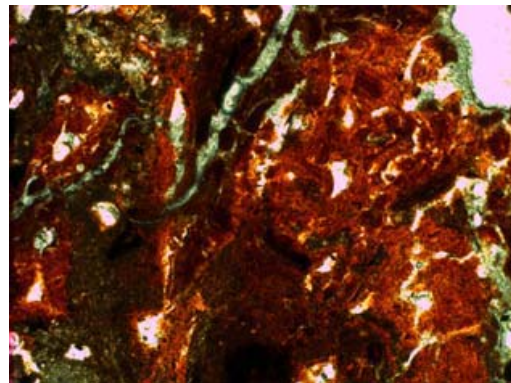
Figure 132, Summary table of micromorphology from a sequence of soils at Caheratrant outer arable area, Ireland

6.4.3 PEDOFEATURES

The three landuse areas sampled contain a number of pedofeatures (Figs 129 to 132), the most common of which are excremental and indicate a high level of biological activity in the soil horizons (Plate 39a). These features consist typically of large fine grained clusters of digested soil material with very distinctive rounded edges and small organic inclusions and occurred in elongate worm cast voids. In the kaleyards these were most common in the upper 250mm of the Ap soil horizons and decrease gradually with depth (Figs 129 and 130).



39a, Microstructure 500µm (ppl)



39b, Fe rich organic material 500µm (ppl)

Plate 39a-b Soil pedofeatures from Caheratrant, Ireland

A similar pattern occurs in the inner and outer arable areas and shows that the majority of the worm activity is located in the areas of highest organic content (Figs 131 and 132). Alongside the excremental features are a number of silt and clay infills which occur as a result of the movement of fine grained soil components down profile by soil water through void spaces. These infills are typically light brown to reddish orange and fine grained with a semi-granular and non-laminated structure. Their distribution in the inner and outer arable areas is fairly uniform with a decrease down profile (Figs 131 and 132) but in the kaleyards the number of clay infills increases slightly with depth in the Ap-1 horizon before becoming more consistent in the Ap-2 horizon but then increasing again in the Ap-3 horizon, probably as a result of the different

periods of organic addition and because of the movement of water through the beach sand horizon above (Figs 129 to 132). Organic coatings are also present in the amended soils but these are much rarer than the other pedofeatures and are mainly within the upper horizons of the kaleyard. However, an unusually high level are present in the Ap-2 horizon of the inner arable area and this has been attributed to the high level of iron present within the soil microstructure and organic inclusions (Figs 129 and 130) (Plate 39b).

6.5 DISCUSSION OF THE MICROMORPHOLOGY RESULTS

The micromorphological analysis of the soil horizons from the three sites enables interpretations to be made about soil formation processes which can aid the fieldwork and bulk laboratory analysis (chapters 2 to 5). The soils analysed from the different landuse areas on Fair Isle have remarkable textural similarity but there are also a number of distinctive differences which allow key inferences to be made regarding soil development. The colour, general microstructure, groundmass and coarse rock and mineral inclusions vary very little in all of the soil horizons and are of little assistance with the interpretation of the development of the soils, however, there are distinctive differences in the organic and inorganic inclusions. All the kaleyard areas have higher levels of organic fragments (peat, turf) and carbonised particles (charcoal, peat, turf) and black and brown amorphous particles which indicate a higher input from settlement waste (Figs 121,122,123,126,129 and 130). But there are small differences in the organic and carbonised particles present in the kaleyards from the three farmsteads which reflect the local development of amended horthisols and also the effects of post burial soil dynamics on manure components. In the infield area at Shirva there is a similar input to the kaleyard but, on a smaller scale, with no turf input and an increase in the plant evidence suggesting that the infield areas were used for harvesting grass and small crops (Fig 124). In the outfield areas there is minimal input from the centre of settlements (charcoal, burnt peat, burnt turf) but an increase in peat inclusions from a buried soil horizon (Fig 125).

Previous micromorphological analysis of Prehistoric arable soils from Fair Isle has shown that the soils are similar to the soils associated with

Shirva (Chrystall, 1994). The majority of the soils have channel and chamber microstructure reddish, brown to greyish brown with dotted and speckled limpidity indicating the input of organics which have been consumed by earthworms and enchytraeids. At both sites quartz and rock fragments are very common and there are many inclusions of fine organics and pedofeatures associated with the bioturbation of a manured soil. There are also clear differences which suggest that a very different manuring process was conducted. Along with the considerably higher total P values the soils also contain calcium carbonate grains which have been deposited with the addition of seaweed (Chrystall, 1994). A predominantly marine source of manure is not uncommon in the Northern Isles of Scotland (Davidson, 2002) but it is usually combined with terrestrial organic material.

Similarities and differences can also be seen between the micromorphological results from Fair Isle and other sites from the northern isles. At Olligarth on Papa Stour, Shetland the micromorphological results of the anthropogenic soils illustrated clear similarities with the results determined in this research and suggests similar manuring regimes are occurring at both localities. Despite the obvious difference in soil depth seen in the field (chapter 2, sections 2.6 and 2.7) and the variations in multi-elemental results (chapter 5, sections 5.6.1) the soils contain similar classifications of organic material typically light brown with porphyric distribution, an undifferentiated b-fabric and spongy to intergrain microstructure alongside abundant carbonised and peat fragments and spherical excrement (Bryant and Davidson, 1996). Micromorphological results from the infield, outfield and natural soils on Fair Isle also mirror the results determined at Olligarth. In Bryant and Davidson's work the arable fields analysed contain micromorphological evidence suggesting manuring had been occurring with organic peaty turf resulting in similar soil textures to the kaleyard. At Shirva the occurrence of a more intergrain microaggregate structures indicates a higher degree of organic breakdown by ploughing and post burial decomposition. Both the sites on Fair Isle and Olligarth illustrate a clear reduction in black amorphous inclusions, ash and burnt stone associated with waste material from the centre of the farms.

At Tofts Ness on Sanday, Orkney the micromorphological evidence suggested that the principal manuring material was grassy turf due to the presence of slightly weathered quartz grains, iron depleted sandstones and siltstones and phytoliths (Simpson, et al., 1998). The micromorphological evidence presented in this chapter includes very few of any of the evidence found at Tofts Ness and therefore considerably less turf input. However there is more evidence of the input of carbonised organic material in the form of burnt peat, rubified stone and fine ashes indicating that this is a process which is occurring across the Northern Isles. Distinctive micromorphological evidence of the addition of domestic waste to arable soils has been found at Quoysgrew on Westray, Orkney (Simpson, et al., 2005). The arable soils contained frequent phytoliths and a high mineral content indicating manuring with turves alongside domestic waste but in contrast settlement features included micromorphological evidence of waste material including fish bones, ash crystals, rubified mineral grains, black charred peat, herbaceous and woody tissue.

The micromorphology results from Olthof are very similar to other analyses conducted on the plaggen soils. Mucher, et al., (1990) described the plaggen soils as predominantly silty sands with common root and faunal channels, faecal pellets and some charcoal. The micromorphological evidence from Olthof complements the results found by Mucher, et al., (1990) and also shows that the source organic material derives from brook sediments and heathland coversands because of the presence of iron cemented sand grains and small deposits of grey/orange silty clay infills (Figs 126 to 128). Both investigations show differences between the lower brown plaggen soil and the upper black plaggen soil identified in the field (Pape, 1970). In Mucher's conclusions he suggests that the majority of decomposition of organic inclusions must have occurred before its addition to the arable fields as this would have led to higher variations in decomposition and more deformation and disturbance of pollen zones. The results so far from this analysis suggest the contrary. It is well known that pollen grains can withstand very acidic soils (Dimbleby, 1967 p112) (chapter 5, section 5.2.2) whereas evidence of the decomposition of organic inclusions in similar freely drained soils has been shown to be an extremely fast process <200 years (Davidson,

2002) and in extreme cases <40 years (Davidson and Carter, 1998). Indeed the micromorphological evidence presented in chapter 6, section 6.3.3 shows clearly that very heavy decomposition of organic material has occurred in situ by biological activity as a result of the addition of rich organic manure to the soil. The frequent occurrence of excremental pedofeatures and the lack of black carbonised and amorphous fragments suggest either limited storage in farm areas or strengthens the idea that organic inclusions were rapidly broken down after deposition.

Micromorphology was also used to investigate the plaggen soils at Valthe, Drenthe (van Smeerdijk, et al., 1995). Throughout the brown and black plaggen soil horizons the groundmass, mineralogy and excremental pedofeatures were very similar indicating heavy, continuous mixing by biological action. Very similar results were determined in this analysis (chapter 6, section 6.3.1 – 6.3.3). Most importantly van Smeerdijk's micromorphology analysis also revealed very few black carbonised particles indicating very little input from settlement waste even though earlier historical and pedological analyses have possibly over emphasised the addition of settlement waste (Pape, 1970).

Between the sites on Fair Isle, the Netherlands and Ireland the microstructure evidence suggests that although the soils have very different appearances in the field, the detailed micromorphological analysis illustrates distinctive similarities. At all three sites quartz is a very dominant mineral due to the similar sandy geologies (Plates 18a, 29a and 36a) and the addition of turf and peat organics has led to a distinctive dark brown to brown, reddish orange coloured fine mineral fabric with mostly intergrain microaggregate, stippled to flecked microstructure and distinctively high levels of iron and some manganese (Plates 19, 30 and 37). The addition of organic manuring components and digging and ploughing over time has lead to an open, well aerated, freely draining soil with high numbers of soil organisms. The cessation of arable farming may have led to many of the amended soils slowly reverting back to acidic podzolic soils but the pattern of manuring can still be recognised from one landuse area to another based upon the inclusions of coarse and fine organics. The micromorphological analysis of the coarse organic inclusions at the three sites illustrates the main materials used in the

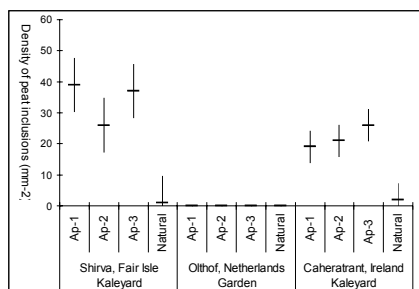
manuring process. At Shirva this is peat and carbonised peat (Plate 21 and 22), Olthof heathland and meadowland turf (Plate 33) together with charcoal (Plate 34) and at Caheratrant peat, turf, carbonised peat and charcoal (Plate 38,. There are, however, several issues with distribution which require discussion. At Olthof and Caheratrant there is a very distinctive reduction in both coarse and fine organic inclusion with distance from the settlement centre. However more detailed analysis of the amorphous black particles is needed in order to try and quantify them within the context of comparative horizons and landuse areas. At Shirva the abundance of peat on the island and the need to create arable land has in the outfield created an inverse relationship where the development of amended soil above a relict peaty podzol has actually increased the number of coarse organic inclusions even though they were not added as part of a manuring regime.

The micromorphology results clearly illustrate that at each of the sites there is an overall decrease of organic and carbonised inclusions with depth and with distance from the farm centre and that the variety of manuring components also decrease at each site suggesting distinctive management of available materials. More accurate analysis using zone counting (section 6.6) and image analysis (section 6.7) provides an alternative approach for quantifying the various manuring components.

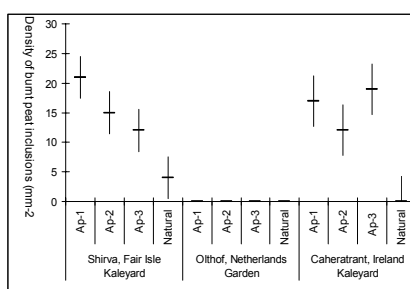
6.6 ZONE COUNT ANALYSIS FROM FAIR ISLE, THE NETHERLANDS AND IRELAND

6.6.1 ZONE COUNT RESULTS FROM KALEYARDS AND GARDENS

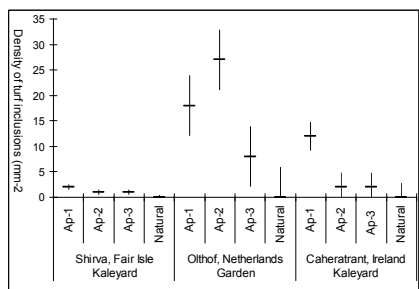
The zone count results from the kaleyards and garden areas illustrate the range of organic and inorganic inclusions which are used as the main manuring components (Fig 133). At Shirva and Caheratrant there is a considerably higher density of peat and burnt peat fragments than at Olthof which have a higher density of turf and burnt turf inclusions. Across each of the sites however there are variations in each of the soil horizons. At Shirva the peat inclusions range from $26 - 39 \pm 8.7/225\text{mm}^{-2}$ in the Ap-1 to Ap-3 horizons, whereas at Caheratrant there is a slight increase with depth from $19 \pm 5.2/225\text{mm}^{-2}$ in the Ap-1 horizon to $26 \pm 5.2/225\text{mm}^{-2}$ in the Ap-3 horizon, possibly because of an increase in input but also because of an increased breakdown by post burial processes. The more resistant burnt peat fragments show a marked decrease in density with depth at Shirva from $21 \pm 3.5/225\text{mm}^{-2}$ (Ap-1) to $12 \pm 3.5/225\text{mm}^{-2}$ (Ap-3) where as at Caheratrant the density is more variable ($12 - 21 \pm 4.2/225\text{mm}^{-2}$), suggesting a more consistent input of organics with an increase in mixing and decomposition. At Olthof the density of turf inclusions is higher than at the other sites and there is a much higher density in the black plaggen soil ($18 - 27 \pm 5.8/225\text{mm}^{-2}$) than in the brown plaggen soil ($8-10 \pm 5.8/225\text{mm}^{-2}$) as a result of post burial decomposition. There is a similar pattern with the burnt turf inclusions, however, the Ap-1 horizon has a lower density than expected ($14 \pm 9.5/225\text{mm}^{-2}$), possibly reflecting the lower levels of carbonised input from farms towards the end of the development of plaggen soils. There is a very small density of turf and burnt turf particles at Shirva and these are likely to have been inadvertent additions mixed in with peat inclusions, but at Caheratrant there is an increase of turf inclusions in the Ap-1 horizon directly associated with the cutting of turf in the kaleyards from the delling process. Charcoal inclusions are most frequent in Olthof garden and Caheratrant kaleyard because of the presence of wood used for fuel.



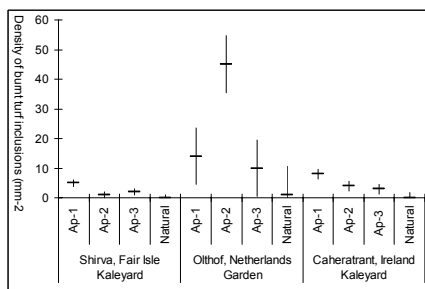
Peat



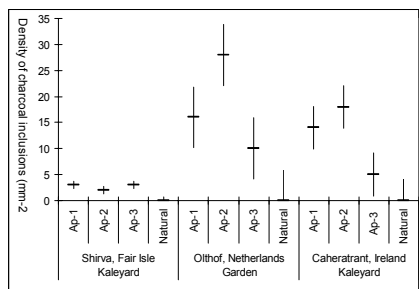
Burnt Peat



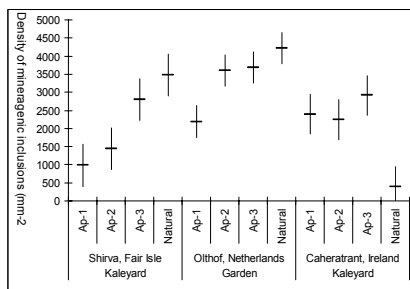
Turf



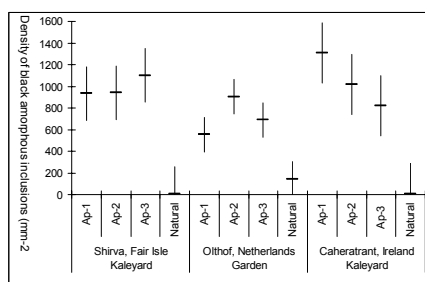
Burnt Turf



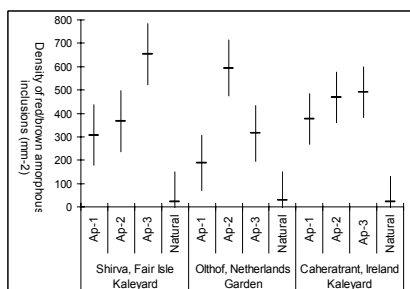
Charcoal



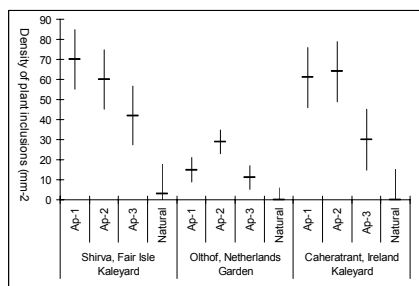
Mineragenic



Black Amorphous



Red/brown Amorphous



Plant

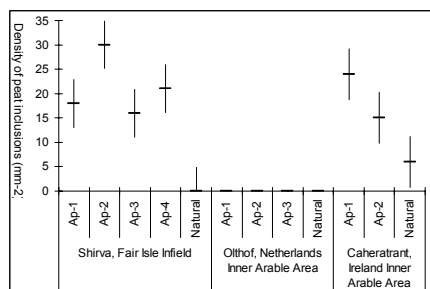
Figure 133, Zone count results for mean density/225mm⁻² of organic and inorganic inclusions from soil horizons within kaleyards and garden areas at Shirva, Fair Isle; Olthof, the Netherlands and Caheratrant, Ireland. Error bars represent 95% confidence interval of the mean

The amount of charcoal at Olthof is the same as the turf and burnt turf fragments with the highest density in the black plaggen soil ($16 - 28 \pm 5.8/225\text{mm}^{-2}$) and lower amounts in the Ap-3 horizon ($10 \pm 5.8/225\text{mm}^{-2}$) which indicates an increase in domestic waste material in the latter development of the amended soils. At Caheratrant the density of charcoal is slightly lower than in the Netherlands possibly because of the larger range of available fuel resources. The Ap-1 and Ap-2 horizons have similar results ($14 - 18 \pm 4.1/225\text{mm}^{-2}$) with less in the Ap-3 horizon. Mineral inclusions are the most prolific across all the sites and at each site there is a gradual increase with depth, but there is also a high density in the amended soils from the organic inputs as well as mixing with the natural. The black amorphous inclusions at the three sites are highly abundant compared to the burnt peat, turf and charcoal fragments. At Shirva there is a very slight increase in density with depth from $934-1100 \pm 248/225\text{mm}^{-2}$ and almost none in the natural soil. At Olthof the black plaggen soil contains between $553 \pm 160/225\text{mm}^{-2}$ in the Ap-1 horizon and $905 \pm 160/225\text{mm}^{-2}$ in the Ap-2 horizon, possibly as a result of the decomposition of burnt turf and charcoal fragments but the brown plaggen soil (Ap-3) also contains a high density ($689 \pm 160/225\text{mm}^{-2}$) which contradicts the carbonised fragment evidence. This suggests that there is either a large amount of mixing with the black plaggen soil or the amorphous inclusions are not organic fragments and have not undergone degradation. Alternatively, the particles may be organic and are the remnants of considerably larger black carbonised fragments which have been heavily degraded. The black amorphous particles decrease in density with depth at Caheratrant from $1310 \pm 278/225\text{mm}^{-2}$ in Ap-1, $1017 \pm 278/225\text{mm}^{-2}$ in Ap-2 and $822 \pm 278/225\text{mm}^{-2}$ in the Ap-3 horizon. This suggests that if the particles are deliberately added, then there is an increase in the later stages of manuring, however, the calcareous sands also contain numerous black mineral fragments, so the number of amorphous inclusions may indicate sanding patterns. Alongside the black amorphous particles are a larger density of red/brown amorphous inclusions. At Shirva there is an increase with depth from $307-653 \pm 129/225\text{mm}^{-2}$ and at Caheratrant there is a smaller increase from $376-491 \pm 108/225\text{mm}^{-2}$ but at Olthof there is a large increase in the black

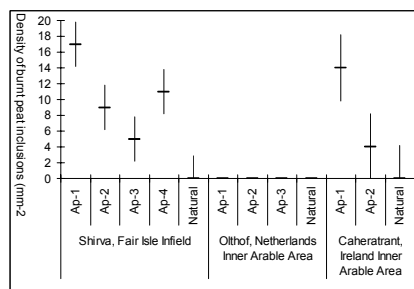
plaggen soil from $188-594 \pm 119/225\text{mm}^{-2}$ and a lower level in the brown plaggen soil ($315 \pm 119/225\text{mm}^{-2}$). Like the black amorphous particles these inclusions may be organic and inorganic and so could indicate different processes occurring within the Ap soil horizons. Plant material density was also counted as this can indicate possible organic input materials or crop species grown. At Shirva the density of plant inclusions decreases with depth from $70-42 \pm 15/225\text{mm}^{-2}$ and at Caheratrant the density decreases from $64-30 \pm 15/225\text{mm}^{-2}$ and have the characteristics of peaty organics. At Olthof the density of plant fragments increases with depth in the black and brown plaggen soils ($15-29 \pm 6/225\text{mm}^{-2}$) but poor preservation and biological decomposition makes species identification very difficult.

6.6.2 ZONE COUNT RESULTS FROM INFELD AND INNER ARABLE AREAS

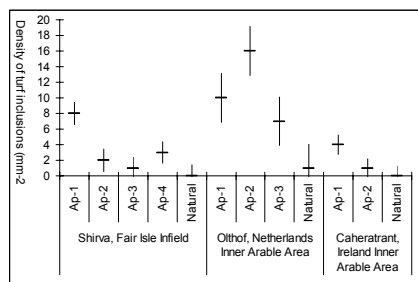
The zone counting results from the infield and inner arable areas of the three sites reveal the density of organic and inorganic components which indicate manuring strategies (Fig 134). Overall peat inclusions at Shirva are lower than in the kaleyard area and there is an inconsistent amount between the Ap-1 to Ap-3 horizons from $16-30 \pm 4.8/225\text{mm}^{-2}$ indicating similar levels of addition but also high amounts of mixing by ploughing, a process not occurring in the kaleyard. In the Ap-4 horizon there is a slight increase in peat inclusions which mirror the increase of elemental enhancement (chapter 5, section 5.7.2). At Caheratrant there is a distinctive decrease in peat inclusions from $24-15 \pm 5.2/225\text{mm}^{-2}$ in the Ap-1 and Ap-2 horizons to a minimal level in the natural soils ($6 \pm 5.2/225\text{mm}^{-2}$) presumably present because of mixing by biological activity. The burnt peat inclusions at Caheratrant have a very similar pattern to the peat with $14 \pm 4.1/225\text{mm}^{-2}$ in the Ap-1 horizon and $4 \pm 4.1/225\text{mm}^{-2}$ in the Ap-2 which suggests much less input from the settlement centre than in the kaleyard. At Shirva there is also slightly less burnt peat than in the kaleyard but there is a more distinctive decrease with depth between the Ap-1 ($17 \pm 2.8/225\text{mm}^{-2}$), Ap-2 ($9 \pm 2.8/225\text{mm}^{-2}$) and Ap-3 ($5 \pm 2.8/225\text{mm}^{-2}$) horizons.



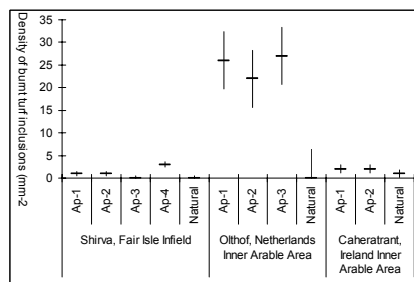
Peat



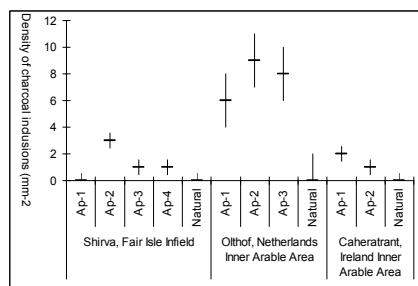
Burnt Peat



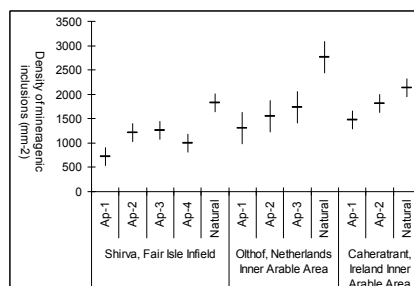
Turf



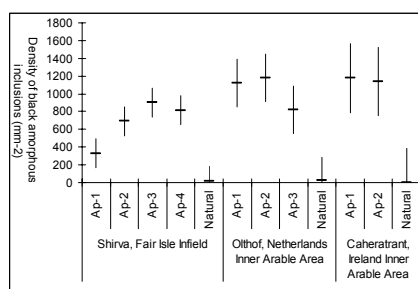
Burnt Turf



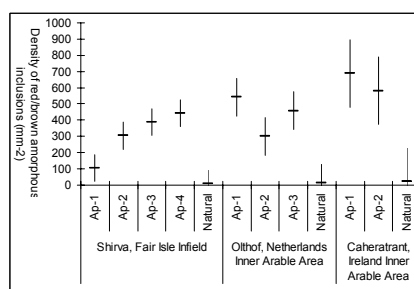
Charcoal



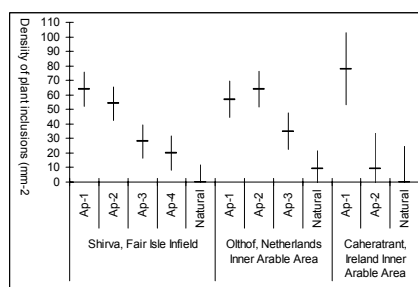
Minerogenic



Black Amorphous



Red/brown Amorphous



Plant

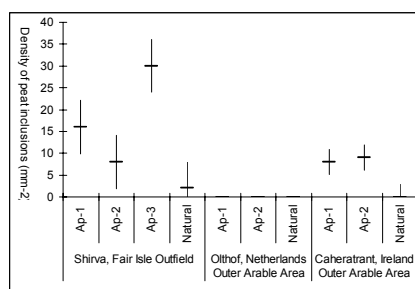
Figure 134, Zone count results for mean density/225mm⁻² of organic and inorganic inclusions from soil horizons within infield and inner arable areas at Shirva, Fair Isle; Olthof, the Netherlands and Caheratrant, Ireland. Error bars show 95% confidence interval of the mean

This could be as a direct result of the level of input in each horizon or partial decomposition, but the same increase is still present in the Ap-4 horizon $11 \pm 2.8/225\text{mm}^{-2}$ which may represent a buried soil developed when the area was used for a different purpose. Of the three sites turf inclusions are most frequent at Olthof but compared to the garden soils the density is significantly lower. The black plaggen horizons (Ap-1 and Ap-2) have between $10-16 \pm 3.1/225\text{mm}^{-2}$ inclusions whereas the brown plaggen soils have $7 \pm 3.1/225\text{mm}^{-2}$. The amounts of burnt turf at Olthof are far higher than the unburnt fragments and this may reflect an increase in input or a better ability to resist decomposition, however in each of the soil horizons there are between $22-27 \pm 6.3/225\text{mm}^{-2}$ carbonised turf particles. This regularity in the density of burnt peat with depth may derive from modern ploughing action thoroughly mixing the black and brown plaggen soils and there are a number of other inclusions which demonstrate this. At Shirva there is an increase in the density of turf inclusions from the kaleyard, especially in the Ap-1 horizon $8 \pm 1.3/225\text{mm}^{-2}$ but a significantly lower density in the Ap-2 and Ap-3 horizons ($1-2 \pm 1.3/225\text{mm}^{-2}$) and a slightly higher level in the Ap-4 horizon. This variation may derive from an increase in unburnt organic materials used for manuring in the infield area, or from the use of peaty turf material from a different upland source. The considerably lower density of burnt turf suggests that if it is being used, it is not being burnt. The upper amended soils at Caheratrant also show a slight increase in turf inclusions ($4 \pm 1/225\text{mm}^{-2}$) but the results are far lower than in the kaleyard and indicates that turf is being used less as a manure in either its natural or burnt form. Overall the charcoal results are lower in the inner arable area compared to the kaleyard and between the three sites Olthof has values of between $6-9 \pm 2/225\text{mm}^{-2}$ fragments in the black plaggen soil and $8 \pm 2/225\text{mm}^{-2}$ in the Ap-3 horizon. At Shirva no charcoal was identified in the Ap-1 horizon but between the Ap-2 to the Ap-4 horizon there is a decrease from $3-1 \pm 0.5/225\text{mm}^{-2}$. A reduction down profile is also present at Caheratrant from $0-2 \pm 0.5/225\text{mm}^{-2}$. All the infield and inner arable areas have an overall increase of mineragenic material with depth as a result of mixing with the natural and from the addition of peat and turf manure. At Shirva the density of mineral inclusions ranges from 720-1831 $\pm 183/225\text{mm}^{-2}$, at Olthof there is between 1307-2762 $\pm 320/225\text{mm}^{-2}$ and

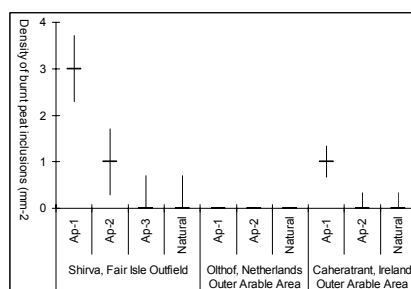
at Caheratrant the mineral inclusions range from $1473-2130 \pm 189/225\text{mm}^{-2}$. Much like the kaleyard sequences the soil horizons in the infield and inner arable areas also contain a large number of both black and red/brown amorphous inclusions. At Shirva there is an increase with depth in both including $330-815 \pm 165/225\text{mm}^{-2}$ black and $104-442 \pm 83/225\text{mm}^{-2}$ red/brown fragments, possibly as a result of an increase in post burial decomposition of burnt and unburnt organics. At Caheratrant the results are also similar ($1141-1171 \pm 386/225\text{mm}^{-2}$ black) and ($582-688 \pm 206/225\text{mm}^{-2}$ red/brown) between the Ap-1 and Ap-2 horizons from addition or decomposition of existing inclusions. The results at Olthof are different, however, with a slightly higher number of black amorphous particles in the black plaggen soil ($1124-1178 \pm 266/225\text{mm}^{-2}$) and a slightly lower level in the brown plaggen horizon ($821 \pm 266/225\text{mm}^{-2}$). The density of red/brown amorphous inclusions decrease between the Ap-1 and Ap-2 horizons from $542-300 \pm 116/225\text{mm}^{-2}$, then increase to $457 \pm 116/225\text{mm}^{-2}$ in the Ap-3 horizon. The plant residue inclusions have a similar pattern to the kaleyards. At Shirva the plant material decreases with depth from $64-20 \pm 11.5/225\text{mm}^{-2}$, at Olthof there is a similar pattern with a reduction down profile and a distinctive change between the black and brown plaggen soils. At Caheratrant there is a larger reduction between the amended soil horizons ($78-9 \pm 24/225\text{mm}^{-2}$).

6.6.3 ZONE COUNT RESULTS FROM OUTFIELD AND OUTER ARABLE AREAS

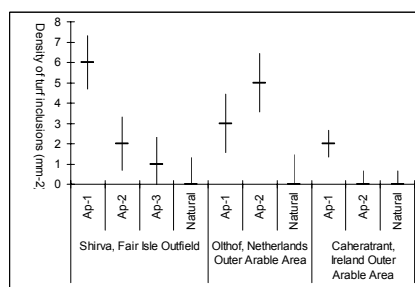
A systematic zone count was also conducted for the soil horizons in the outfield and outer arable areas of the three sites (Fig 135). At Shirva there is an overall decrease in density of peat inclusions in the Ap-1 and Ap-2 horizons compared to the kaleyard and infield areas, however, there is an increase from $8-30 \pm 6/225\text{mm}^{-2}$ in the Ap-3 horizon because of the truncation of the remnant peaty H horizon. The use of an existing organic rich buried peat soil makes it very difficult to determine between peat added as a manure and peat soil mixing by post burial mixing of the H horizon. What is clear, however, is that in the peat are also very low amounts of burnt peat material suggesting a limited amount of additional manuring.



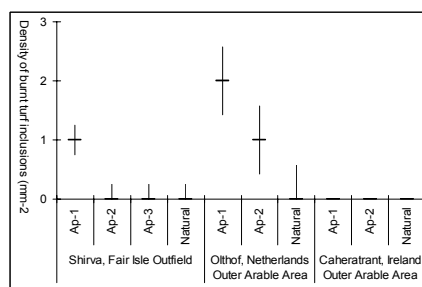
Peat



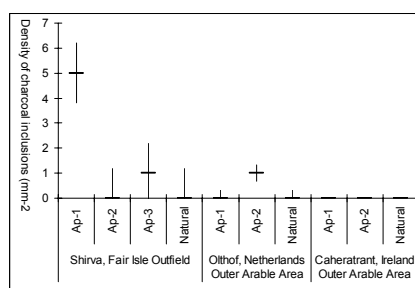
Burnt Peat



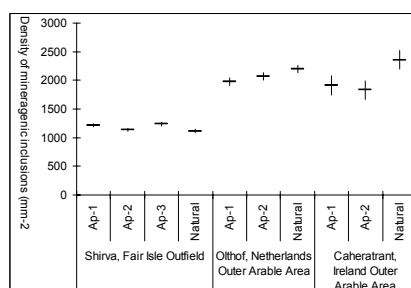
Turf



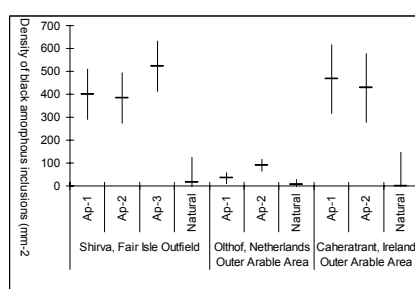
Burnt Turf



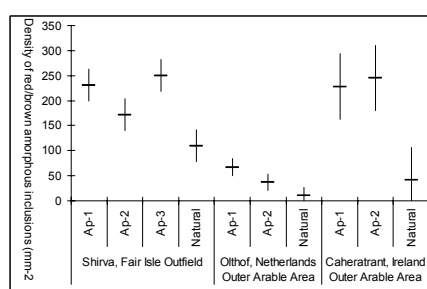
Charcoal



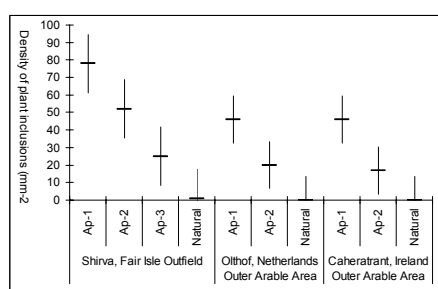
Minerogenic



Black Amorphous



Red/brown Amorphous



Plant

Figure 135, Zone count results for mean density/225mm⁻² of organic and inorganic inclusions from soil horizons within outfield and outer arable areas at Shirva, Fair Isle; Olthof, the Netherlands and Caheratrant, Ireland. Error bars show 95% confidence interval of the mean

At Caheratrant the peat and burnt peat results are considerably lower than in the kaleyard and inner arable areas, suggesting that only minimal manuring was being conducted in the outer areas of the farm. Turf levels at Olthof, which are so prevalent in the kaleyard area, are considerably lower in the shallow black plaggen soil ($3.5 \pm 1.4/225\text{mm}^{-2}$) in the reclaimed heathland area, and this may be due to the use of modern fertilisers in the soils and the obliteration of delicate organic particles by modern ploughing. The density of carbonised turf particles also decrease in the outfield and outer arable area ($<2 \pm 0.5/225\text{mm}^{-2}$) indicating a decrease in the use of carbonised manure from settlements in outer arable land areas. The use of turf and burnt turf at Shirva and Caheratrant is minimal and the very low levels demonstrate a high level of mixing of numerous manuring components which occurred in the settlement centres. The charcoal levels at Shirva are very low but the level is higher than the amount recorded in the inner arable area and this demonstrates a distinct irregularity in manuring across the farm and the complexity of developing and maintaining good quality arable soils in such a restricted landscape. At Olthof and Caheratrant the density of charcoal inclusions in the outer arable areas is very low indicating very small inputs from settlement centres. Despite the very low levels of identifiable black carbonised and uncarbonised particles the density of black amorphous inclusions is still high and in places not much different from the inner arable areas. Mineragenic inclusions are very high illustrating the interaction between the natural and anthropogenic soils and many of the black amorphous particles may be of mineral origin, however they may also be the remnants of heavily degraded organic inclusions and indicate how the soils developed. At Shirva the Ap-1 and Ap-2 horizons contain between $383-401 \pm 109/225\text{mm}^{-2}$ particles with a slight increase in the Ap-3 horizon ($522 \pm 109/225\text{mm}^{-2}$). If organic they may well be strongly decomposed peat inclusions from the buried H soil horizon and the density of the red/brown amorphous inclusions mirror this pattern. At Olthof the number of black amorphous particles is lower than in the garden and inner arable areas and the density increases with depth from $35-90 \pm 25/225\text{mm}^{-2}$. These particles may well be fragments of degraded carbonised particles which have been

broken down over time from larger particles but alternatively they may also be small concretions of iron commonly found in the natural soils. A similar pattern is evident from the red/brown particles which demonstrate a decrease with depth from $67-10 \pm 16.4/225\text{mm}^{-2}$ and may also derive from an organic source. At Caheratrant the pattern of black and red/brown amorphous particles is very similar, decreasing down profile and illustrating that the amended soils have a much higher number than the natural soils. As seen in all the other landuse areas, the density of plant inclusions decreases with depth at each site suggesting a gradual increase in post burial soil processes on the plant material. The results from Olthof are surprisingly low for an area with continued arable agriculture but may represent the speed at which new organic material added to the soil is broken down. At Shirva and Caheratrant the upper amended soil horizons illustrate slightly higher densities than in other landuse areas possibly because of the change from an arable landscape to a grassland one.

6.6.4 DISCUSSION OF THE ZONE COUNT RESULTS

The zone count analysis alongside the micromorphology of the amended soils from the three sites details a number of very important points about the soils development. The results from zone counting highlight that each site utilised a distinctive manuring process involving many different raw materials. Across each of the sites and landuse areas there is an overall reduction in the density of particles with depth and away from the centre of farm areas, especially large carbonised particles of peat, turf and charcoal (Figs 133 to 135). Interestingly, however, the zone count shows a much larger number of black amorphous particles present and these may well be fragments of heavily decomposed carbonised organics or mineral fragments associated with manuring or post burial processes. The next stage of this thesis is to attempt to quantify the identifiable black carbonised particles and the black amorphous particles with image analysis in order to get a more detailed idea of the density and size of the inclusions.

6.7 THE QUANTIFICATION OF BLACK PARTICLES BY IMAGE ANALYSIS

6.7.1 DENSITY AND SIZE OF BLACK PARTICLES IN KALEYARD AND GARDEN SOILS

The mean density of black particles is greatest at Shirva where between $3024\text{--}4788\pm 346\mu\text{m}^{-2}/225\text{mm}^{-2}$ inclusions are present in the amended soils (Fig 136). Overall the density of particles is highly variable and indicates a very high level of addition but also a large amount of mixing throughout the sequence. At the other two sites there are considerably less black particles. Busta kaleyard demonstrates an overall decrease in density with depth from $1995\text{--}1211\pm 189\mu\text{m}^{-2}/225\text{mm}^{-2}$ (Fig 136) whereas at Leogh there is a fairly stable density throughout $974\text{--}1082\pm 38\mu\text{m}^{-2}/225\text{mm}^{-2}$ suggesting a much lower addition and less post burial alteration of carbonised material (Fig 136). In a wider context the density of inclusions identified at Shirva is also considerably higher than the kaleyard at Caheratrant and the garden area at Olthof. At the Irish site there is a stable density throughout each of the soil horizons ($863\text{--}711\pm 27\mu\text{m}^{-2}/225\text{mm}^{-2}$), whereas at Olthof the density of black inclusions decrease with depth from $820\text{--}144\pm 30\mu\text{m}^{-2}/225\text{mm}^{-2}$ (Fig 137).

The mean size of the black particles analysed from Fair Isle is illustrated in figure 138. Although the kaleyard at Shirva contains the highest density of black carbonised and amorphous particles the largest mean inclusions are present at Busta, especially in the Ap-2 horizon ($7610\pm 1526\mu\text{m}^{-2}$) as a result of recent additions. Overall, however, the soil horizons contain a larger average particle size possibly because carbonised material has been added until very recently and post burial degradation occurs at different rates to the other sites. At Shirva the soil horizons have a very similar mean size range, which decreases slightly with depth from $5792\pm 1202\mu\text{m}^{-2}$ (Ap-1) to $4617\pm 760\mu\text{m}^{-2}$ (Ap-3) (Fig 138).

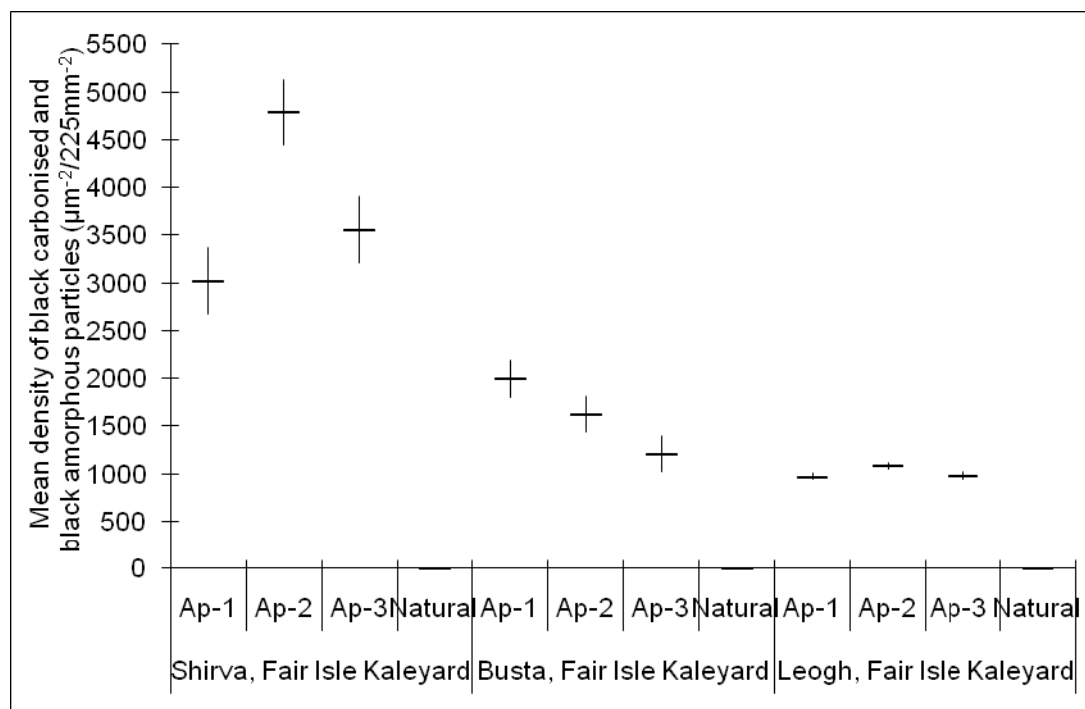


Figure 136, Mean density ($\mu\text{m}^{-2}/225\text{mm}^{-2}$) of black carbonised and black amorphous particles from three kaleyards on Fair Isle identified with image analysis

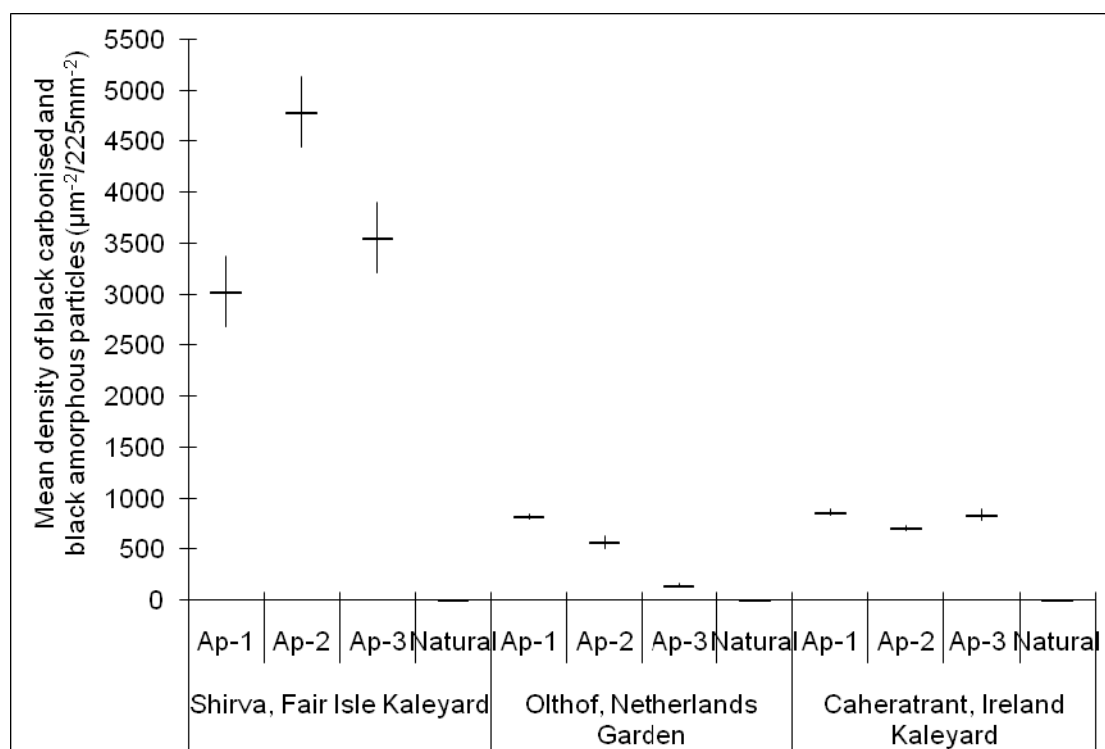


Figure 137, Mean density ($\mu\text{m}^{-2}/225\text{mm}^{-2}$) of black carbonised and black amorphous particles from kaleyard and garden areas on Fair Isle, the Netherlands and Ireland identified with image analysis.

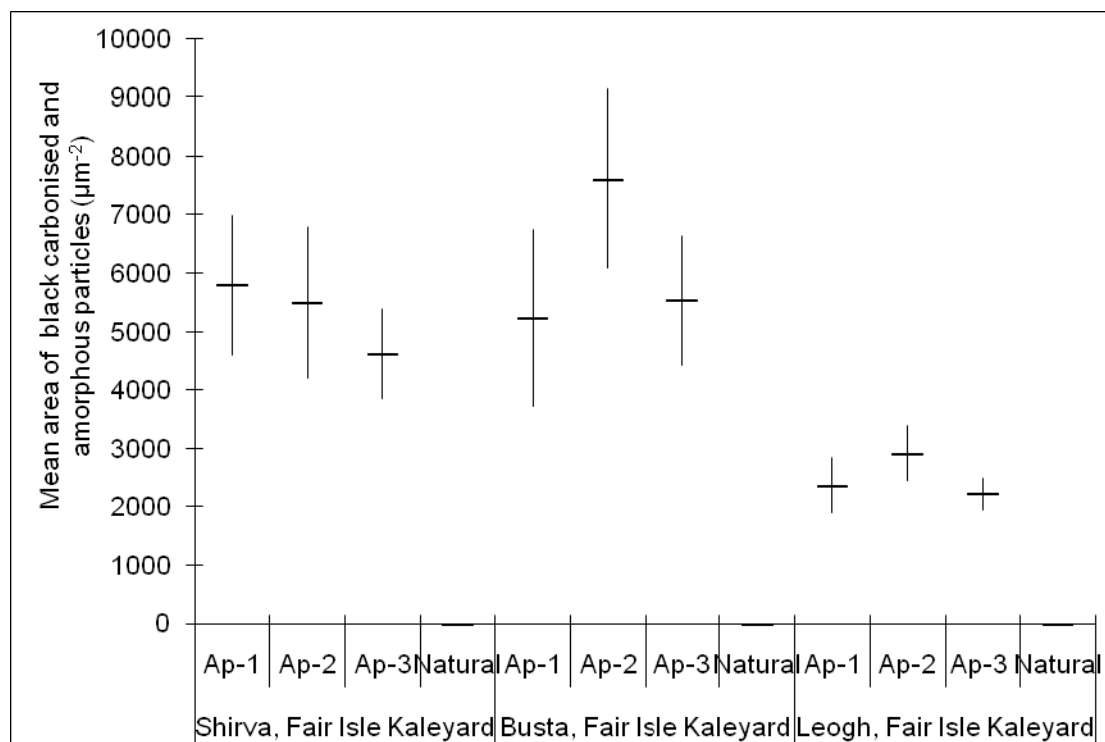


Figure 138, Mean size (μm^2) of black carbonised and black amorphous particles from three kaleyards on Fair Isle identified with image analysis

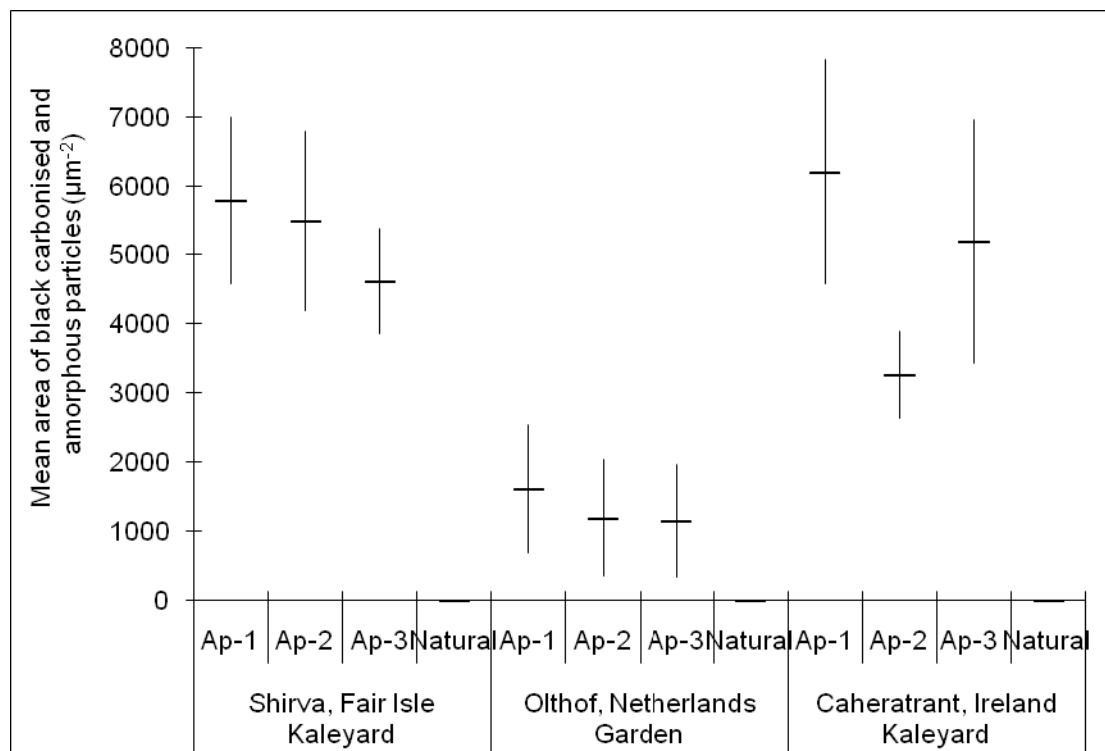


Figure 139, Mean size (μm^2) of black carbonised and black amorphous particles from kaleyard and garden areas on Fair Isle, the Netherlands and Ireland identified with image analysis

The similarity in size but the variety in density of black amorphous particles suggests that the level of degradation is slow and fairly uniform throughout the formation of the amended soils. The soil horizons at Leogh contain the smallest size of black inclusions, but like Shirva the results differ very little throughout the soil horizons. The results range from $2368 \pm 480 \mu\text{m}^{-2}$ to $2217 \pm 274 \mu\text{m}^{-2}$ and suggest that they have undergone the most post burial alteration (Fig 138). At Olthof and Caheratrant the results are even more contrasting and this is a reflection of input and post burial change (Fig 139). At Olthof the particles density is low and so is the average size of inclusions ($1609 \pm 929 \mu\text{m}^{-2}/225\text{mm}^{-2}$ Ap-1 to $1147 \pm 811 \mu\text{m}^{-2}/225\text{mm}^{-2}$ Ap-3) which is likely to be due to the rapid breakdown of organic inclusion by biological and chemical action. At Caheratrant the size of the black amorphous and carbonised particles is considerably larger suggesting less post burial degradation, but the variation in size is also very large suggesting variations in the amount of mixing and alteration after deposition.

6.7.2 DENSITY AND SIZE OF BLACK PARTICLES IN INFIELD AND INNER ARABLE SOILS

The mean density from the infield and inner arable areas are illustrated in figure 140. In the upper soil horizons at Shirva there is a much lower density of black particles than in the kaleyard, the density decreases from $879 \pm 579 \mu\text{m}^{-2}/225\text{mm}^{-2}$ to $397 \pm 579 \mu\text{m}^{-2}/225\text{mm}^{-2}$. However, there is a huge increase in the Ap-3 horizon to $2738 \pm 579 \mu\text{m}^{-2}/225\text{mm}^{-2}$ possibly because of the addition of carbonised particles to a new arable soil developed in an old occupation area. Alternatively, the small black inclusions may derive from an archaeological feature below and have been mixed into the Ap-3 horizon by plough action. At Olthof the density of black carbonised particles and amorphous particles varies very little between the garden and the inner arable area but there is still a distinctive decrease with depth from $850 \pm 226 \mu\text{m}^{-2}/225\text{mm}^{-2}$ (Ap-1) to $503 \pm 111 \mu\text{m}^{-2}/225\text{mm}^{-2}$ (Ap-2) and $305 \pm 33 \mu\text{m}^{-2}/225\text{mm}^{-2}$ (Ap-3). Figure 140 suggests that input in the inner arable area is not dissimilar from the garden area but that there is a clear increase in addition between the brown and black plaggen soils.

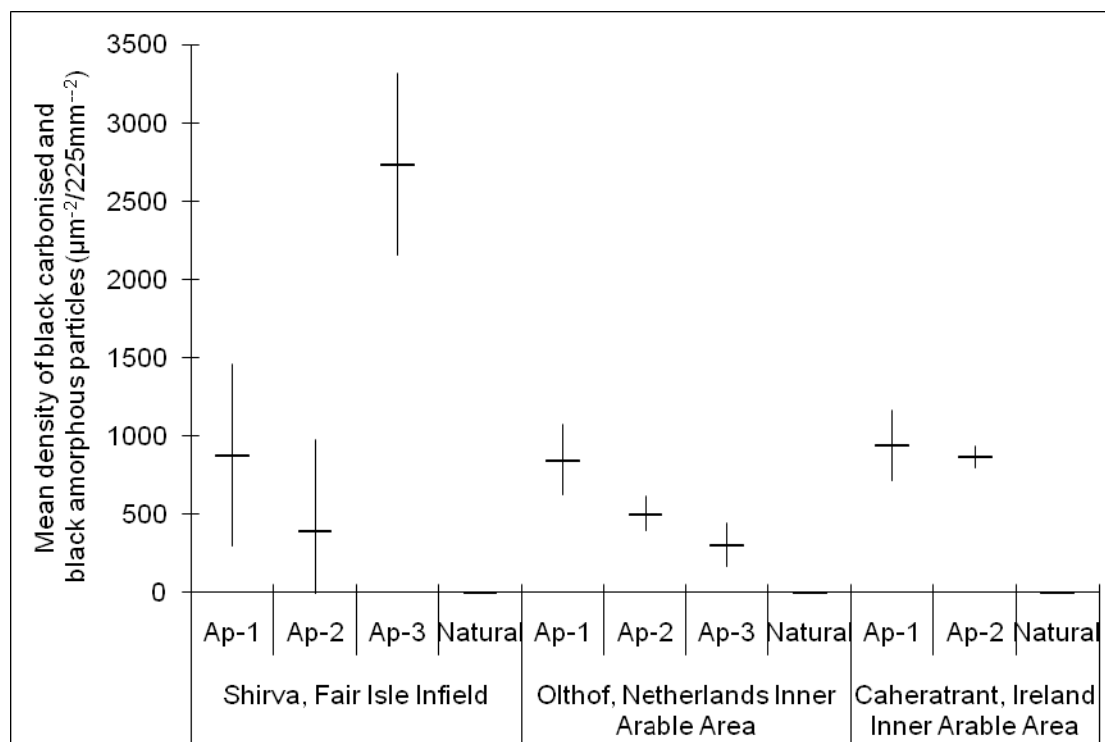


Figure 140, Mean density ($\mu\text{m}^{-2}/225\text{mm}^{-2}$) of black carbonised and black amorphous particles from infield and inner arable areas from Fair Isle, the Netherlands and Ireland identified with image analysis

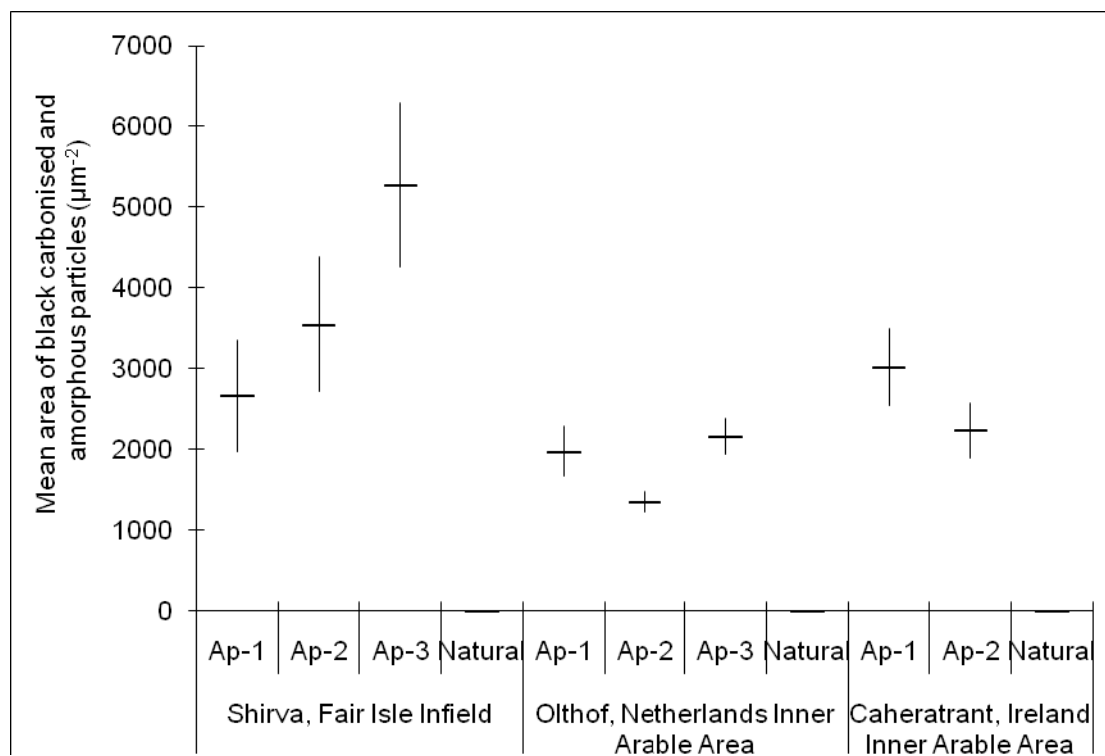


Figure 141, Mean size (μm^2) of black carbonised and black amorphous particles from infield and inner arable areas at Fair Isle, the Netherlands and Ireland identified with image analysis

The density of particles in the inner arable area at Caheratrant (Fig 140) ranges from $942 \pm 226 \mu\text{m}^{-2} / 225 \text{mm}^{-2}$ to $869 \pm 69 \mu\text{m}^{-2} / 225 \text{mm}^{-2}$ which is a slight increase to the numbers identified in the kaleyard, most likely because an increase in the decomposition of larger carbonised particles from physical, biological and chemical action.

The infield and the inner arable soil horizons contain a variety of sizes of black carbonised and amorphous particles (Fig 141). At Shirva the inclusions gradually increase in size with depth from $2661 \pm 688 \mu\text{m}^{-2}$ to $5279 \pm 1016 \mu\text{m}^{-2}$ possibly indicating the inclusion of more anthropogenic material during the early development of the Ap-3 horizon or that post depositional processes have been more active in the upper layers. A clear difference in size is very evident however, between the infield of Shirva and the other two sites. At Olthof the mean size of the particles is much smaller across each horizon but the results are relatively consistent. In the black plaggen soils (Ap-1 and Ap-2) the mean particle size decreases from $1972 \pm 305 \mu\text{m}^{-2}$ to $1348 \pm 126 \mu\text{m}^{-2}$ but there is a distinctive increase in the brown plaggen soil ($2155 \pm 220 \mu\text{m}^{-2}$) suggesting either a similar level of input into the plaggen soils from settlement centres, a change in the rate of decomposition of the particles or the inclusion of dark opaque iron concretions which are common in the natural and Ap-3 horizons. At Caheratrant the average size of black inclusions decreases with depth from $3019 \pm 475 \mu\text{m}^{-2}$ in the Ap-1 horizon to $2232 \pm 345 \mu\text{m}^{-2}$ in the Ap-2 horizon. The results are considerably lower than results from the kaleyard suggesting a much smaller influence from material added from settlement centres but the error factor was much more consistent and may indicate the addition of organic material with a similar degradation rate i.e. peat and turf.

6.7.3 DENSITY AND SIZE OF BLACK PARTICLES IN OUTFIELD AND OUTER ARABLE SOILS

In the outfield area (Fig 142) the density of particles identified in the upper soil horizons at Shirva outfield is very large with $1966 \pm 288 \mu\text{m}^{-2} / 225 \text{mm}^{-2}$ in the Ap-1 horizon and $2216 \pm 288 \mu\text{m}^{-2} / 225 \text{mm}^{-2}$ in the Ap-2 horizon, as a result of the addition of the breakdown of a peaty organic buried soil to the

arable soil horizons. In the Ap-3 horizon there is a decrease in density ($877 \pm 288 \mu\text{m}^{-2} / 225 \text{mm}^{-2}$) suggesting either a reduction in the addition of black amorphous particles or post burial decomposition. The high density of particles in the outfield and in the natural sand horizon most likely derives from the disturbed H horizon which contains over $2321 \pm 288 \mu\text{m}^{-2} / 225 \text{mm}^{-2}$. By comparison the density of inclusions identified in the outer arable soils at Olthof is considerably lower than in the other areas which range from $36-48 \pm 6.5 \mu\text{m}^{-2} / 225 \text{mm}^{-2}$ and at Caheratrant the density of particles decreases with depth from $618-236 \pm 37 \mu\text{m}^{-2} / 225 \text{mm}^{-2}$ indicating very little input from settlement centres.

In the outer arable areas the results from each site clearly illustrate that the areas furthest from the farm contain the smallest black carbonised particles (Fig 143). At Olthof and Caheratrant the results are consistently low and vary very little with depth. At Olthof the means range from $1593 \pm 194 \mu\text{m}^{-2}$ to $1577 \pm 99 \mu\text{m}^{-2}$ and in Ireland the results decrease from $2053 \pm 108 \mu\text{m}^{-2}$ to $1592 \pm 124 \mu\text{m}^{-2}$ indicating little to no addition of waste from settlement centres, a considerably shallower profile of anthropogenic soils and manuring by direct addition of organic and mineral materials. At Shirva the outfield results illustrate a very different process. In the upper soil horizons (Ap-1 and Ap-2) the size of black inclusions is very low ($1957 \pm 609 \mu\text{m}^{-2}$ to $1904 \pm 375 \mu\text{m}^{-2}$) and suggests little input of domestic material, however, the Ap-3 horizon illustrates a greatly increased size ($8858 \pm 2049 \mu\text{m}^{-2}$) directly relating to the disturbance of the underlying buried organic H horizon which contains humified peat fragments averaging $23215 \pm 5152 \mu\text{m}^{-2}$. The large error in both the Ap-3 and H horizons suggests that post burial degradation has been occurring and confirms the theory that the H horizon is a naturally occurring soil and has been incorporated into the development of the Ap-3 horizon rather than deliberately added as a manure. If this is the case then the outfield at Shirva does fit into the model of reduced input from settlement centres as seen at the other sites.

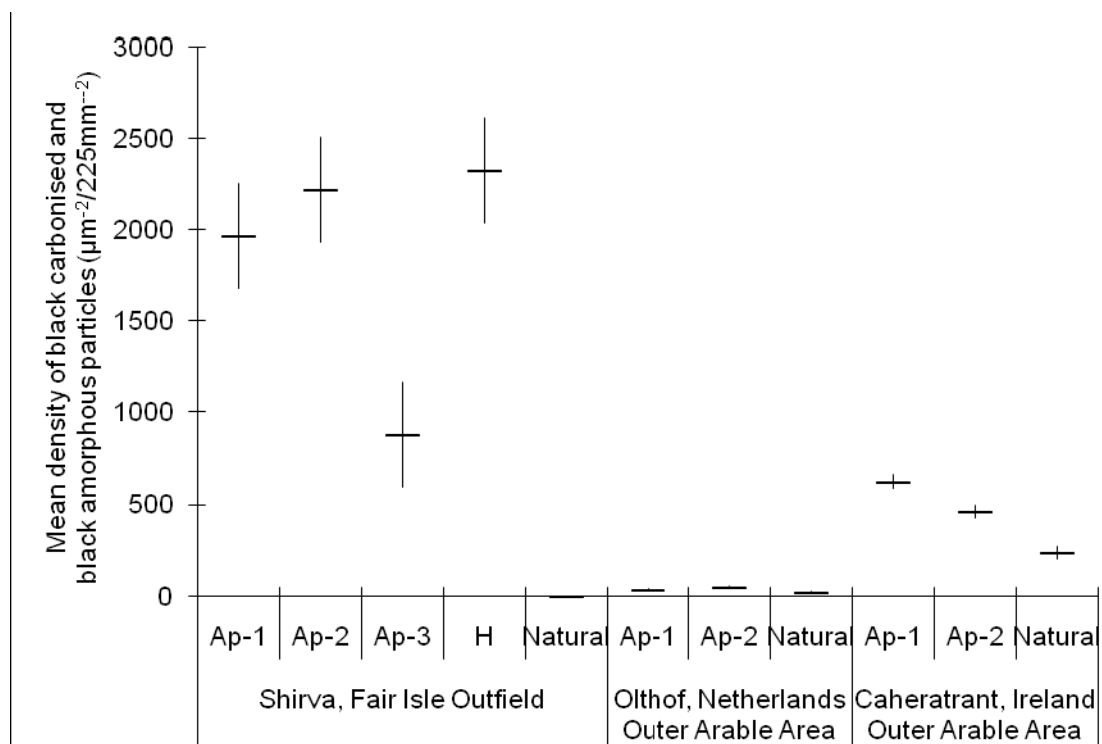


Figure 142, Mean density ($\mu\text{m}^{-2}/225\text{mm}^{-2}$) of black carbonised and black amorphous particles from outfield and outer arable areas from Fair Isle, the Netherlands and Ireland identified with image analysis

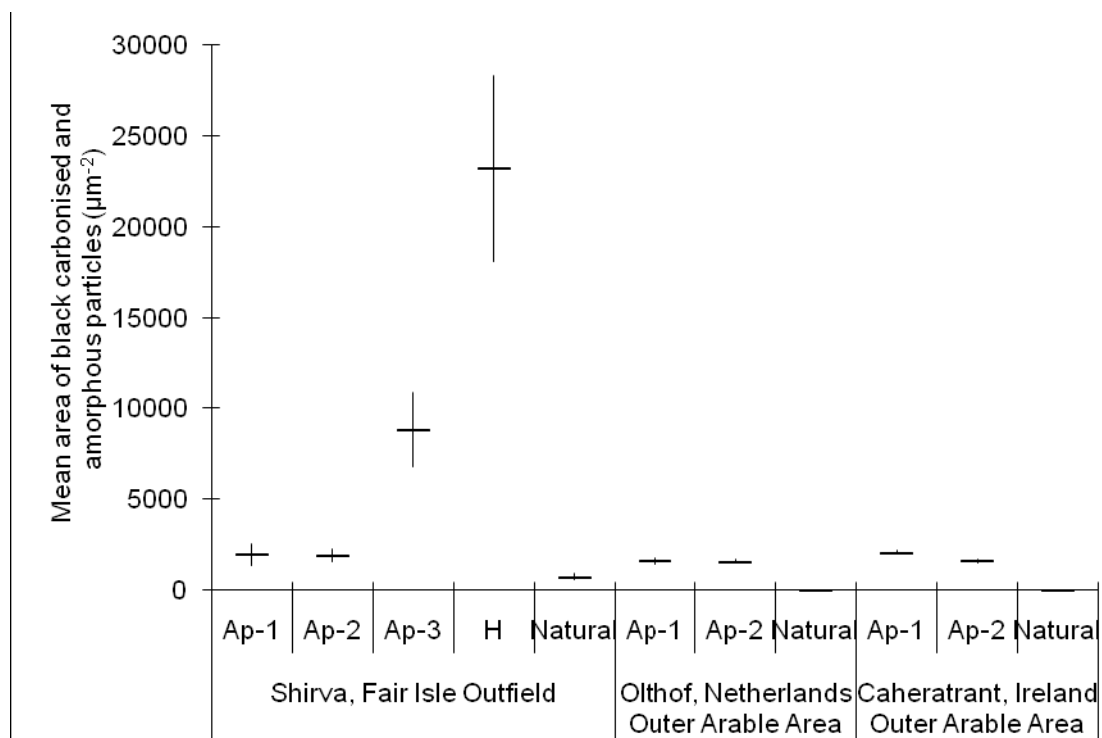


Figure 143, Mean size (μm^2) of black carbonised and black amorphous particles from outfield areas from Fair Isle, the Netherlands and Ireland identified with image analysis

6.7.4 DENSITY AND SIZE OF VOID SPACES IN BLACK PARTICLES IN KALEYARD AND GARDEN SOILS

Alongside determining the density and size of black particles it is also important to calculate the density and size of void spaces in order to try and identify whether the particles have an organic origin. It is hypothesised that the particles with a higher density and size of void spaces are more likely to be carbonised organics and ones with an absence of void space may have an inorganic or mineragenic origin. The results collected from section 6.7.4 will also provide a comparative data set to compare against the elemental analysis from individual black particles discussed in chapter 7.

On Fair Isle the black particles within the soil horizons in the three kaleyards have relatively similar densities of void spaces with several exceptions (Fig 144 and 145). At Shirva the inclusions in the Ap-1 horizon have a considerably higher density of void spaces ($25.3 \pm 4.87 \mu\text{m}^2/225\text{mm}^2$) with an average size of $785 \pm 269 \mu\text{m}^2$ suggesting that the upper soil horizons contain more black carbonised particles, and there has been less post burial degradation. The sequence at Shirva shows a distinctive decrease in density and size of void spaces with depth which may indicate a reduction in organic inclusions. At Busta the mean density of void spaces in black particles also decreases with depth from $9.72 \pm 1.72 \mu\text{m}^2/225\text{mm}^2$ (Ap-1) to $4.43 \pm 0.60 \mu\text{m}^2/225\text{mm}^2$ (Ap-3) and the size of those voids decreases from $600 \pm 282 \mu\text{m}^2$ (Ap-1) to $317 \pm 88 \mu\text{m}^2$ (Ap-3), possibly indicating a similar level of addition of carbonised particles over time. A more diverse set of results is seen at Leogh where the average density of voids is highest in the Ap-2 horizon ($7.58 \pm 0.81 \mu\text{m}^2/225\text{mm}^2$) but the mean size of the voids decreases with depth from $115 \pm 52 \mu\text{m}^2$ to $74 \pm 17 \mu\text{m}^2$. At Olthof there is almost no variation in the density of voids (7.66 ± 1.16 to $7.29 \pm 1.98 \mu\text{m}^2/225\text{mm}^2$) or the size ($58.6 \pm 19.7 \mu\text{m}^2$ to $51.2 \pm 18.5 \mu\text{m}^2$) in the soil horizons which suggests a large quantity of organic inclusions have been degraded and many are fragmented without void spaces (Fig 146 and 147).

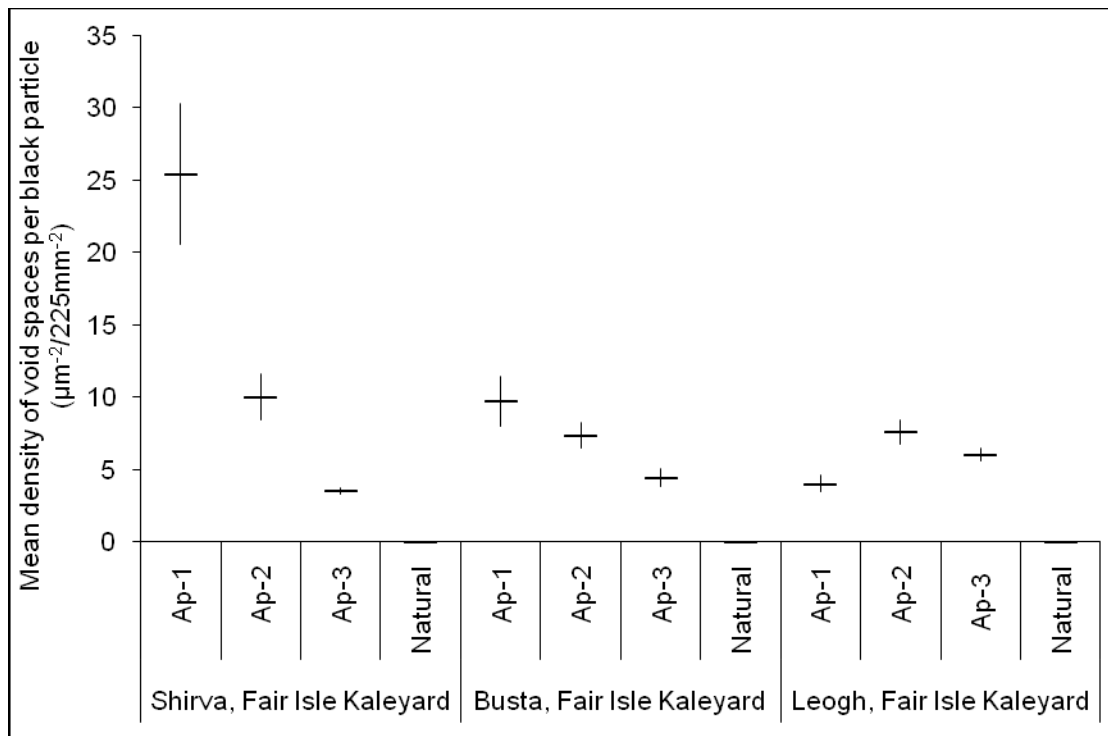


Figure 144, Mean density ($\mu\text{m}^2/225\text{mm}^2$) of void space within black inclusions from three kaleyards on Fair Isle identified with image analysis

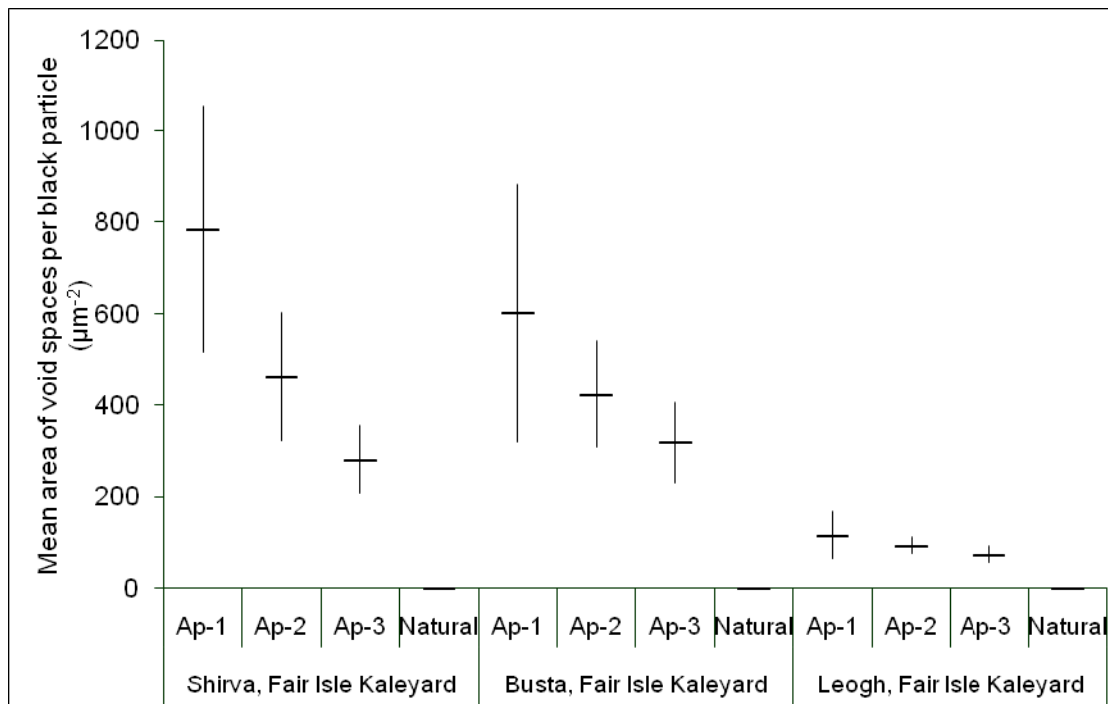


Figure 145, Mean size (μm^2) of void space within black particles from three kaleyard areas on Fair Isle identified by image analysis

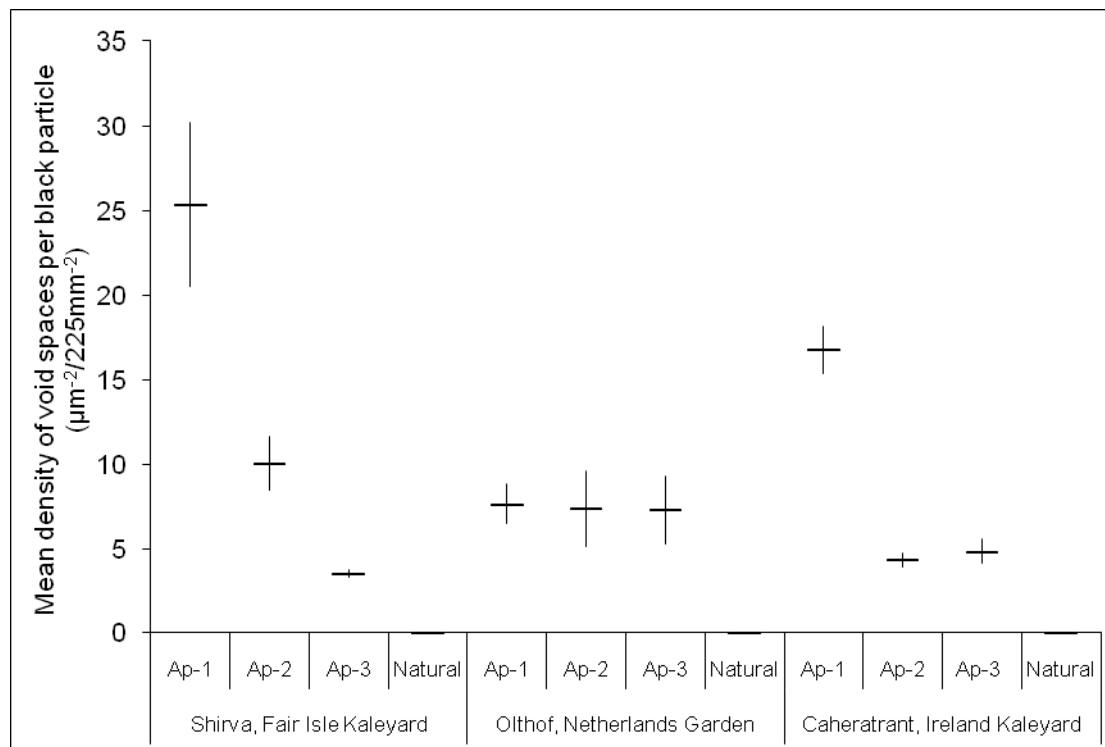


Figure 146, Mean density ($\mu\text{m}^2/225\text{mm}^2$) of void space within black particles in kaleyard and garden areas from Fair Isle, the Netherlands and Ireland identified by image analysis

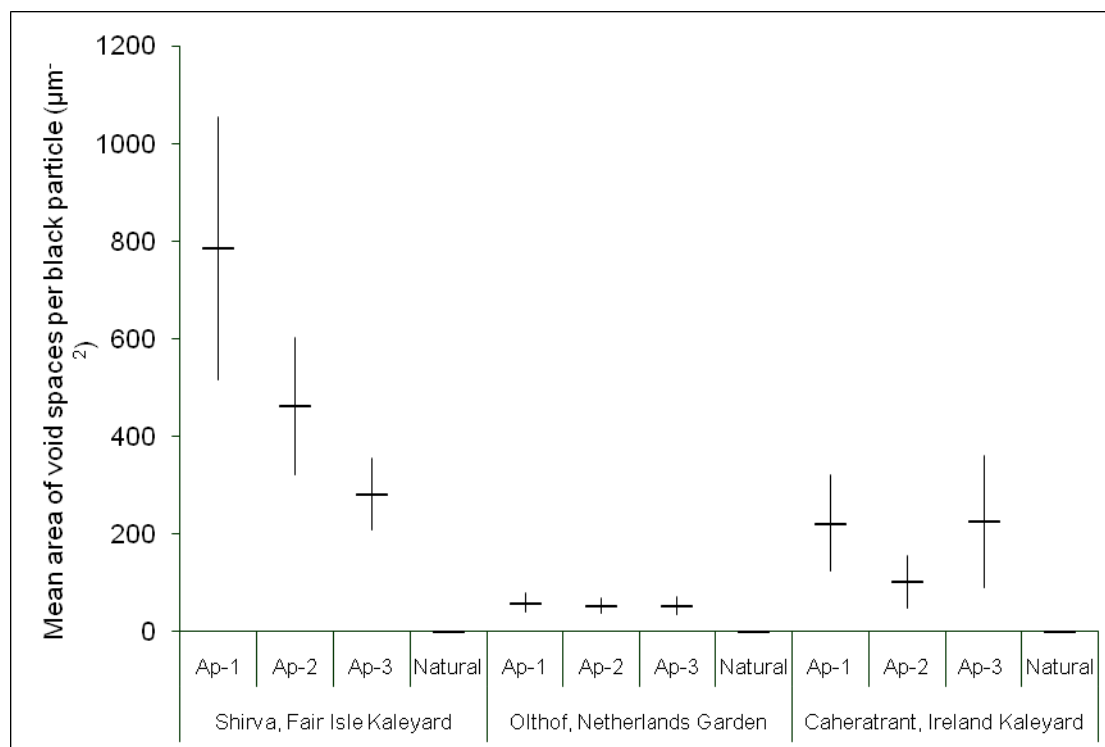


Figure 147, Mean size (μm^2) of void space within black particles in kaleyard and garden areas from Fair Isle, the Netherlands and Ireland identified by image analysis

At Caheratrant (Fig 146 and 147) the black particles in the Ap-1 horizon have the highest density of void spaces ($16.79 \pm 1.40 \mu\text{m}^2/225\text{mm}^{-2}$) and a lower density in the Ap-2 and Ap-3 horizons ($4.34 \pm 0.41 \mu\text{m}^2/225\text{mm}^{-2}$ to $4.84 \pm 0.73 \mu\text{m}^2/225\text{mm}^{-2}$) but the mean sizes of the voids are much more variable with similar results in the Ap-1 and Ap-3 horizons ($221 \pm 99 \mu\text{m}^2$ and $225 \pm 135 \mu\text{m}^2$) but smaller void space in the Ap-2 horizon $102 \pm 54 \mu\text{m}^2$ suggesting considerable mixing between the context and organic breakdown.

6.7.5 DENSITY AND SIZE OF VOID SPACES IN BLACK PARTICLES IN INFELD AND INNER ARABLE SOILS

The mean density of void spaces from the infield and inner arable areas (Fig 148) decreases with depth at Shirva and Caheratrant but at Olthof there is a very small increase, however, there is considerable variation in the size of those voids (Fig 149). At Shirva the density of void space in the black inclusions is between $13.17 \pm 1.43 \mu\text{m}^2/225\text{mm}^{-2}$ in the Ap-1 horizon and $4.90 \pm 0.25 \mu\text{m}^2/225\text{mm}^{-2}$ in the Ap-3 horizon but there is a distinctive increase in average size with depth from $129 \pm 39 \mu\text{m}^2$ to $458 \pm 151 \mu\text{m}^2$ indicating either an increase in organic inclusions within the soil horizons, or an increase in biological and chemical degradation. In Ireland the density of void spaces within black particles decreases from $10.48 \pm 1.82 \mu\text{m}^2/225\text{mm}^{-2}$ to $3.84 \pm 0.35 \mu\text{m}^2/225\text{mm}^{-2}$ and the size decreases with depth from $102 \pm 29 \mu\text{m}^2$ to $41 \pm 16 \mu\text{m}^2$ suggesting an overall decrease of organic inclusions. As seen in other landuse areas the plaggen soils at Olthof contain the lowest densities of internal voids and overall they are much smaller than from the other sites. The voids identified in the inner arable size increase from $2.72 \pm 0.39 \mu\text{m}^2/225\text{mm}^{-2}$ (Ap-1) to $5.42 \pm 0.48 \mu\text{m}^2/225\text{mm}^{-2}$ (Ap-3) but the size of those spaces vary very little from the black to the brown plaggen soil ($59 \pm 15 \mu\text{m}^2$ to $54 \pm 9 \mu\text{m}^2$) suggesting similar levels of addition and degradation of black carbonised particles during the development of the anthropogenic soils.

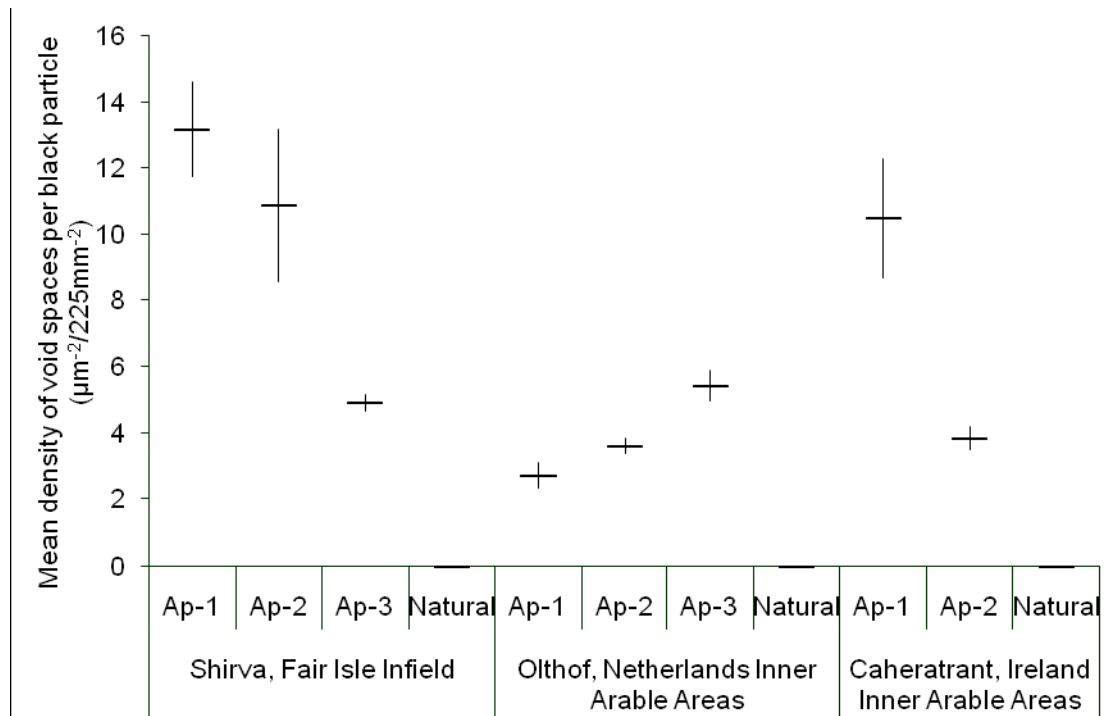


Figure 148, Mean density ($\mu\text{m}^2/225\text{mm}^2$) of void space within black particles from infield and inner arable areas from Fair Isle, the Netherlands and Ireland identified by image analysis

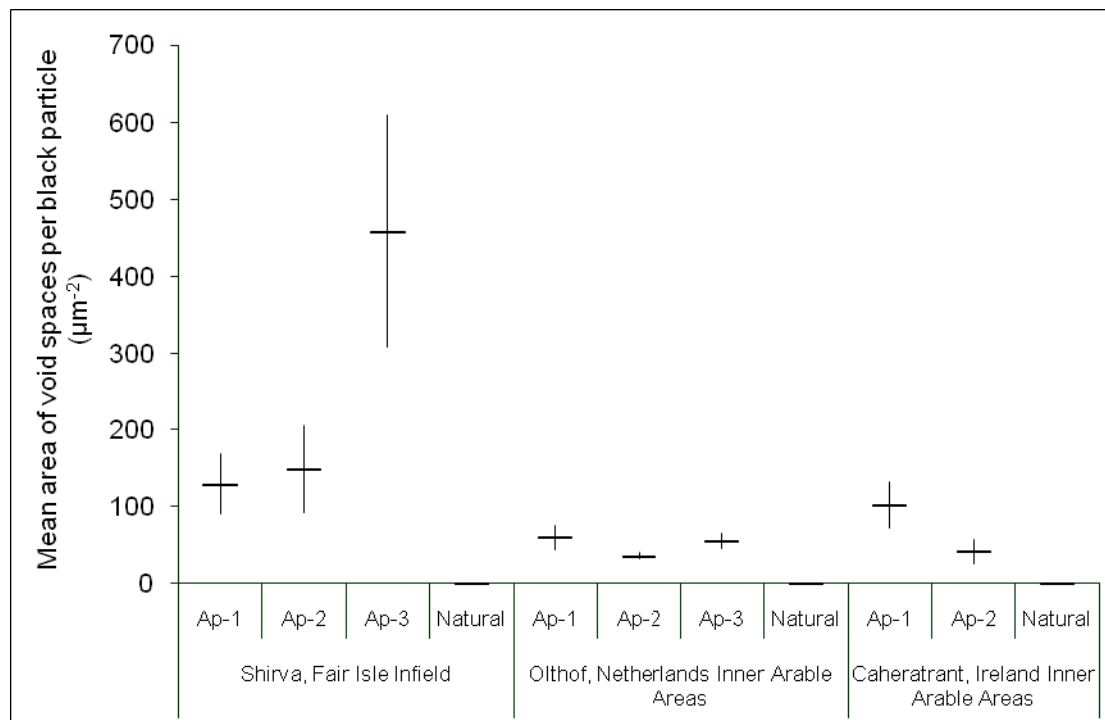


Figure 149, Mean size (μm^2) of void space within black particles from infield and inner arable areas from Fair Isle, the Netherlands and Ireland identified by image analysis

6.7.6 DENSITY AND SIZE OF VOID SPACES IN BLACK PARTICLES IN THE OUTFIELD AND OUTER ARABLE SOILS

The presence of the buried H horizon in the Shirva outfield explains the huge increase in the density and size of void spaces in black particles (Figs 150 and 151). The density of voids increases from $5.84 \pm 0.47 \mu\text{m}^2/225\text{mm}^{-2}$ to $7.91 \pm 0.44 \mu\text{m}^2/225\text{mm}^{-2}$ between the Ap-1 to Ap-3 horizons and the mean size increases from $59 \pm 10 \mu\text{m}^2$ to $301 \pm 129 \mu\text{m}^2$ possibly as a result of anthropogenic input and the mixing of the buried H horizon into the development of the arable soil horizons.

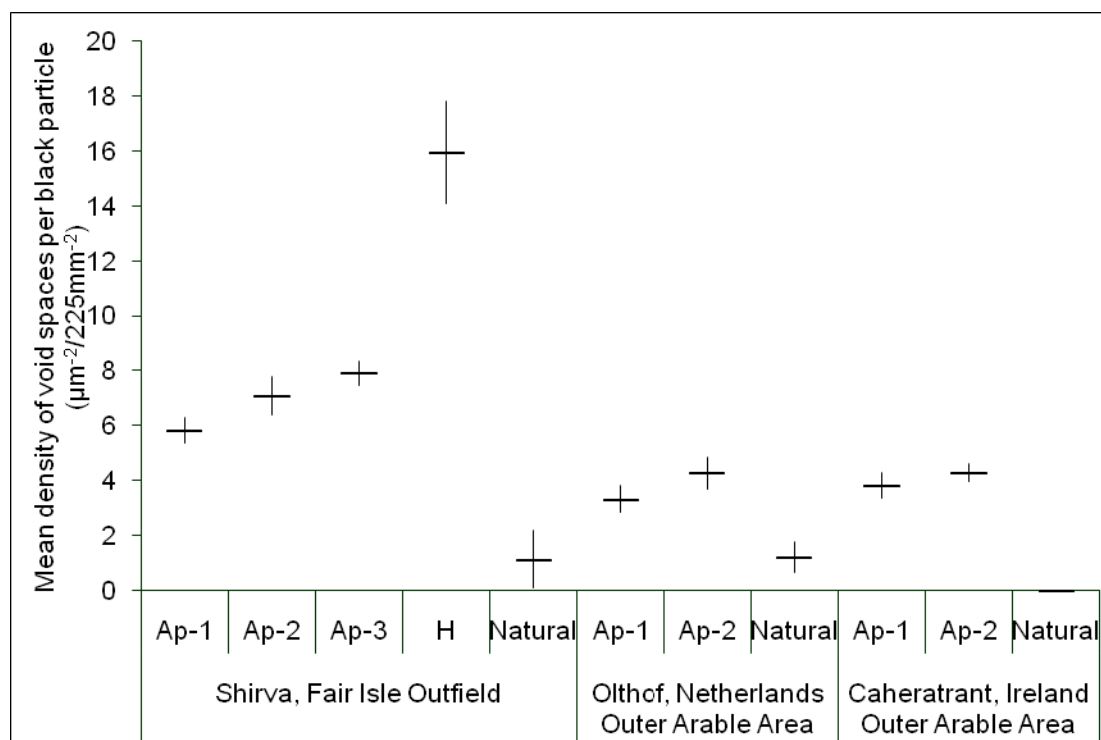


Figure 150, Mean density ($\mu\text{m}^2/225\text{mm}^{-2}$) of void space within black particles from outfield and outer arable areas from Fair Isle, the Netherlands and Ireland identified by image analysis

Evidence for mixing is also clear in the H horizon itself which has a mean void density of $15.95 \pm 1.88 \mu\text{m}^2/225\text{mm}^{-2}$ and mean void size of $2811 \pm 433 \mu\text{m}^2$. This complements the interpretation of high organic contents in this landuse area and mirrors the zone count and micromorphological evidence (this chapter, sections 6.2 and 6.6) and loss on ignition results

(chapter 5, section 5.3). In the outer arable areas at both Olthof and Caheratrant the density and size of voids are far smaller than at Fair Isle possibly indicating a much higher number of black amorphous particles and a greater level of post burial breakdown.

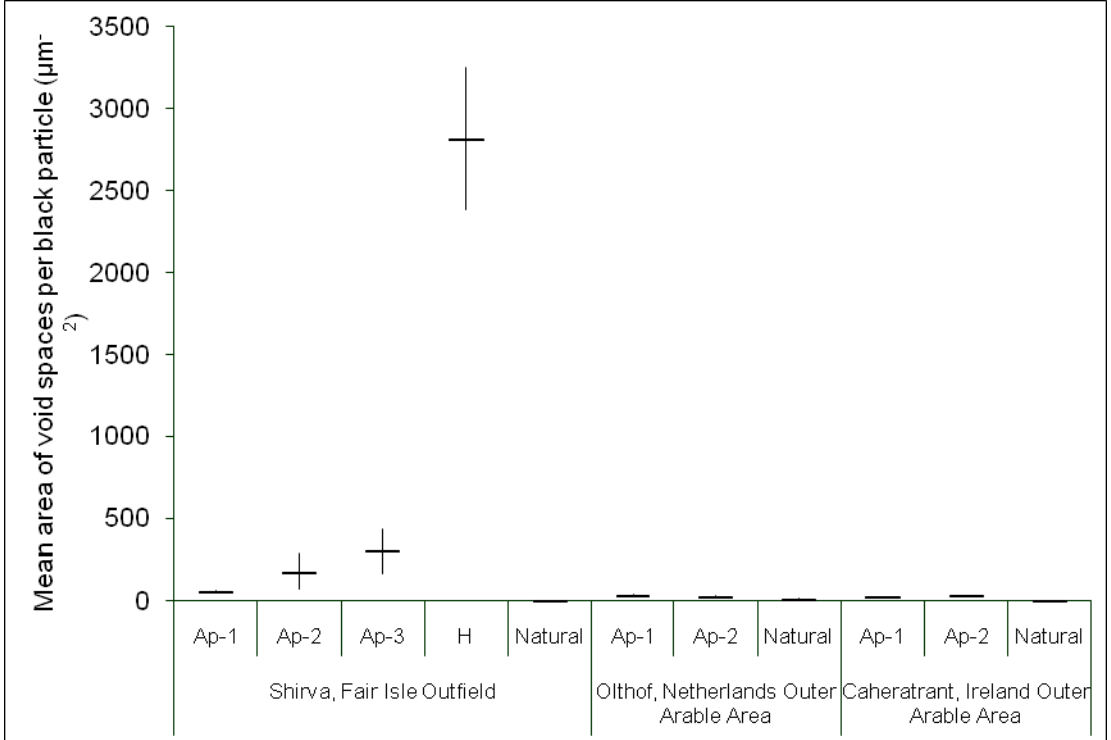


Figure 151, Mean size (µm²) of void space within black particles from outfield and outer arable areas from Fair Isle, the Netherlands and Ireland identified by image analysis

6.8 A COMPARISON OF BLACK PARTICLE DENSITY RESULTS AS IDENTIFIED BY ZONE COUNTING AND IMAGE ANALYSIS

The results of the density of black particles identified by zone counting and image analysis are illustrated in figures 152 to 154. At Shirva the percentage density of black particles identified by zone counting decreases down profile from 42 – 24% indicating a gradual reduction in inclusions associated with anthropogenic amendment to the soils. By comparison the image analysis results range from 26 – 43% with the highest percentage in the Ap-2 horizon. This demonstrates that there is considerable variation in the black particles throughout the soil horizons.

At Olthof the zone count results illustrate a very close mean distribution (16 – 19%) in the black and brown plaggen soils. However, the deviation of the results is much higher than at the other two sites (5 – 35%) and suggests that the inclusions are very small with little to no internal structure. The image analysis results illustrate a more distinct decrease down profile from 54 – 10% suggesting more addition of black inclusions in the black and brown plaggen soils. The zone count results from Caheratrant decrease down profile from 35 – 24% and like the results from Olthof there is a fairly high variation in the range of results indicating a range of possible inclusions. The image analysis results in the Ap horizons demonstrate less variation (30 – 37%) than the zone counting results and this suggests that there may be more smaller black inclusions possibly associated with the addition of calcareous sand.

In the infield area (Fig 153) at Shirva the zone counting results decrease with depth from 26 – 35% with similar variations in values and <3% in the natural. The results also show a higher density of black particles in the Ap-4 horizon which has been shown to contain a higher loss on ignition and multi-element component suggesting more anthropogenic addition in the past. The image analysis results also indicate a variation in the Ap-4 horizon (46%) and between 10 – 21% in the Ap-1 to Ap-3 horizons. At Olthof there is a sharp reduction in density with depth with 30 – 50% in the black plaggen soil and 20% in the brown plaggen soil but there is a large variation in results suggesting a range of sizes. The image analysis results illustrate a lower percentage density in the black plaggen soil horizons (35 – 37%) and in the brown plaggen soil (25%) also indicating a large percentage of very small inclusions. At Caheratrant the zone counting in the Ap-1 and Ap-2 horizons show a very similar pattern to the results from Shirva. The results range from 34 – 35% but the image analysis results are considerably higher (48 – 52%) indicating the majority of black particles are either heavily decomposed fragments or possibly mineral inclusions.

In the outer arable areas (Fig 154) the density of black particles increases with depth from 21 – 25% with a very low percent in the natural soil. Black amorphous particles were identified by the zone counting in each of the horizons but the image analysis results show a similar decrease down profile towards the H horizon.

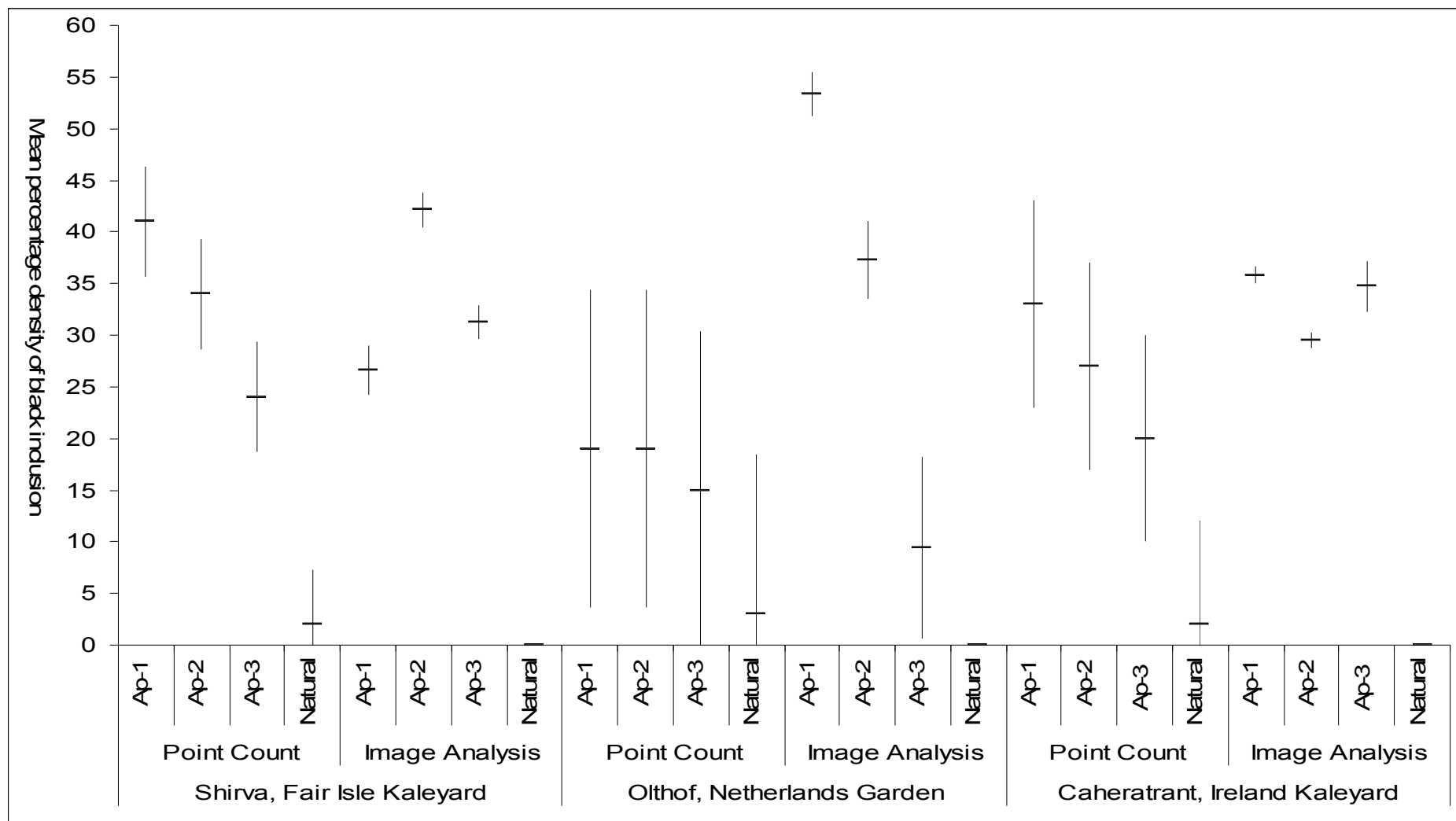


Figure 152, Percentage density of black particles identified by zone counting and image analysis in kaleyad and garden areas

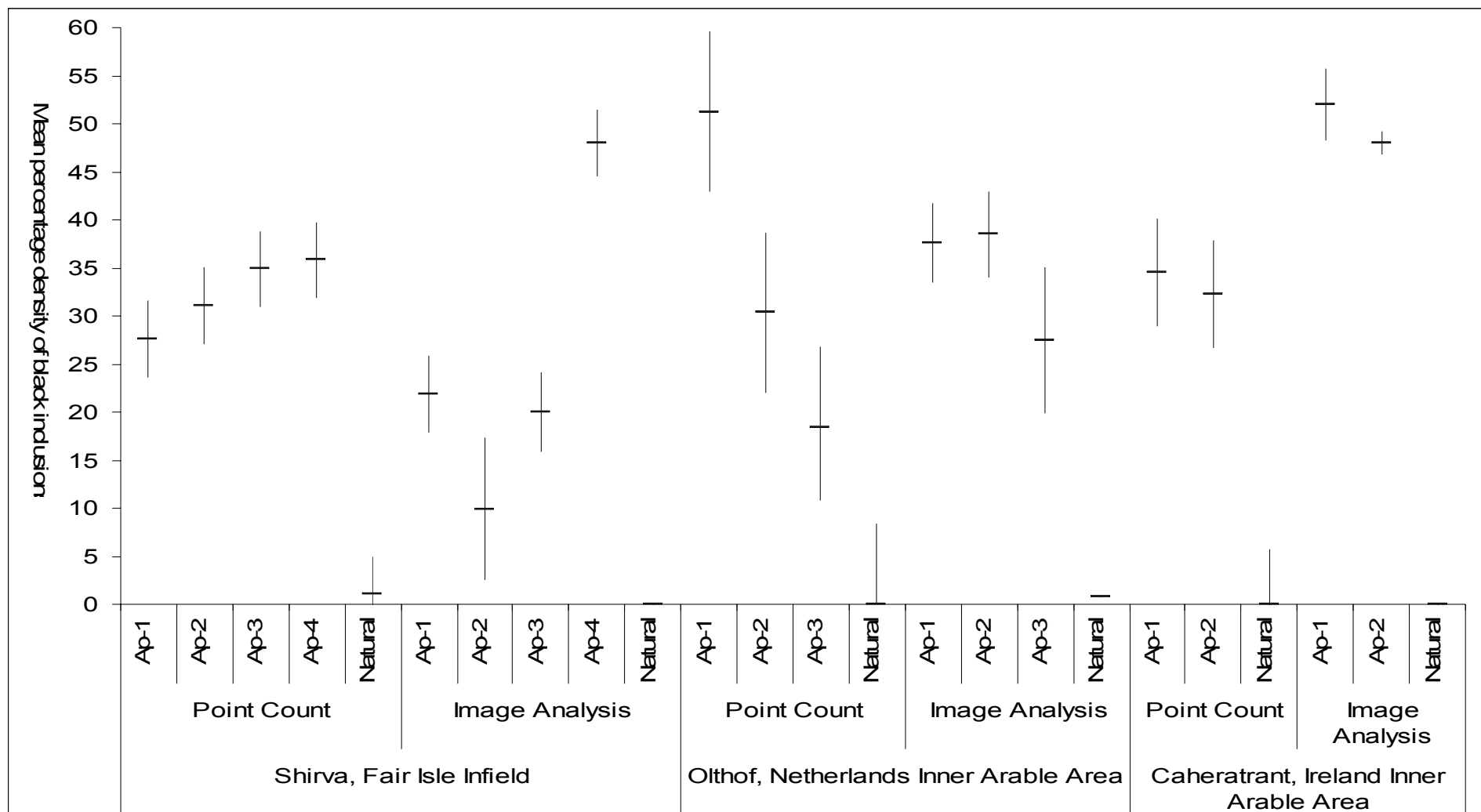


Figure 153, Percentage density of black particles identified by zone counting and image analysis in infield and inner arable areas

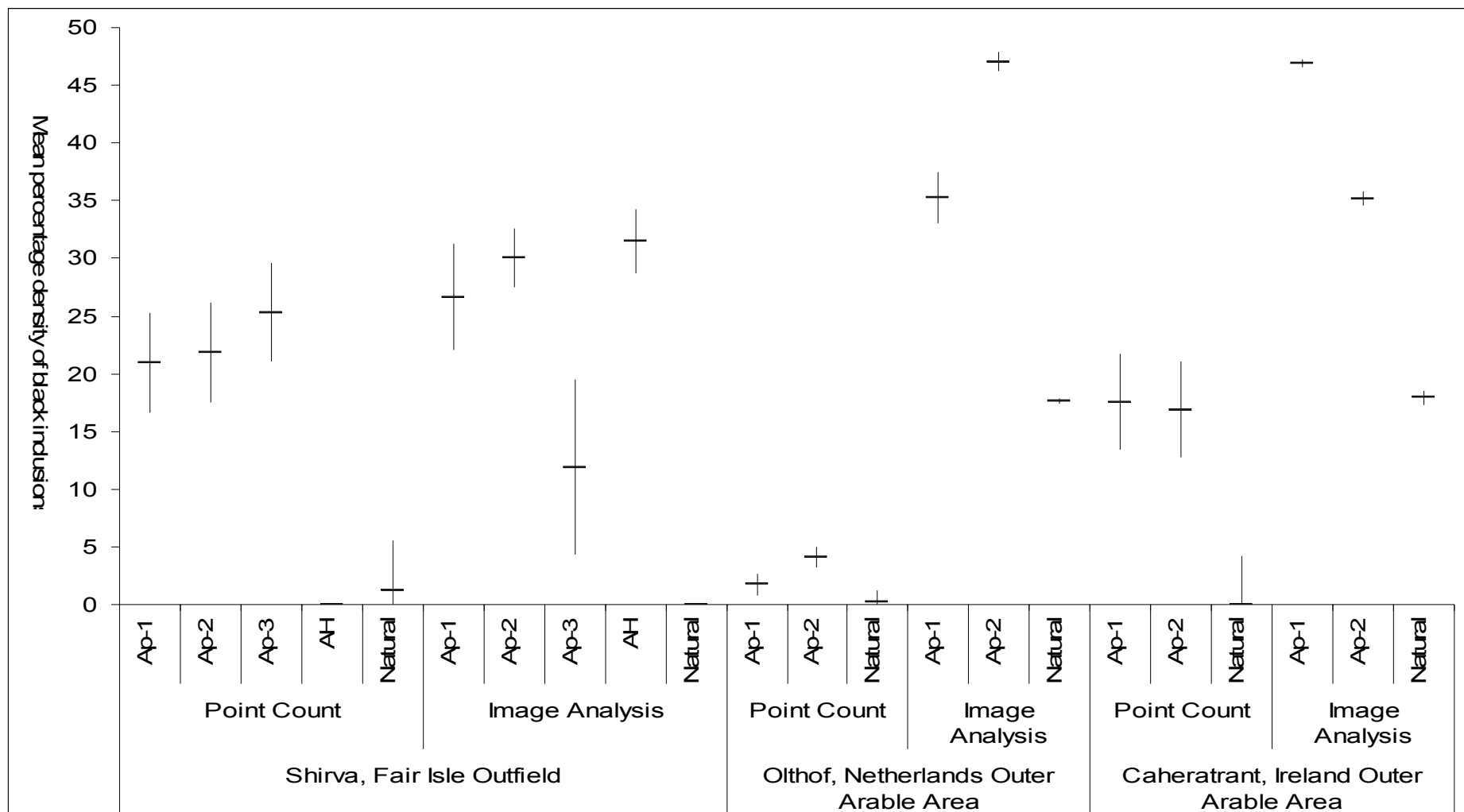


Figure 154, Percentage density of black particles identified by zone counting and image analysis in outfield and outer arable areas

The analysis of the H horizon by zone counting and image analysis has highlighted the importance of using both techniques in identifying anthropogenic inclusions in soil horizons. The zone count results did not identify any black carbonised or black amorphous inclusions because the horizon was dominated by organic inclusions. The image analysis results, by contrast, identified a density of over 30% because of the very dark brown to black colour of the humified peat fragments. At Olthof there were clear differences between the results from the zone counting and image analysis. The zone counting results indicate a small density of black particles in both the black and brown plaggen soils (2 – 4%) The image analysis results of the same horizons indicate between 34 – 46% density possibly because many of the inclusions are extremely small and below the threshold of identification used in the zone counting.

The image analysis may also be identifying small mineral and heavily rubified inclusions as black particles and so indicating an erroneous density. Despite the differences in density both sets of results clearly show an increase with depth possibly as a result of increased manuring or because of the breakdown of inclusions added to the soil horizons by post burial processes. At Caheratrant there is also a large variation in the results. The zone count results in the Ap-1 and Ap-2 horizons (19 – 20%) are considerably higher than the natural soils, but like the Dutch soils, the image analysis results indicate higher densities (36 – 46%). Again this suggests that the image analysis is identifying black mineral or rubified organic particles or extremely weathered black carbonised particles, indicating much higher input from settlement centre than the loss on ignition, multi-element or fieldwork analysis has suggested. It is highly likely that because of the variation in the results from the zone counting and image analysis that in the outfield and outer arable areas the black inclusions are not anthropogenic inclusions and therefore cannot be used to indicate human amendment to soils.

6.9 A DISCUSSION OF THE ZONE COUNT AND IMAGE ANALYSIS RESULTS FROM THE THREE FARMS

The use of zone counting and micromorphology to identify and quantify a range of organic and inorganic manuring inclusions are still relatively new forms of interpreting anthropogenic additions to soils but the results presented here for the site of Olthof and Caheratrant represent the first detailed analysis using these techniques. At Shirva the results can be compared to the image analysis results from Papa Stour, Shetland (Bryant and Davidson, 1996; Adderley, et al., 2006). Both studies measured the mean size and area of opaque minerals along with the area, mean size and number of large voids. Bryant and Davidson's results showed that the black, opaque minerals were consistent with the micromorphological description of the organic material and inclusions. Bryant and Davidson concluded that the mean size and shape of the opaque minerals indicated the relative amount, size and distribution of large, macro carbonised particles. This has also been determined at Shirva, Olthof and Caheratrant, however, the majority of black amorphous and carbonised inclusions are extremely small and results can be underestimated unless used alongside zone counting. Spatially Bryant and Davidson's results mirror those found at each of the sites analysed in this project. The kaleyard and garden soil sequences contain the largest density and size of opaque minerals with a decrease away from the settlement centre, however, there appears to be a completely inverse relationship between the depth of soils in the field and the quantity of black amorphous and carbonised inclusions. The shallow arable soils of Shirva, Busta and Leogh kaleyards (chapter 2, section 2.6 and 2.7) contain the largest area and size of black inclusions (chapter 6, section 6.6.1 and 6.6.3) and this relationship is also present in the zone counting results (chapter 6, section 6.8.1 to 6.8.3). At Olthof the zone count analysis illustrated a very different manuring regime to the other sites (section 6.6.1 to 6.6.3) which has resulted in considerably deeper plaggen soils (chapter 3, section 3.5 and 3.6) but also more micromorphological evidence of post burial mixing and decomposition by biological action and ploughing leading to smaller black amorphous inclusions (chapter 6, section 6.3.3). Inverse relationships with image analysis results were also determined on

Papa Stour, Shetland (Adderley, et al., 2006). At the isolated farm of Hamna Voe the shallow arable soils contained larger concentrations of uncarbonised turf than at the larger farms of Bragasetter and The Biggins. The results may be due to better preservation but it appears that Hamna Voe and Bragasetter was putting more emphasis on the addition of turf manure and less on fuel residue (Adderley, et al., 2006). This contradicts the relationship on Fair Isle where there appears to be a lack of organic manuring to deliberately raise the soil profile and an emphasis on the input of uncarbonised and carbonised peat inclusions. At each of Adderley's farms there is a gradual reduction in the area of carbonised organic material from the farm to the grazing land and this pattern is repeated at each of the sample sites in this project but overall the mean area of the inclusions is considerably larger possibly due to the larger sample size. The density and size of void spaces identified by image analysis in the black amorphous and carbonised particles complements the hypothesis that most of the black inclusions are of organic origins and mirrors the zone count results (chapter 6, section 6.6.1 to 6.6.3) and past image analysis work (Bryant and Davidson, 1996; Adderley, 2006). The results of micromorphology, zone counting and image analysis have also made it abundantly clear that many of the black amorphous inclusions are extremely small and without any internal structure and therefore need to be identified and provenanced using their elemental compositions.

7 ELEMENTAL ANALYSIS OF BLACK CARBONISED PARTICLES

7.1 INTRODUCTION

The broad aim of this chapter is to investigate further the elemental composition of the black carbon particles and the black amorphous inclusions in a range of arable soils from the three farm sites. This enables further classification of the variety of black inclusions identified in the micromorphology, zone counting and image analysis (chapter 6) and will aid interpretation about material inputs and post depositional processes acting upon these inclusions.

Previous analysis of the amended and anthropogenic soils within the gardens and kaleyards of the three sites has shown clearly that the areas closest to the farm centres have the highest density and area of black carbonised and amorphous inclusions (chapter 6, sections 6.7 and 6.8). The elemental analyses of the black particles was conducted in order to answer three main aims; first, can black amorphous particles be identified and categorised based upon the ratio of C:O? Secondly, do the O:C ratios of black carbonised particles illustrate possible source materials for the organic components in the soils? Lastly, do the black carbonised particles contain distinctive concentrations of elemental loadings associated with settlement/agriculture/industry and if so how do the results compare and contrast to the total multi-elemental results gathered in chapter 5?

In order to accomplish this, scanning electron microscopy (SEM-EDS) was utilised to complement the bulk soil analysis, discussed in chapter 5, by allowing comparative analysis of the elements present in the soil and the black particles and so indicate possible reservoirs with distinctive signatures of phosphorus, sodium, potassium, calcium, associated with organic additions and contaminant elements lead, strontium, barium, zinc, copper, arsenic, sulphur and chlorine. The results from the SEM-EDS analysis would also complement the micromorphological analysis (chapter 6) to aid the identification of black amorphous and black carbonised particles which had not been identified using optical microscopy, zone counting and image analysis methodologies. Alongside the black carbonised and black

amorphous particles SEM-EDS analysis would also be conducted upon mineral and organic inclusions, the soil groundmass and the micromorphological slide in order to accurately compare and contrast the range of elements found and to aid the provenance for the inclusions. The sampling strategy and methodology for the chapter is detailed in chapter 1, section 1.13 but this chapter is split into several components; The SEM-EDS results are discussed in section (7.2) and these are broken down into the quantification of black amorphous and carbonised particles (section 7.2.1), the percentage carbon content in each landuse area, across the three farm sites (sections 7.2.2) and the oxygen to carbon ratio analysis (section 7.2.3). Section 7.2.4 describes the elemental concentrations from the black carbonised particles at each landuse area of each farm and this is followed by a discussion of the elemental results (section 7.3) and an overall discussion of elemental concentrations from bulk soil analysis and black carbonised particles (section 7.4). (Raw data in displayed in appendix 17).

7.2 SCANNING ELECTRON MICROSCOPY RESULTS

7.2.1 BLACK CARBONISED PARTICLES AND BLACK AMORPHOUS PARTICLES

A key research question was the distinction between black carbonised particles and black amorphous fragments. The problem was partially resolved using a combination of detailed micromorphological description (chapter 6, sections 6.4 to 6.6) and quantification of internal void space (chapter 6, section 6.8.1), however, the determination of the elemental composition of the inclusions in question could aid the identification of the particles, complement the earlier analysis work and aid the interpretations of the development of amended soils (chapter 5).

The carbon data from all 1254 black inclusions which were analysed were tabulised and for each site differentiate between carbonised organics and black amorphous fragments (Table 28). The results show that at each site the vast majority of fragments tested contain carbon concentrations over 40% and are therefore are likely to be fragments of carbonised particles. At the three Fair Isle sites the number of carbonised particles ranges from 98.2-

99.4% with slightly less at Olthof (89.7%) and 83.5% at Caheratrant. At all the sites there were very few positively identified black amorphous particles and these may be mineral fragments

Site		Total No of Black particles analysed	No & % Black Carbonised Particles	No & % Black Amorphous Particles
Fair Isle	Shirva	371	369 (99.46)	2 (0.54)
	Busta	357	351 (98.31)	6 (1.69)
	Leogh	284	279 (98.23)	5 (1.77)
Netherlands	Olthof	78	70 (89.74)	8 (10.26)
Ireland	Caheratrant	164	137 (83.53)	27 (16.47)

Table 28, Number of black carbonised particles and black amorphous inclusions from kaleyard and garden areas at five farmsteads

7.2.2 CARBON CONCENTRATION RESULTS FROM THREE KALEYARDS ON FAIR ISLE

Carbon results from inclusions within the kaleyards of Fair Isle are illustrated in figures 155 to 157. At Shirva (Fig 155) the majority of BC particles contain between 60-90% carbon and there is a similarly high level of carbon in the organic fragments. This has led to similar carbon percentages in the organic groundmass of the amended soils in the kaleyard where the mineral inclusions contain less than 40% carbon. The mineral inclusions contain considerably lower carbon concentrations (10-30%) and the resin results were also clustered between 15-30%. At Busta (Fig 156) there is a similar pattern of carbon distribution between the soil components. The macro and micro black carbon particles contain between 65-95% carbon indicating an addition of burnt material into the soils. The organic groundmass inclusions also mirror the black carbonised results (50-80%) suggesting a high level of mixing and breakdown of carbon organic materials.

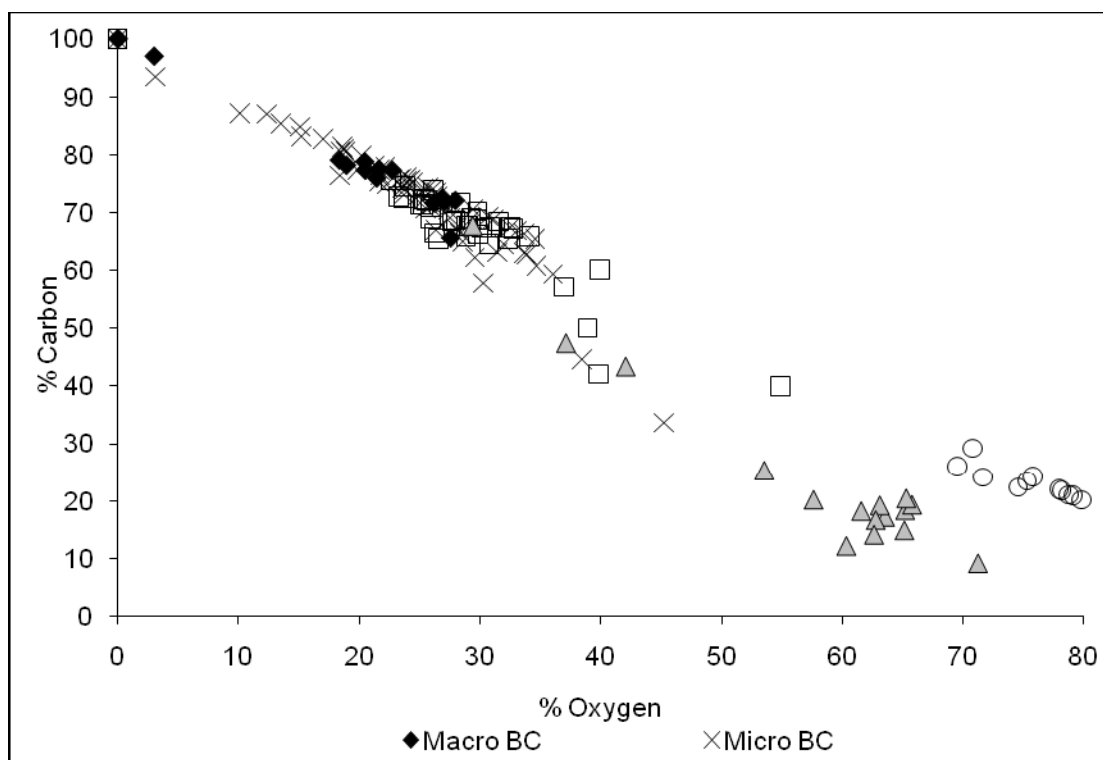


Figure 155, Carbon and oxygen percentages from various inclusions at Shirva kaleyard

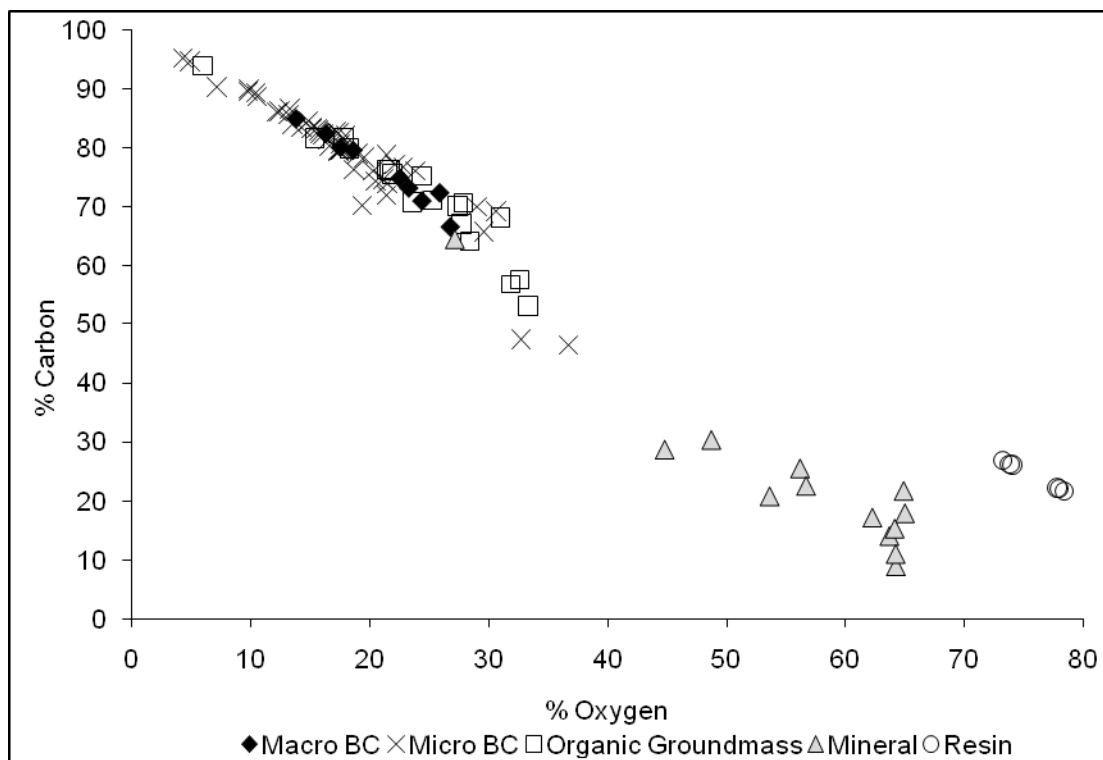


Figure 156, Carbon and oxygen percentages from various inclusions at Busta kaleyard

As expected the mineral fragments tested contains the lowest quantities of carbon (10-30%) and the resin results are also clustered between the 20-40% carbon.

The results from Leogh (Figure 157) are similar to the other kaleyard sites on Fair Isle. The majority of the carbonised particles have concentrations of carbon between 60-80%. This suggests that most of the black fragments are organic and probably derive from carbonised turf and peat fragments. The organic groundmass also has a similar carbon concentration illustrating a key relationship between the manuring material added and the overall carbon levels in the amended soils. There is no clear relationship between the black inclusions analysed and a mineral source as the carbon concentrations are considerably lower 5-20% and the resin of the slides ranges from 20-30% carbon.

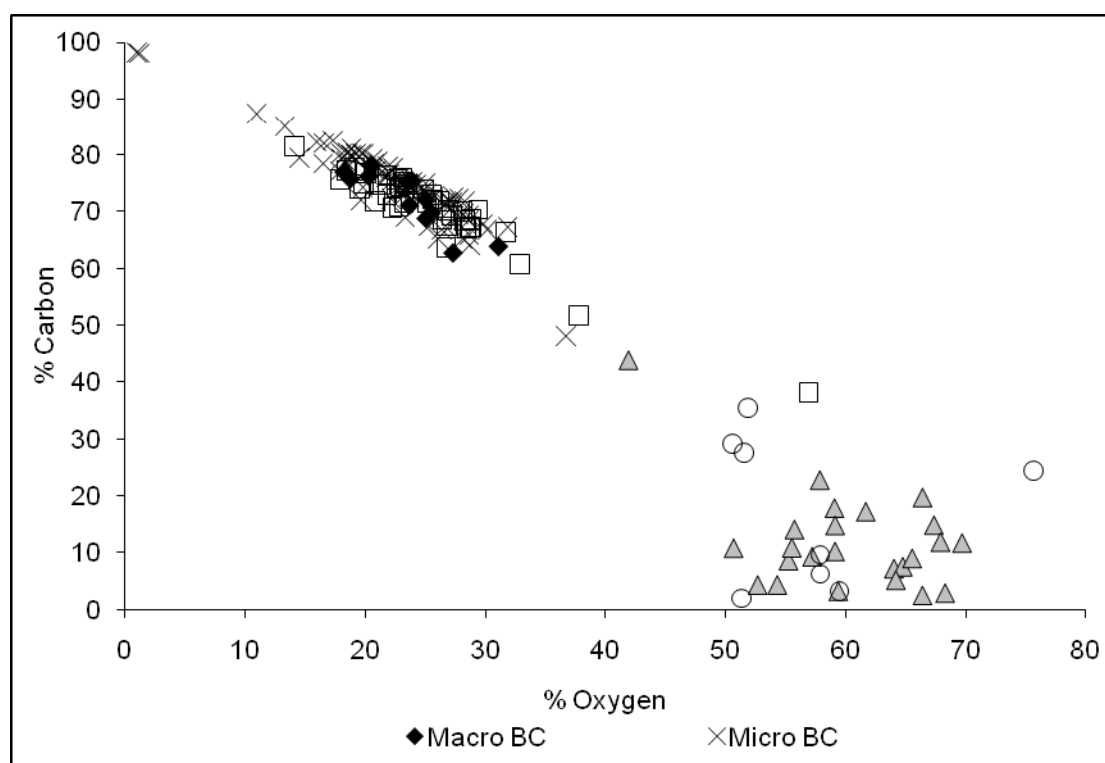


Figure 157, Carbon and oxygen percentages from various inclusions at Leogh kaleyard

7.2.3 CARBON CONCENTRATION RESULTS FROM OLT Hof GARDEN

The carbon concentrations from the inclusions within the anthropogenic soils from Olthof have a range of distinctive patterns (Fig 158). Overall the macro and micro carbonised particles contain a similar range of concentrations between 60-100% but there are also a number of particles with between 10-50% carbon and these may well equate to black mineragenic inclusions. The majority of the black particles contain a higher carbon concentration than the organic groundmass (20-40%) which indicates a ability to retain elemental concentrations. The distinctive range of results in the organic inclusions suggests considerable post burial degradation which mirrors the results from the zone counting (chapter 6, section 6.7.2) and image analysis (chapter 6, section 6.9). The mineral inclusions from Olthof contain between 5-20% carbon and the resin has an unusually large range from 20-60% carbon indicating slight differences in the chemistry of the slides.

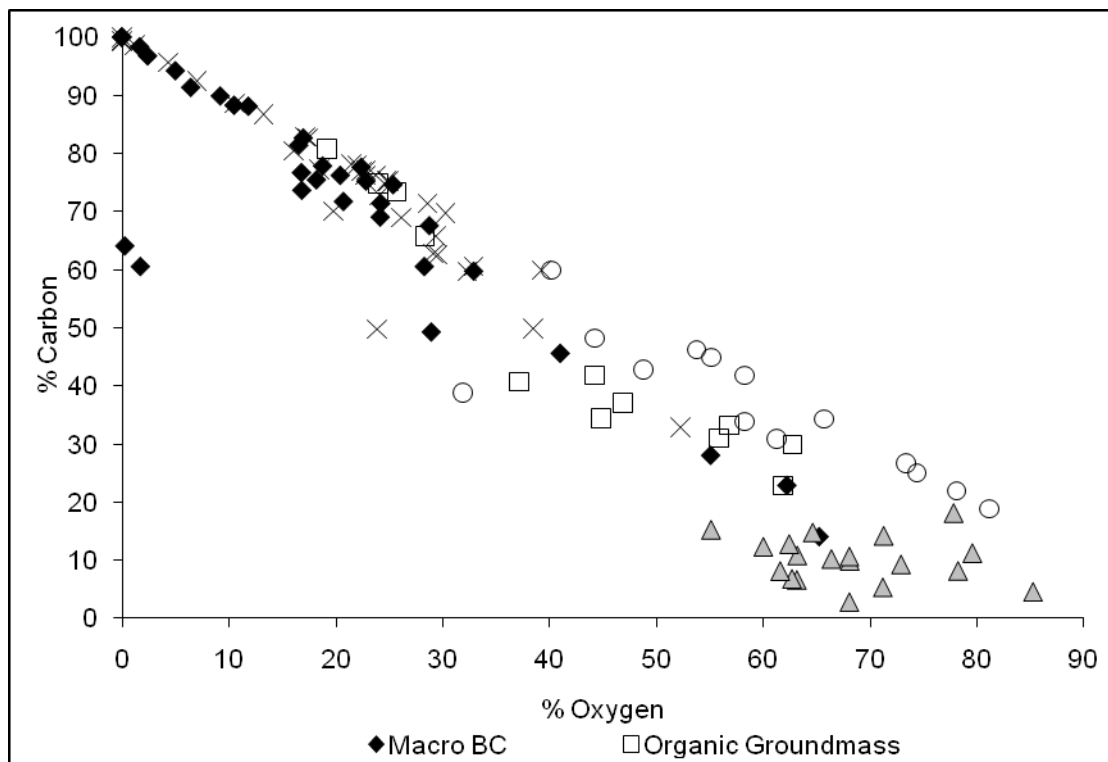


Figure 158, Carbon and oxygen percentages from various inclusions at Olthof garden

7.2.4 CARBON CONCENTRATION RESULTS FROM CAHERATRANT KALEYARD

The carbon concentration results from inclusions taken from Caheratrant kaleyard show a very similar pattern to the other sites (Fig 159). Once again the micro and macro BC particles contain between 60-80% carbon with two outliers between 80-100% carbon possibly from different manuring events. There is, however, slightly more variation between the black inclusions and the organic groundmass which suggests that burnt organic material was added less frequently than organic manure and sea-sand. The difference may also indicate a higher degree of post burial breakdown of organic material over time.

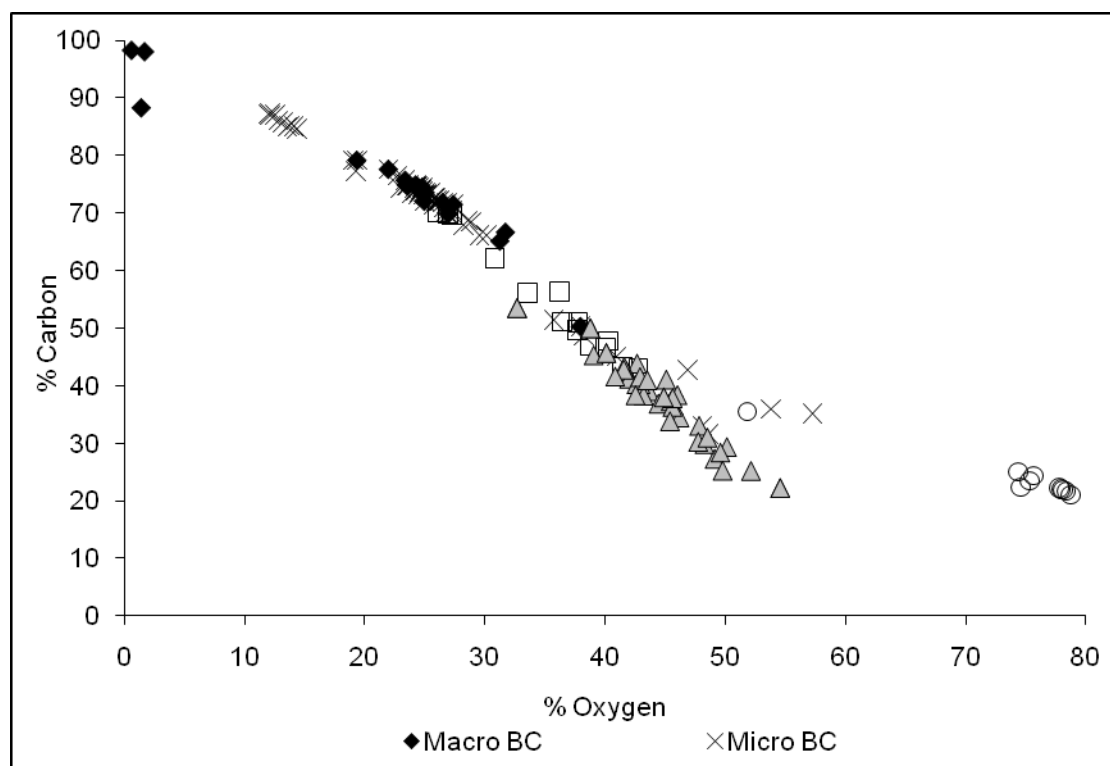


Figure 159, Carbon and oxygen percentages from various inclusions at Caheratrant kaleyard

The mineral results from Caheratrant are also unlike any from the other sites and range from 20-50% with considerable cross over with the organic groundmass results. It is already clearly understood that calcium carbonate beach sand was added to the Irish soils (chapter 5, sections ***) and this may

have increased the concentrations of carbon in the soils and the organic inclusions. As identified at the other sites the percentage carbon in the resin ranges from 20-30% and illustrates a distinctly uniform resin chemistry used in the production of the slides.

7.3 OXYGEN:CARBON RATIO RESULTS FROM FAIR ISLE, THE NETHERLANDS AND IRELAND

Figure 160 shows the results of the O:C ratio results for the analysed micro black carbonised particles. The majority of the data from the five sites occurs between 0.15-0.44% and suggests that the majority of the black inclusion analysed are carbonised organic fragments of peat and turf.

These results are directly comparable with the evidence from the micromorphology (chapter 6, section 6.3 to 6.5) and zone counting results (chapter 6, section 6.7). There are, however, outliers of values which suggest that other materials are present in the soils possibly as a result of anthropogenic addition. At Olthof there is a very high percentage between 0.00-0.09% which indicates the addition of wood charcoal. But there are also large quantities at Busta and Shirva, especially in the upper amended soil horizons. The presence of small charcoal particles is difficult to explain as there are very few trees on the island and the particles may derive from imported wood or charcoal brought to the island as fuel and then added to the garden with other manure material. There is also a peak of results between 0.10-0.14% (softwood carbonised particles) at Busta which received wood from outside the island for fuel and roofing material until the late 18th century (Fenton, 1978). Values for the O:C ratio over 0.45% have considerably fewer results and most likely represents the background non-black carbonaceous material and heavily decomposed organic fraction within the amended soils. At Caheratrant there is a fairly high percentage of charcoal and carbonised softwood but considerably higher amounts of burnt peat and turf inclusions mirroring the farms on Fair Isle.

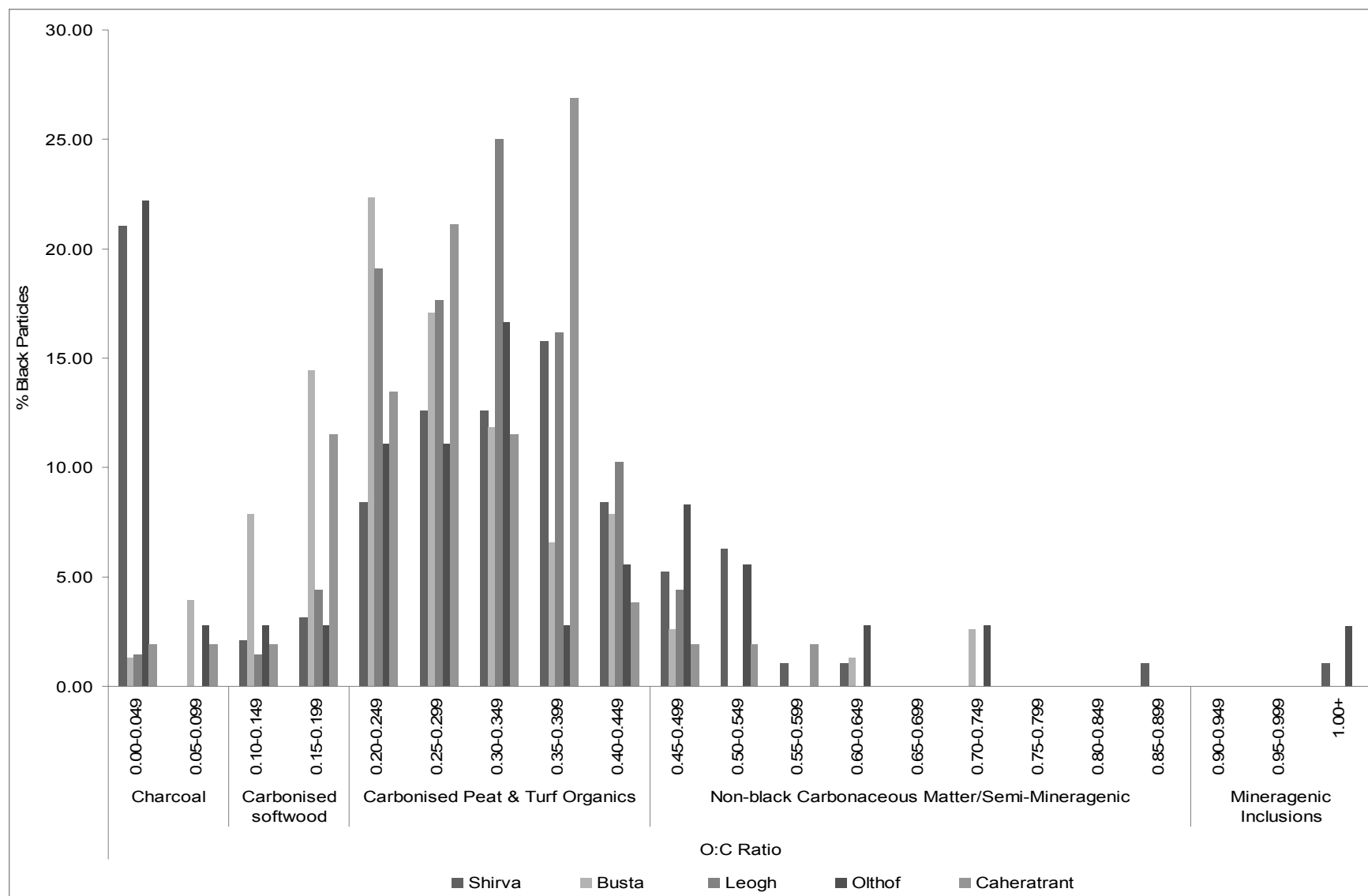


Figure 160, O:C ratio results from black carbonised particles <500µm² from the kaleyard and gardens of five farmsteads

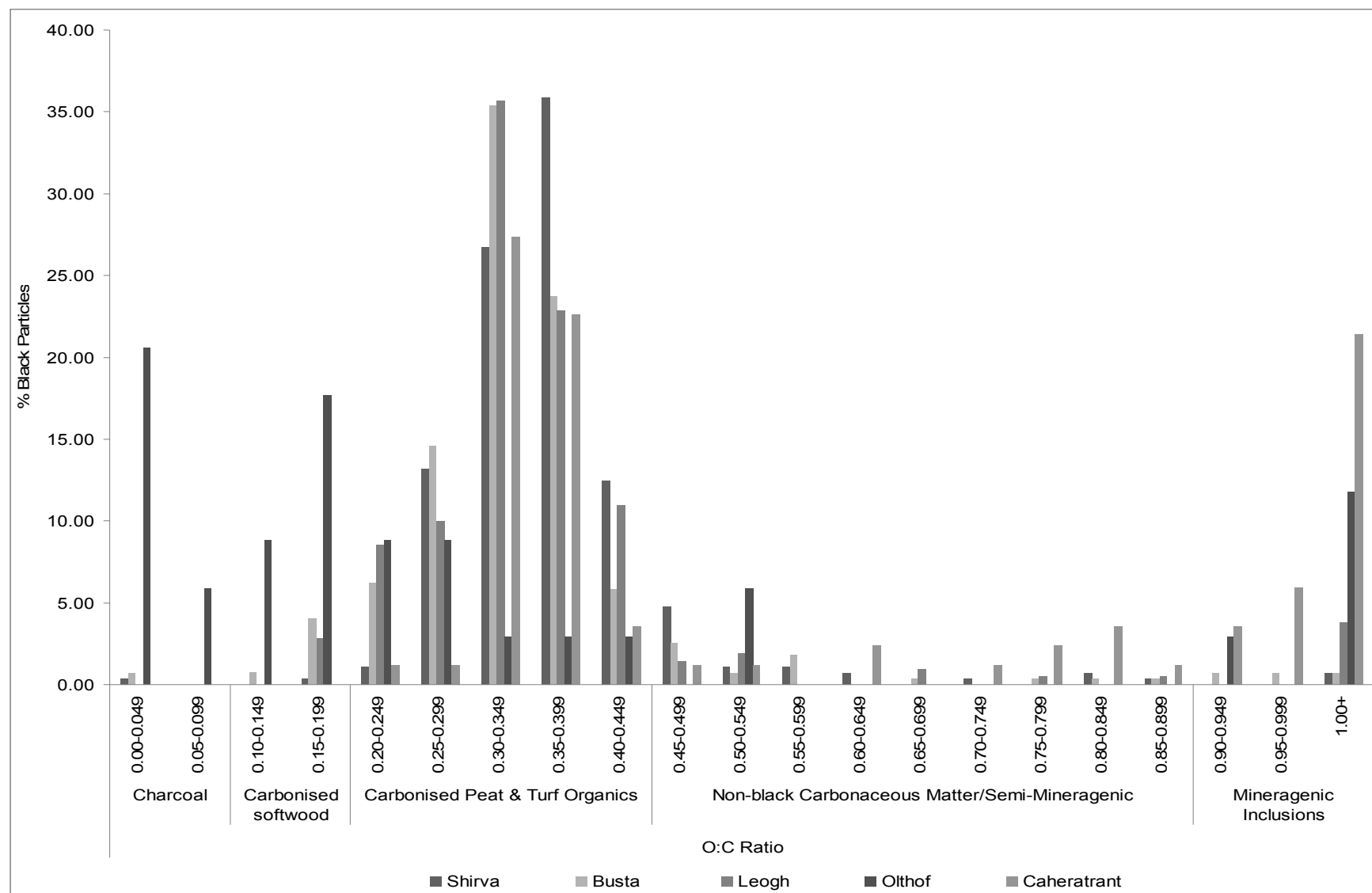


Figure 161, O:C ratio results from black carbonised particles +500 μm^2 from the kaleyard and garden areas of five farmsteads

Figure 161 shows the O:C ratios for the black carbonised particles above $500\mu\text{m}^2$. Like the micro black carbonised fraction the macro sized particles are clustered within the 0.15-0.44% range which is associated with carbonised peat and turf fragments. The sites on Fair Isle have a very similar pattern of distribution, mainly between 0.30-0.39% with smaller outliers either side. This indicates very similar material input, which coincide with the predominant use of carbonised and uncarbonised peat material. At Olthof there are very few results in the turf and peat category and significantly larger peaks between 0.00-0.19% suggesting a much higher input of charcoal and carbonised softwoods as seen in the micro black carbonised fraction. At Caheratrant there are a large number of results in the peat and turf category, but also a large number in the non-black carbonaceous matter probably from the addition of beach sand and plant material included from spade delling which is, in places, still practised.

7.4 ELEMENTAL CONCENTRATIONS FROM BLACK CARBONISED PARTICLES AND ORGANIC INCLUSIONS FROM FAIR ISLE, OLT Hof AND CAHERATRANT

7.4.1 ELEMENTAL CONCENTRATIONS FROM SHIRVA KALEYARD

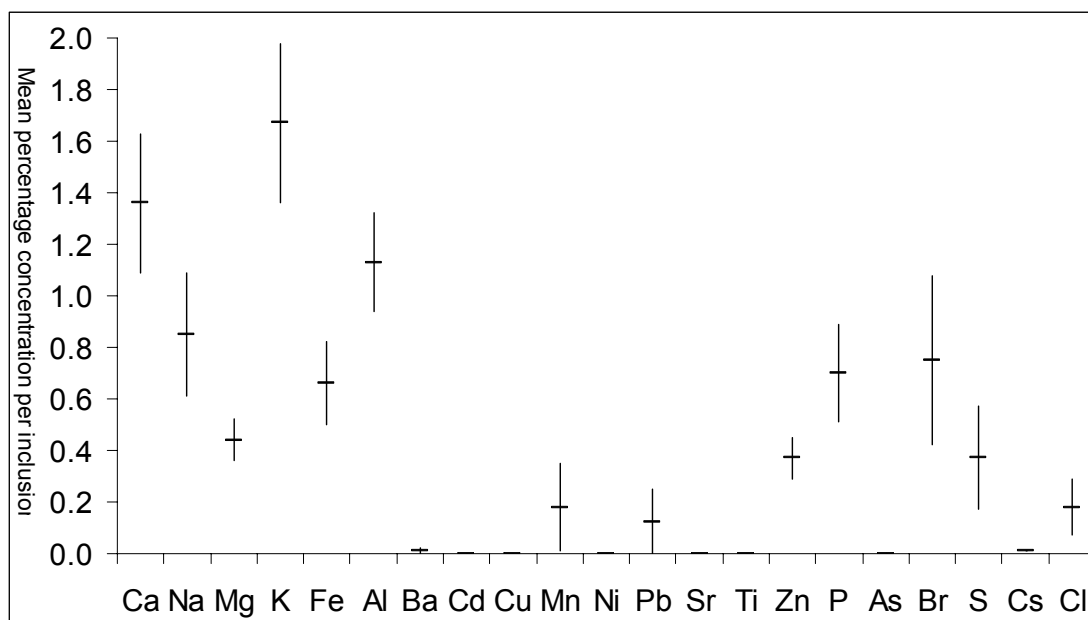


Figure 162, Mean percentage concentration of elements in black carbonised particles $>500\mu\text{m}^2$ from Shirva kaleyad (Error bars show 95% confidence interval of the mean)

Figures 162 and 163 illustrate the elemental concentrations within black carbonised particles in the kaleyard at Shirva. There is an overall higher elemental concentration in the larger carbonised particles suggesting better retention but both the small and large black carbonised particles contain a wide range of elements.

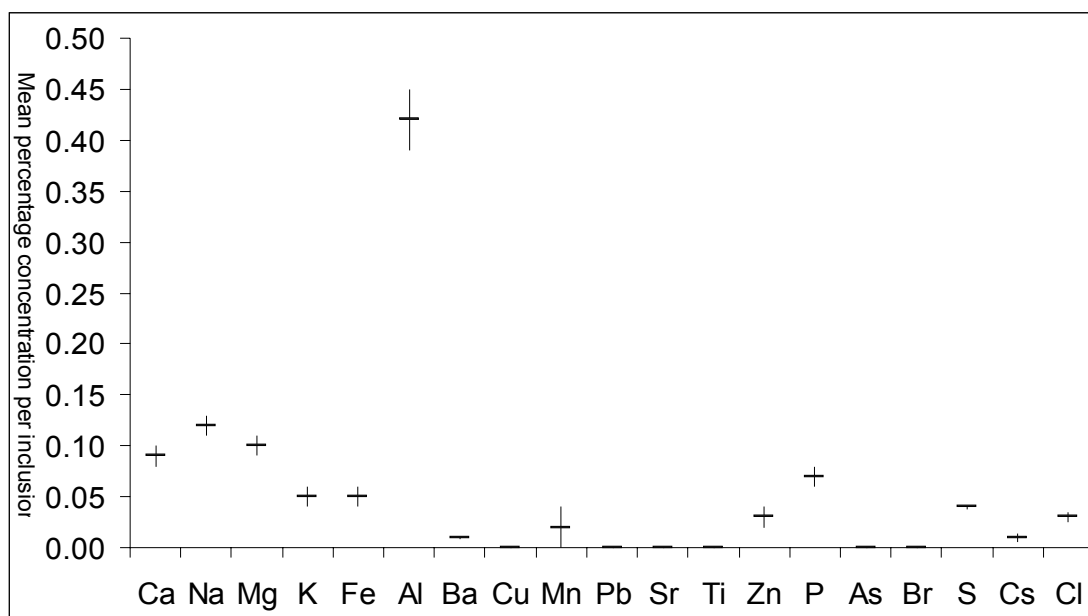


Figure 163, Mean percentage concentration of elements in black carbonised particles <500µm² from Shirva kaleyard (Error bars show 95% confidence interval of the mean)

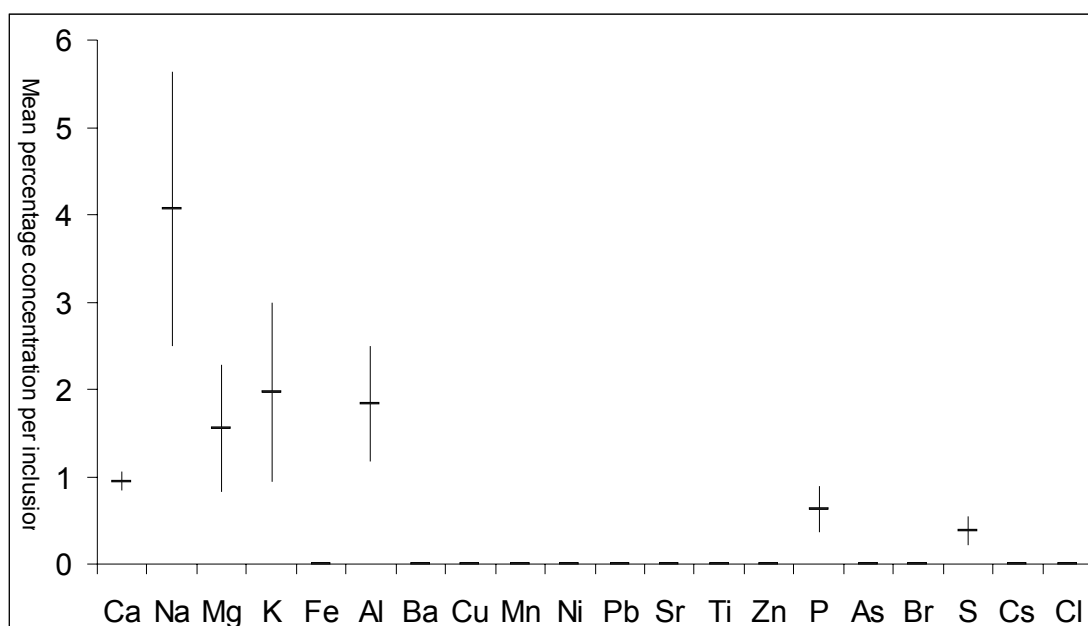


Figure 164, Mean percentage concentration of elements in organic inclusions from Shirva kaleyard (Error bars show 95% confidence interval of the mean)

In the larger black carbonised fragments (Fig 162) there is distinctive elemental evidence to suggest minimal mixing of carbonised inclusions with organic manure especially K ($1.68 \pm 0.28\%$), Ca ($1.35 \pm 0.23\%$), Al ($1.15 \pm 0.22\%$), P ($0.79 \pm 0.18\%$) along with smaller concentrations of Pb, Zn, S and Cl elements associated with hearth residues and small industrial areas within settlements.

The small black carbonised inclusions from Shirva kaleyard (Fig 163) contain 13 elements including Ca, Na, Mg, K, Fe, Ba, Mn, Zn, P, S, Cs and Cl all with results between 0.02 to 0.13% concentration except Al ($0.42 \pm 0.06\%$) which may be due to the elements frequent presence in the natural B horizons. The similar diversity of elements to the large black carbonised fragments suggest that the micro black carbonised particles were probably once part of the larger inclusions and the smaller elemental concentrations is due to an increase in post burial breakdown and leaching of elements. The lower results in the smaller black carbonised particles may also be due to the smaller surface areas upon which ionic binding could take place.

Overall the elemental concentrations within the black carbonised particles from Shirva is very low and indicates minimal industrial pollution but the elements present may well have been absorbed during the burning process in settlement hearths and when mixed with organic manures.

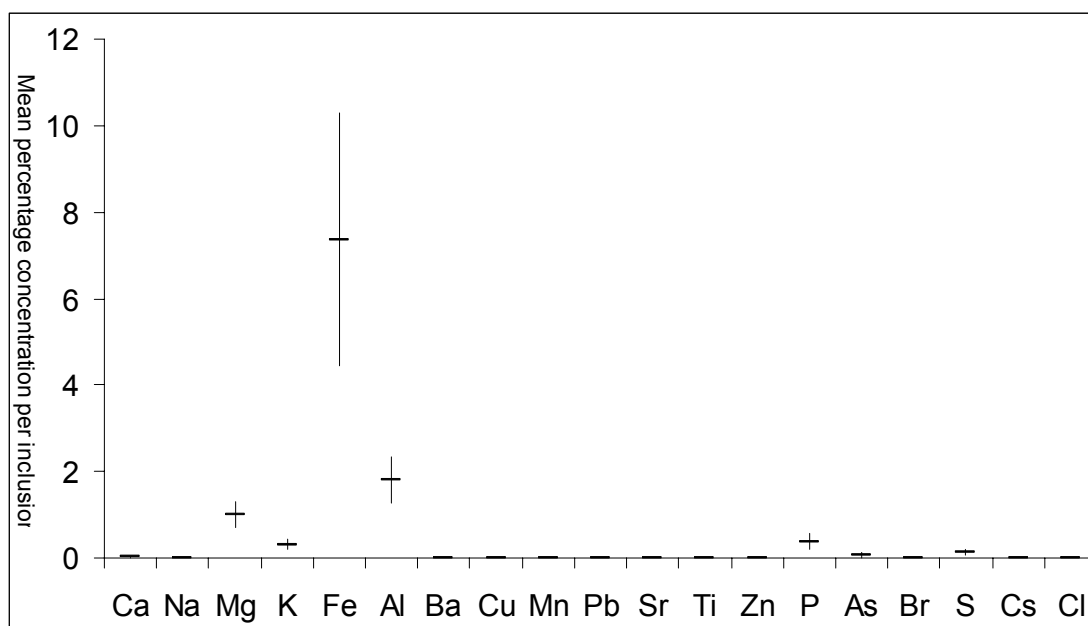


Figure 165, Mean percentage concentration of elements from soil groundmass samples from Shirva kaleyard (Error bars show 95% confidence interval of the mean)

Compared to the black carbonised particles the elemental results found within the organic inclusions (Fig 164) and the soil groundmass (Fig 165) are much less diverse. In the organic inclusions (Fig 164) seven elements were found alongside C, O and Si. Of these there are higher concentrations of Na ($4.05 \pm 1.42\%$), K ($1.93 \pm 0.85\%$), Al ($1.83 \pm 0.67\%$) and Mg ($1.58 \pm 0.66\%$) which occur commonly in peat and turf material but may also derive from atmospheric deposition. Overall there is very little evidence of the transfer of elements between the black carbonised particles and the organic inclusions but there is small concentrations of Ca ($0.99 \pm 0.15\%$), P ($0.58 \pm 0.29\%$) and S ($0.38 \pm 0.22\%$) which may derive from the kaleyard hortisols or more likely from natural sources. Elemental results from the amended soil groundmass (Fig 165) reveal very high Fe percentages ($7.37 \pm 2.92\%$) likely to derive from the natural soils, but there are also high levels of Mg ($1.00 \pm 0.30\%$), Al ($1.81 \pm 0.53\%$) and K ($0.31 \pm 0.11\%$) which could also derive from the natural soil or from the breakdown of organic and black carbonised particles which may also have added trace amounts of As ($0.07 \pm 0.06\%$) and S ($0.13 \pm 0.07\%$) to the soil

7.4.2 ELEMENTAL CONCENTRATIONS FROM BUSTA KALEYARD

Within the amended soils in Busta kaleyard the black carbonised particles contain a very similar variety of elements as seen at Shirva. However, unlike Shirva the elemental concentrations in the micro carbonised particles are higher than in the larger carbonised fragments ($+500\mu\text{m}^2$), (Figures 166 and 167). Overall the elemental concentrations are low but there are distinctive differences between the large and small inclusions. In the large carbonised particles (Fig 166) there are higher concentrations of Al ($0.44 \pm 0.02\%$), Fe ($0.24 \pm 0.09\%$) and Br ($0.20 \pm 0.03\%$). Alongside these however, are smaller concentrations of elements including Ca, Na, Mg, K, Mn and P, which range between 0.06 to 0.12%, as well as very small loadings of Ba ($0.02 \pm 0.01\%$), Cu ($0.02 \pm 0.01\%$), Zn ($0.04 \pm 0.02\%$), S ($0.07 \pm 0.01\%$) and Cs ($0.02 \pm 0.01\%$), typical of burning within settlement centres and mixing with anthropogenic waste.

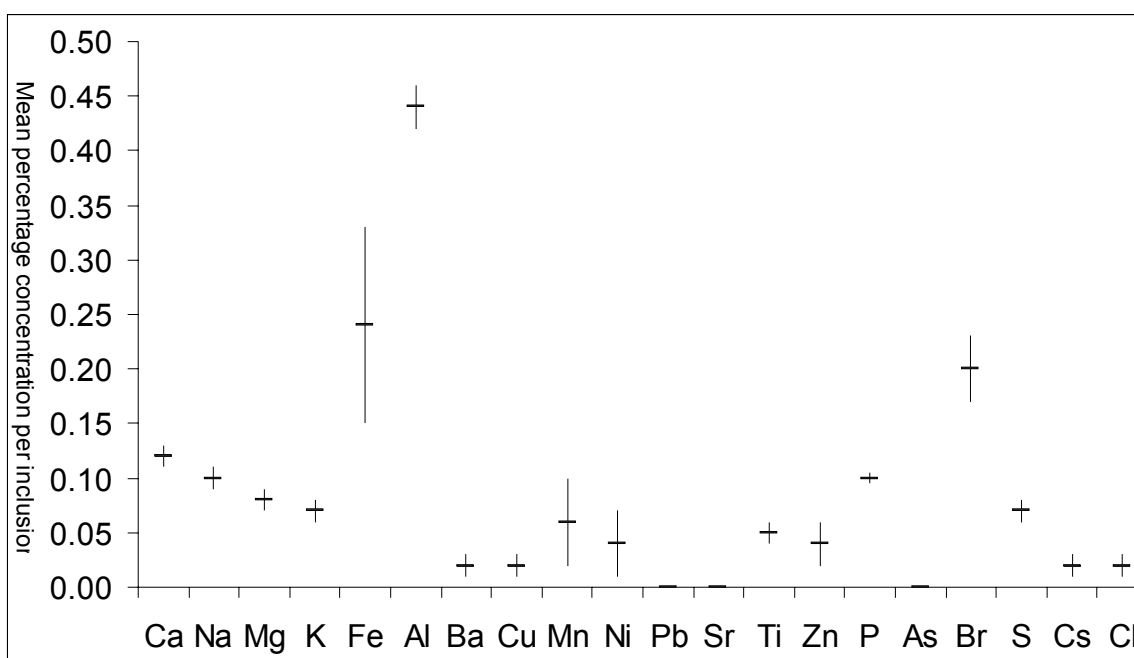


Figure 166, Mean percentage concentration of elements in black carbonised particles +500µm² from Busta kaleyard (Error bars show 95% confidence interval of the mean)

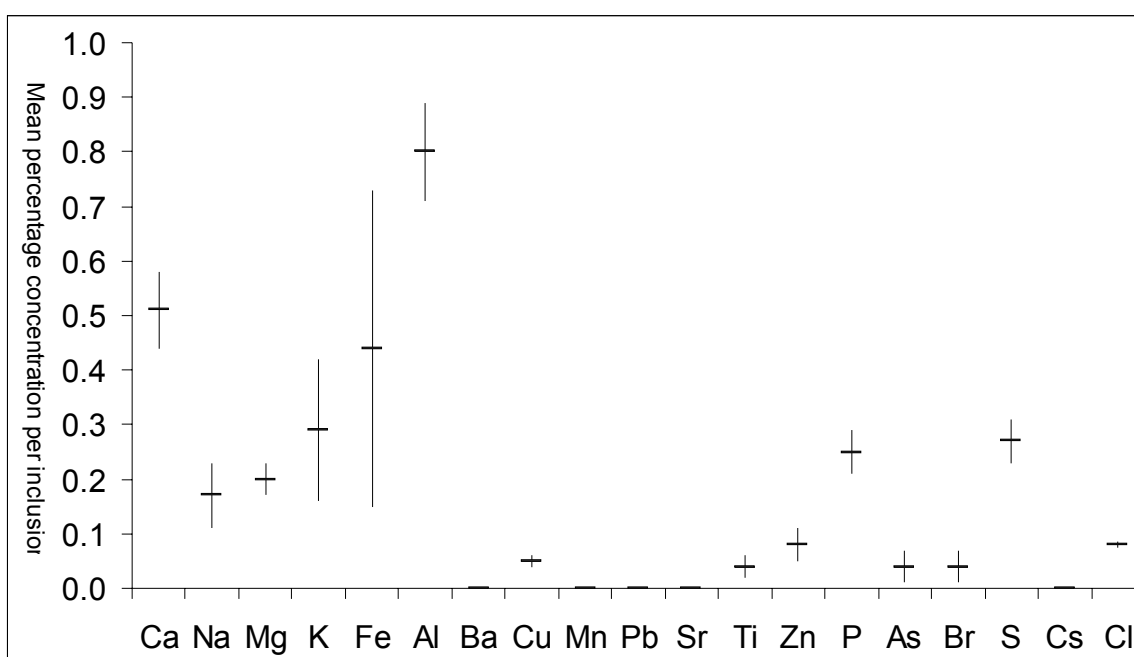


Figure 167, Mean percentage concentration of elements in black carbonised particles <500µm² from Busta kaleyard (Error bars show 95% confidence interval of the mean)

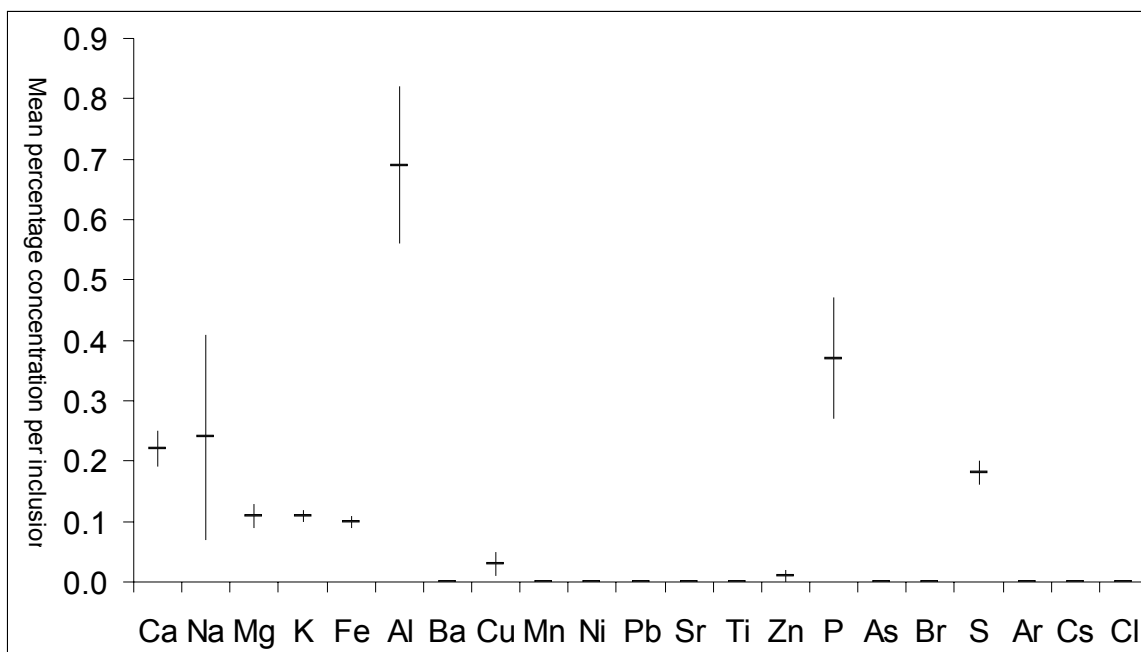


Figure 168, Mean percentage concentration of elements in organic inclusions from Busta kaleyard (Error bars show 95% confidence interval of the mean)

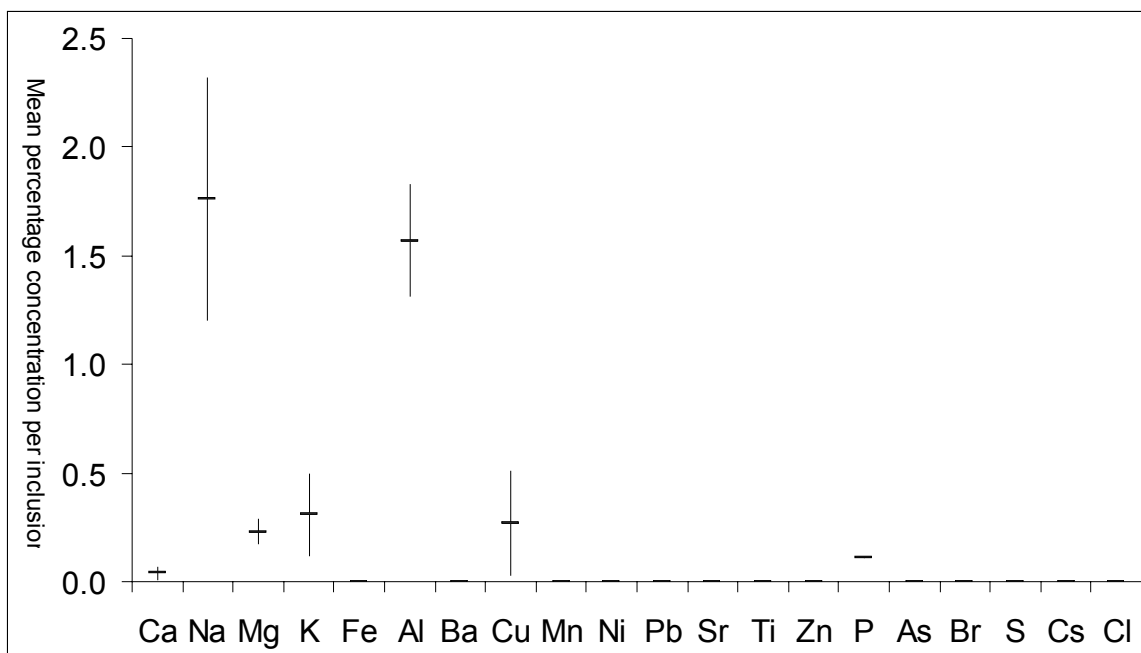


Figure 169, Mean percentage concentration of elements from soil groundmass samples from Busta kaleyard (Error bars show 95% confidence interval of the mean)

The small black carbonised particles (Fig 167) show higher percentage concentrations of Fe ($0.44\pm0.29\%$), Al ($0.80\pm0.09\%$), Ca ($0.51\pm0.07\%$), K ($0.29\pm0.13\%$), P ($0.25\pm0.04\%$) and Na ($0.17\pm0.06\%$) as well as smaller concentrations of S ($0.27\pm0.04\%$), As ($0.04\pm0.03\%$), Zn ($0.08\pm0.03\%$) and Cu ($0.05\pm0.01\%$) possibly from the mixing of burnt residue from fires and hearths with organic manures prior to addition to the kaleyard. The results from Busta appear to differ from those at Shirva indicating different burning and manuring processes over time and suggest that the micro sized black carbon particles may derive from the residue of fires burnt in settlement centres whereas the larger fragments may equate to burnt organic fragments carbonised away from settlement areas.

The organic inclusions of peat and turf tested from Busta (Fig 168) show higher values for Al ($0.69\pm0.13\%$) and P ($0.37\pm0.10\%$) as well as low concentrations of Ca, Na, Mg and Fe but only very small traces of elements associated with mixing with ash and hearth residues (Cu, Zn, S), however the results vary considerably than those from Shirva suggesting possible mixing between the organic fragments and micro black carbonised particles. Within the soil groundmass at Busta (Fig 169) there are greater values of Na ($1.76\pm0.56\%$) and Al ($1.57\pm0.26\%$) alongside smaller concentrations of Ca ($0.04\pm0.03\%$), Mg ($0.23\pm0.06\%$), K ($0.31\pm0.19\%$) and P ($0.11\pm0.01\%$). These elements possibly may originate from either natural soil sources or the breakdown of organic inclusions but unlike the black carbon particles and organic inclusions there is much less elemental evidence of the addition of settlement waste.

7.4.3 ELEMENTAL CONCENTRATIONS FROM LEOGH KALEYARD

Elemental results from Leogh kaleyard are illustrated in figures 170 to 173. The small carbonised particles (Fig 171) within the kaleyard include distinctive concentrations of Mn ($1.61\pm0.23\%$), Al ($0.79\pm0.08\%$) and Fe ($0.57\pm0.23\%$) as seen at Shirva and Busta alongside smaller percentages of Ca, Na, Mg, K and P indicating similar processes of manuring and post burial breakdown.

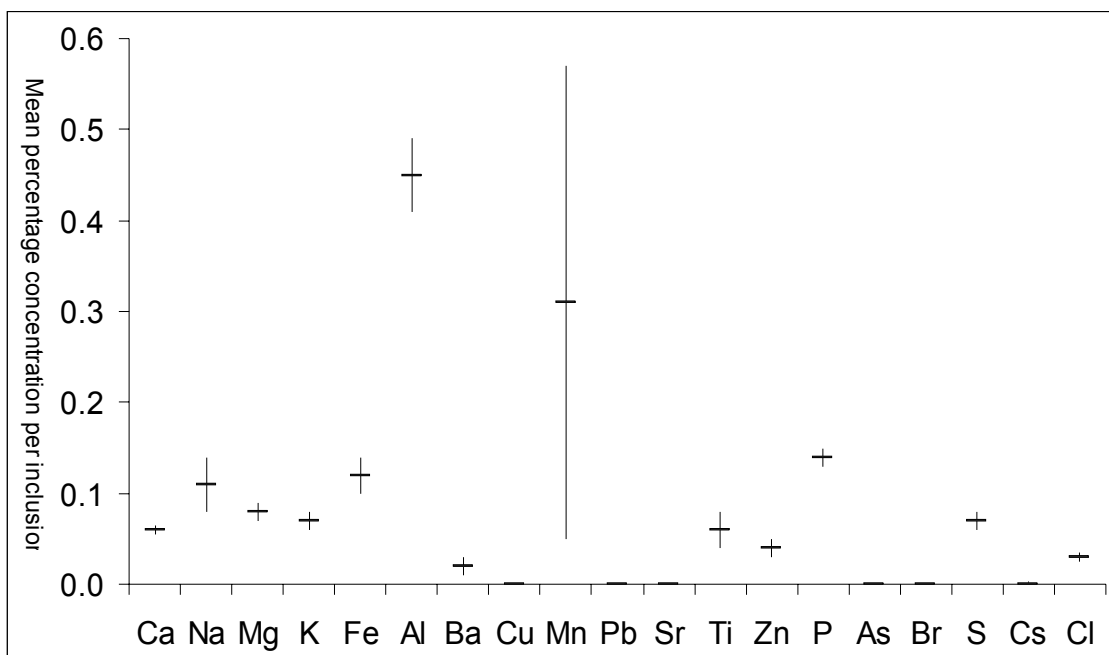


Figure 170, Mean percentage concentration of elements in black carbonised particles $>500\mu\text{m}^2$ from Leogh kaleyard (Error bars show 95% confidence interval of the mean)

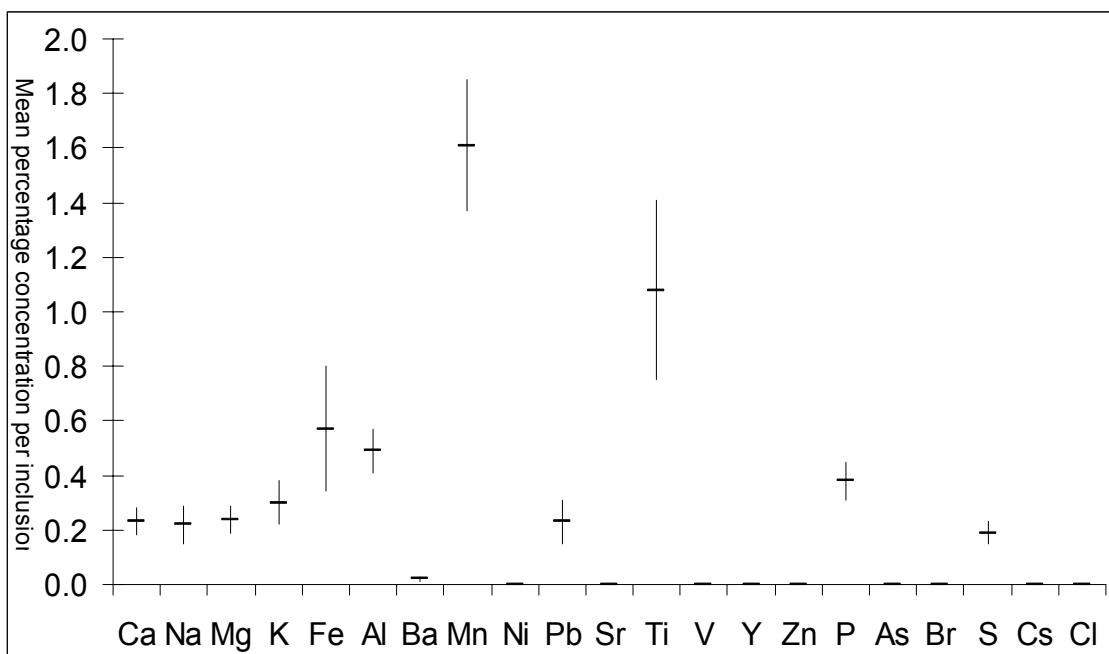


Figure 171, Mean percentage concentration of elements in black carbonised particles $<500\mu\text{m}^2$ from Leogh kaleyard (Error bars show 95% confidence interval of the mean)

There are also small concentrations of Ba ($0.01 \pm 0.005\%$), Pb ($0.23 \pm 0.08\%$) Br ($0.04 \pm 0.02\%$), Cl ($0.07 \pm 0.03\%$) and S ($0.19 \pm 0.04\%$) suggesting the inclusion of burnt material alongside unburnt organics. The results from the macro black carbonised particles (Fig 170) are lower than the small inclusions but there are similar patterns of elemental concentration including Al ($0.45 \pm 0.04\%$) and Mn ($0.31 \pm 0.26\%$) and smaller percentages of Ca ($0.06 \pm 0.005\%$), Na ($0.11 \pm 0.03\%$), Mg ($0.08 \pm 0.03\%$), K ($0.07 \pm 0.01\%$), Fe ($0.12 \pm 0.02\%$), Ti ($0.06 \pm 0.02\%$) and P ($0.14 \pm 0.01\%$). There is also very little difference in the concentration of elements associated with hearth residues and industrial activity in the larger inclusions with very low concentrations of Ba ($0.02 \pm 0.01\%$), Zn ($0.04 \pm 0.01\%$), S ($0.07 \pm 0.01\%$) and Cl ($0.03 \pm 0.003\%$) but the results still suggest that the smaller inclusions are retaining some elemental concentration.

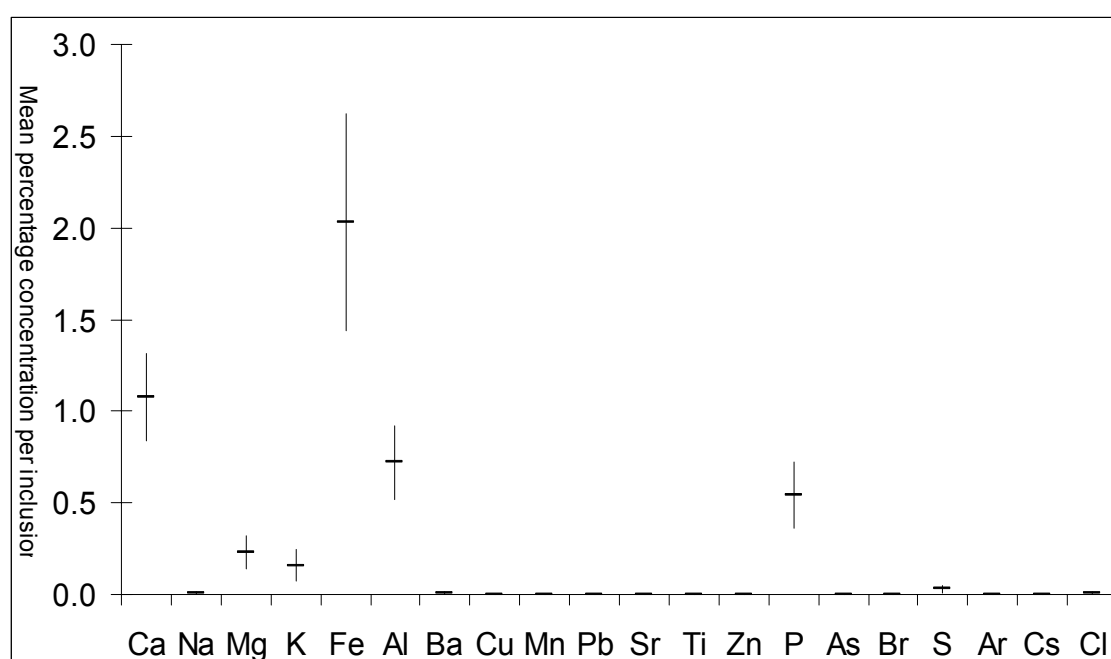


Figure 172, Mean percentage concentration of elements in organic inclusions from Leogh kaleyard (Error bars show 95% confidence interval of the mean)

The similarity in the elemental results suggest that the large and small black carbonised particles may have been burnt together or at least mixed together before being added to the garden hortisols, possibly because of a different manuring regime to the larger farms at Shirva and Busta. Interestingly the unburnt organics (Fig 172) are also likely to be the main input material at Leogh as the elemental results are

surprisingly high, especially in Fe ($2.03 \pm 0.59\%$), P ($0.54 \pm 0.18\%$), Al ($0.72 \pm 0.20\%$) and smaller quantities of Ca ($0.22 \pm 0.14\%$), Mn ($0.23 \pm 0.09\%$) and K ($0.16 \pm 0.09\%$). The high Fe content is also present in the soil groundmass (Fig 173) with Mn, Al, Mg and Br but the large standard errors suggests a distinctive variation in results and large amounts of mixing and post burial translocation through the soil profile by soil water. The soil groundmass at Leogh has no evidence of anthropogenic manuring from settlement centres, possibly because the evidence has been removed from the soil profile by post burial leaching. Of all the farms on Fair Isle, Leogh kaleyard has been deserted the longest whereas amended additions have continued at Shirva and Busta until recently and probably includes modern dumps of material.

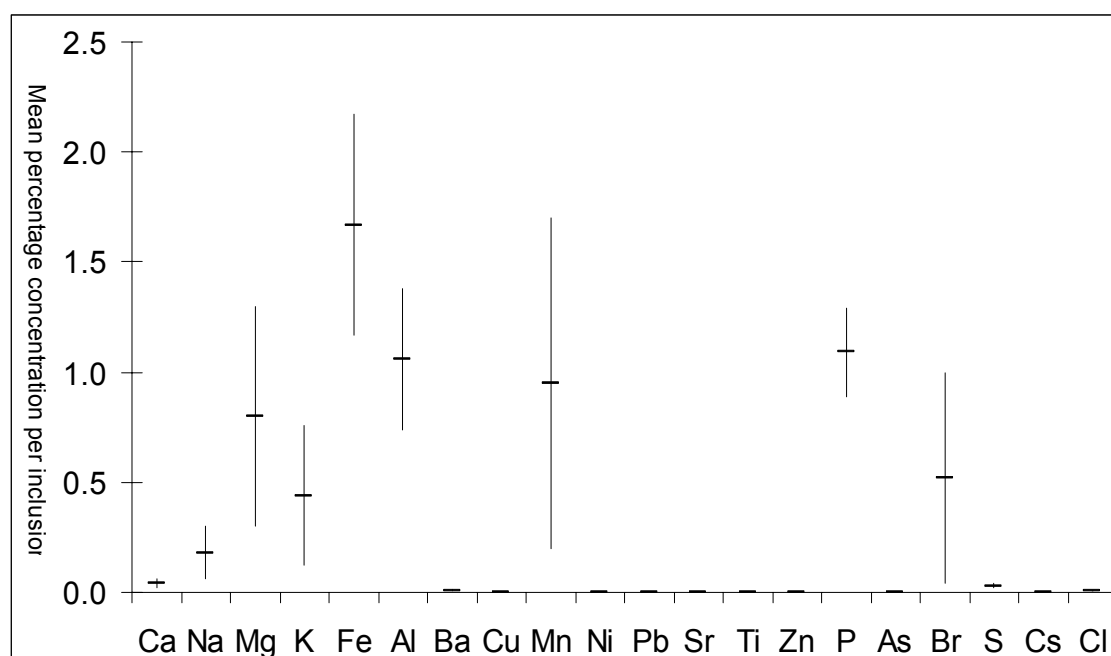


Figure 173, Mean percentage concentration of elements from soil groundmass samples from Leogh kaleyard (Error bars show 95% confidence interval of the mean)

7.4.4 ELEMENTAL CONCENTRATIONS FROM OLTHOF GARDEN

Of all the areas analysed, Olthof contains the fewest black carbon particles and the majority of the ones analysed are smaller than $500\mu\text{m}^2$. Like Fair Isle inclusions the large black carbonised particles contain higher concentrations of Fe ($3.20\pm1.10\%$), Al ($2.71\pm0.18\%$), P ($2.68\pm0.22\%$), K ($2.34\pm0.38\%$), Ca ($2.28\pm0.25\%$) and Na ($2.00\pm0.09\%$) (Fig 174). In contrast the smaller carbonised particles contain lower percentage concentrations of Fe ($2.20\pm0.47\%$), Al ($1.00\pm0.19\%$) and P ($0.47\pm0.24\%$) and considerably lower concentrations of Ca, Na, Mg and K (Fig 175).

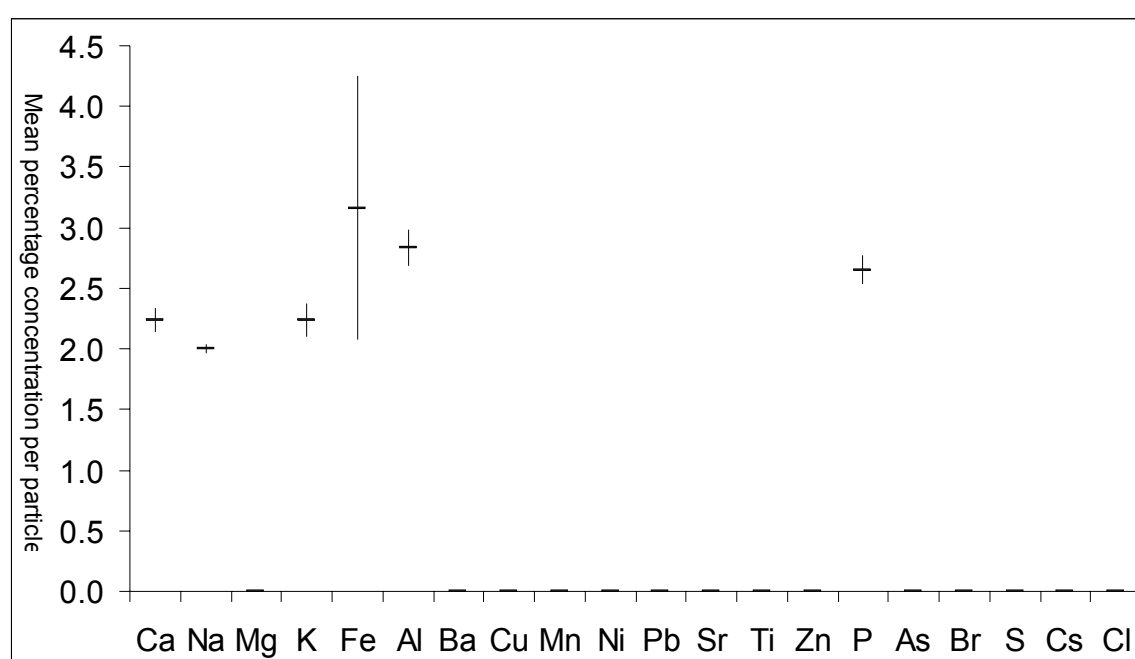


Figure 174, Mean percentage concentration of elements in black carbonised particles $>500\mu\text{m}^2$ from black plaggen soils in Olthof garden (Error bars show 95% confidence interval of the mean)

These results contradict the understanding that an increase in post burial breakdown would increase the surface area of the black carbon particles and therefore the binding surfaces. In this case the breakdown of the black carbonised particles and high post burial leaching must be removing elemental evidence from the soil horizons.

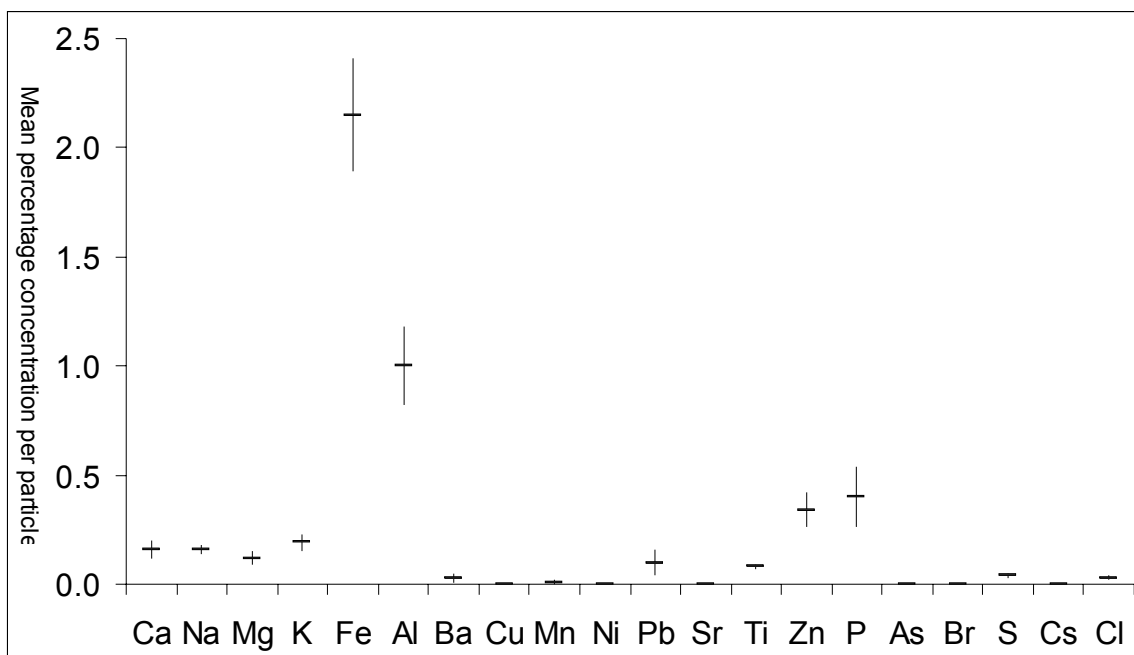


Figure 175, Mean percentage concentration of elements in black carbonised particles $<500\mu\text{m}^2$ from black plaggen soils in Olthof garden (Error bars show 95% confidence interval of the mean)

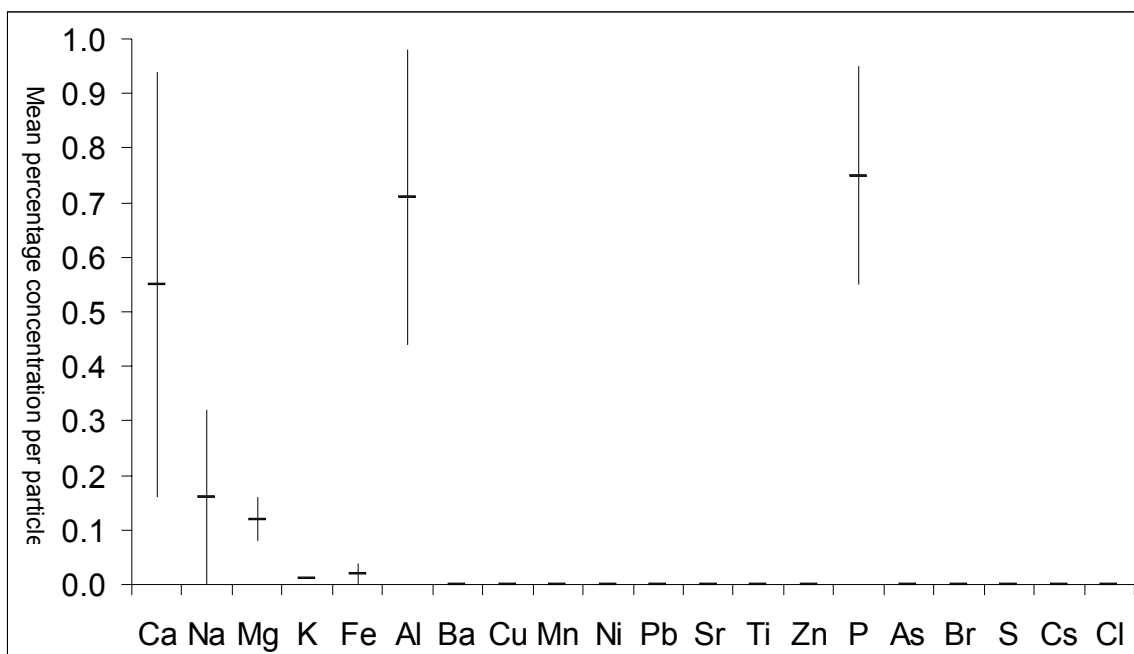


Figure 176, Mean percentage concentration of elements in black carbonised particles $<500\mu\text{m}^2$ from brown plaggen soils in Olthof garden (Error bars show 95% confidence interval of the mean)

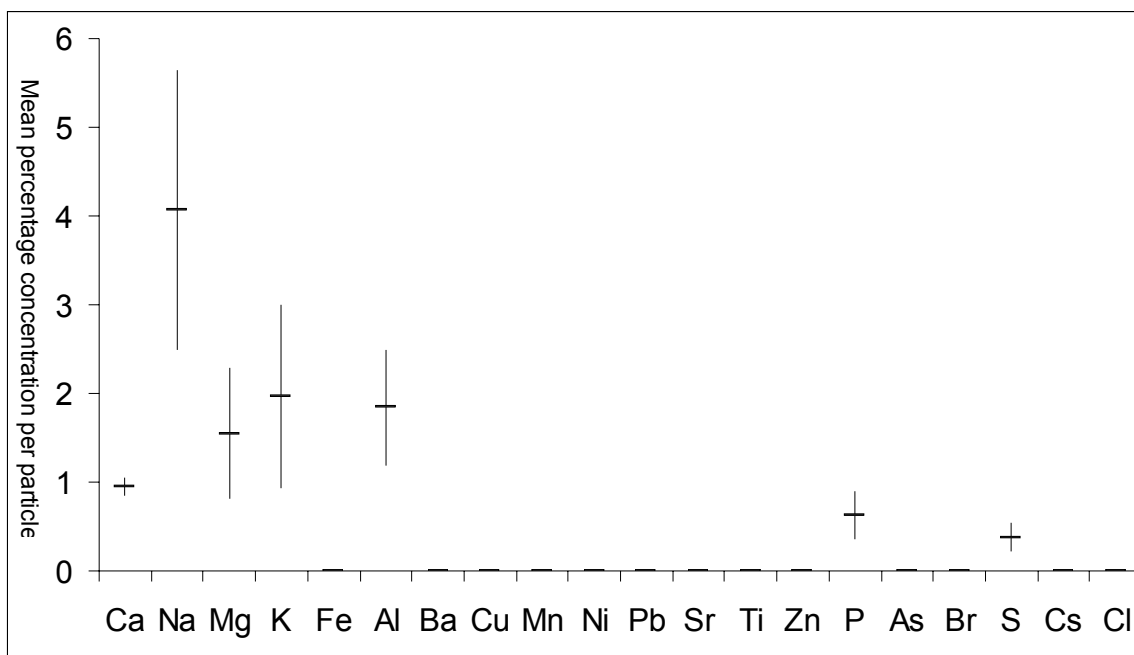


Figure 177, Mean percentage concentration of elements from soil groundmass samples from the black plaggen soils in Olthof garden (Error bars show 95% confidence interval of the mean)

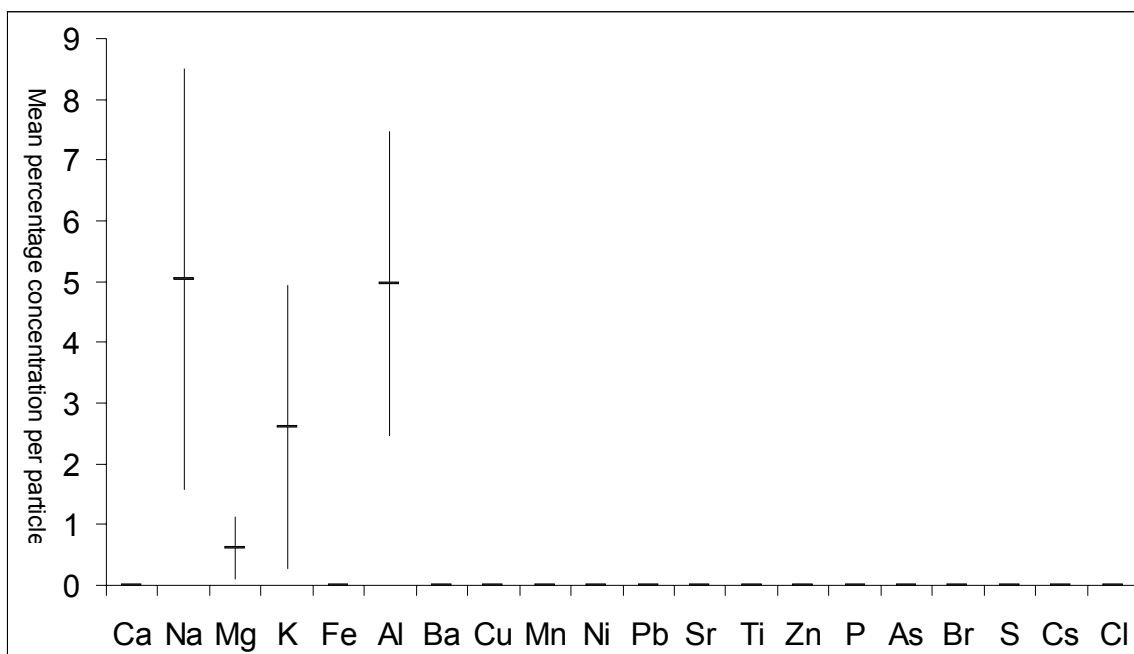


Figure 178, Mean percentage concentration of elements from soil groundmass samples from the brown plaggen soils in Olthof garden (Error bars show 95% confidence interval of the mean)

The results suggest that on average, the small black carbonised particles are more affected by post burial degradation and this increases the elemental concentration in the groundmass (Fig 178). The micromorphological analysis (chapter 6, section 6.4) and oxygen to carbon ratio analysis (chapter 7, section 7.5) show that most of the black carbon particles in the Dutch hortisols are charcoal particles, however, they do not contain high concentrations of elements associated with anthropogenic activity. The micro black carbonised particles also contain low concentrations of Zn ($0.37 \pm 0.08\%$), Pb ($0.12 \pm 0.08\%$), Ba ($0.03 \pm 0.02\%$), As ($0.02 \pm 0.01\%$) and S ($0.04 \pm 0.01\%$) which could be attributed to the mixing of material burnt in settlement centres. The evidence is strengthened by the fact that neither the macro black carbonised particles or the organic groundmass show any evidence of similar elemental concentrations. Clear evidence of elemental variation over time can be seen between the results from the black and the brown plaggen soils (Figs 175 and 176). In the black plaggen soil horizons there are more elements present than in the brown plaggen soils and in every case the concentrations are higher. The brown plaggen soils typically have concentrations of Ca ($0.55 \pm 0.40\%$), Al ($0.72 \pm 0.27\%$) and P ($0.75 \pm 0.20\%$) alongside smaller concentrations of Na, Mg, Fe and K (Fig 176). There is however, no evidence of any mixing with elements from hearths or industrial areas within settlements. Results from the micromorphological analysis of the plaggen soils at Olthof (chapter 6, section 6.4) reveal very few whole organic inclusions, due to the poor level of preservation. Therefore, no comprehensive elemental data could be gathered from these particles, but this does suggest that the small and large black carbonised fragments may explain how the plaggen soils are able to retain some soil elements even if the turf organic inclusions are broken down by post burial processes. Evidence of the poor retention of elements by the black and brown plaggen soils can be seen in the soil groundmass results (Fig 177 and 178). In both anthropogenic soils there are considerably less elements present than in the black carbonised particles suggesting that leaching has removed much of the elemental evidence, as determined in the bulk soil chemistry results (chapter 5, sections 5.2.1, 5.3.1, 5.4.4, 5.6.1). The black plaggen soil contains Ca, Na, Mg, K, Al, P and S and the brown plaggen soil contains similar concentrations of Na, Mg, K and Al all of which may be of natural or anthropogenic origin and certainly occur within the natural sandy soils and meadowland turves used as manure. The error bars in the brown plaggen soils of figures 176 and 178 are much more varied than in

the other samples and suggest that there is much more variation in the results due to mixing with the natural soil horizons.

7.4.5 ELEMENTAL CONCENTRATIONS FROM CAHERATRANT KALEYARD

Elemental results for the micro particles of black carbonised inclusions (Fig 180) show high concentrations of Fe ($2.18 \pm 0.76\%$) and P ($0.59 \pm 0.12\%$), but the fragments over $500\mu\text{m}^2$ (Fig 179) contain more Ca ($0.40 \pm 0.17\%$), Na ($0.19 \pm 0.03\%$), Al ($1.32 \pm 0.13\%$), Mg ($0.24 \pm 0.05\%$), K ($0.27 \pm 0.03\%$), Mn ($0.09 \pm 0.03\%$) and Ti ($0.19 \pm 0.03\%$) per particle, a pattern more like Olthof than the Fair Isle farms. The larger carbonised particles also contain very small amounts of Ba ($0.02 \pm 0.01\%$), Pb ($0.03 \pm 0.01\%$) and As ($0.01 \pm 0.005\%$) which most likely derive from natural sources.

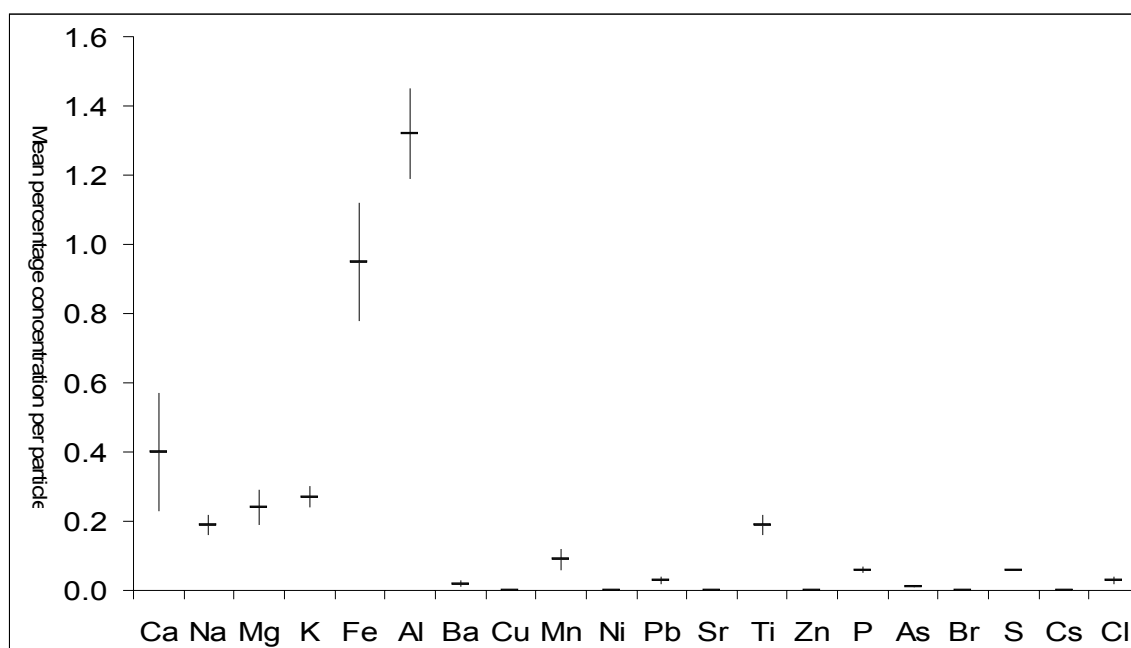


Figure 179, Mean percentage concentration of elements in black carbonised particles $>500\mu\text{m}^2$ from Caheratrant kaleyard (Error bars show 95% confidence interval of the mean)

In contrast, the smaller carbonised particles contain a wider range of elemental evidence including Cu ($0.36 \pm 0.27\%$), Zn ($0.21 \pm 0.10\%$) and S ($0.38 \pm 0.08\%$) suggesting that the two fractions of carbonised particles derive from different sources and represent carbonised wood or peat/turf fragments which have

been burnt after being used or stored in domestic areas. Organic fragments in the garden hortisol (Fig 181) show that there are concentrations of Al ($1.08 \pm 0.21\%$), K ($0.64 \pm 0.08\%$), Mg ($0.53 \pm 0.07\%$), Na ($0.17 \pm 0.13\%$) and Ca ($0.34 \pm 0.14\%$) present from organic additions, and also concentrations of Cu ($0.42 \pm 0.15\%$), Zn ($0.19 \pm 0.08\%$), S ($0.52 \pm 0.16\%$) and Cl ($0.19 \pm 0.14\%$). These elements may occur naturally within the soils, a result of absorption after the breakdown of carbonised charcoals and ashes or possibly derive from the mixing of burnt and un-burnt manuring components prior to addition. By comparison the soil groundmass results (Fig 182) show higher values for Fe ($1.30 \pm 0.13\%$), Al ($0.81 \pm 0.33\%$) and Ca ($0.54 \pm 0.23\%$) which may occur from the addition of peat and turf organics or from the natural soil. The values of P ($0.46 \pm 0.12\%$) may originate from the degradation of organic and black carbonised inclusions. The soil groundmass shows no evidence, however, of any distinctive evidence of elements associated with the addition of amended waste, suggesting either retention by the inclusions, or a slow release which enables the elements to be lost by leaching.

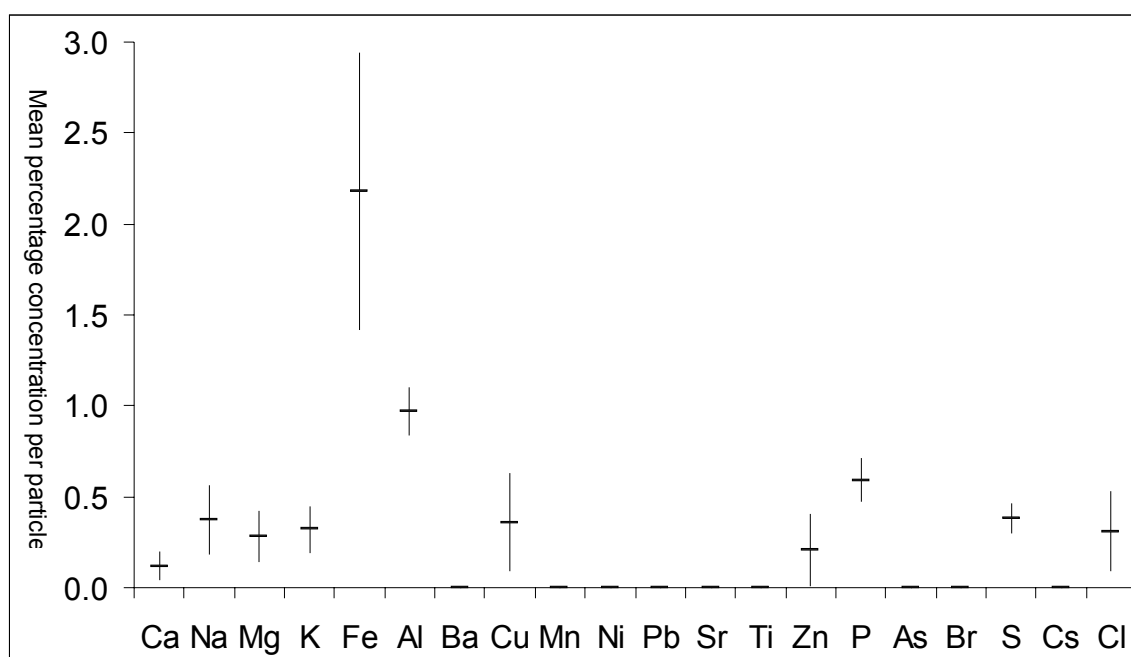


Figure 180, Mean percentage concentration of elements in black carbonised particles $<500\mu\text{m}^2$ from Caheratrant kaleyard (Error bars show 95% confidence interval of the mean)

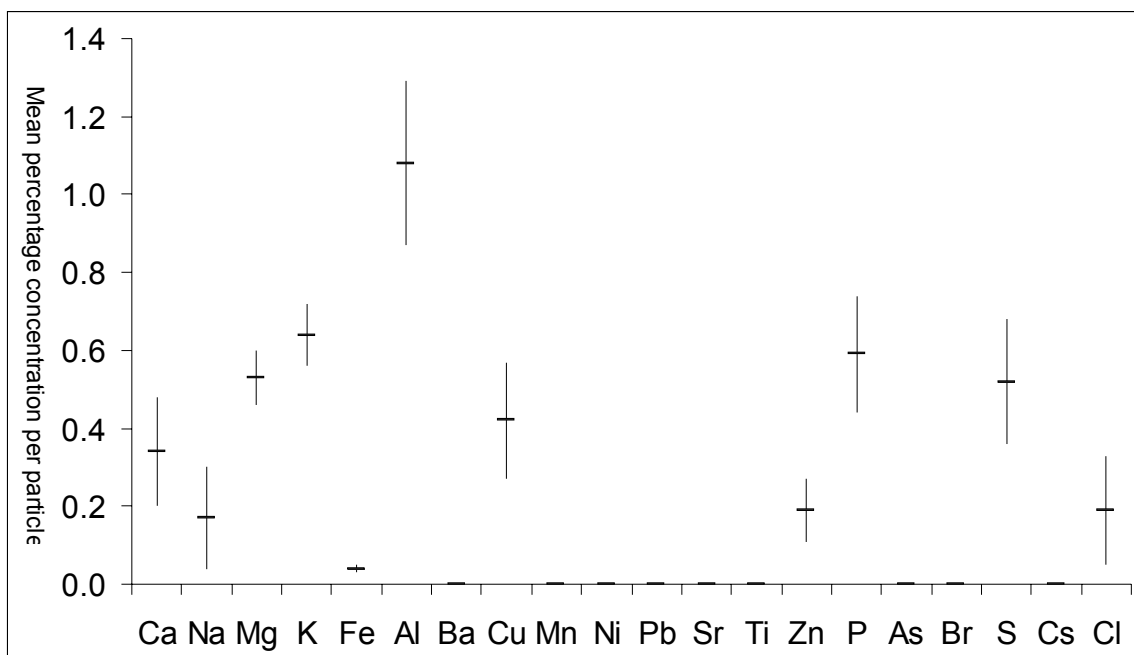


Figure 181, Mean percentage concentration of elements in organic inclusions from Caheratrant kaleyard (Error bars show 95% confidence interval of the mean)

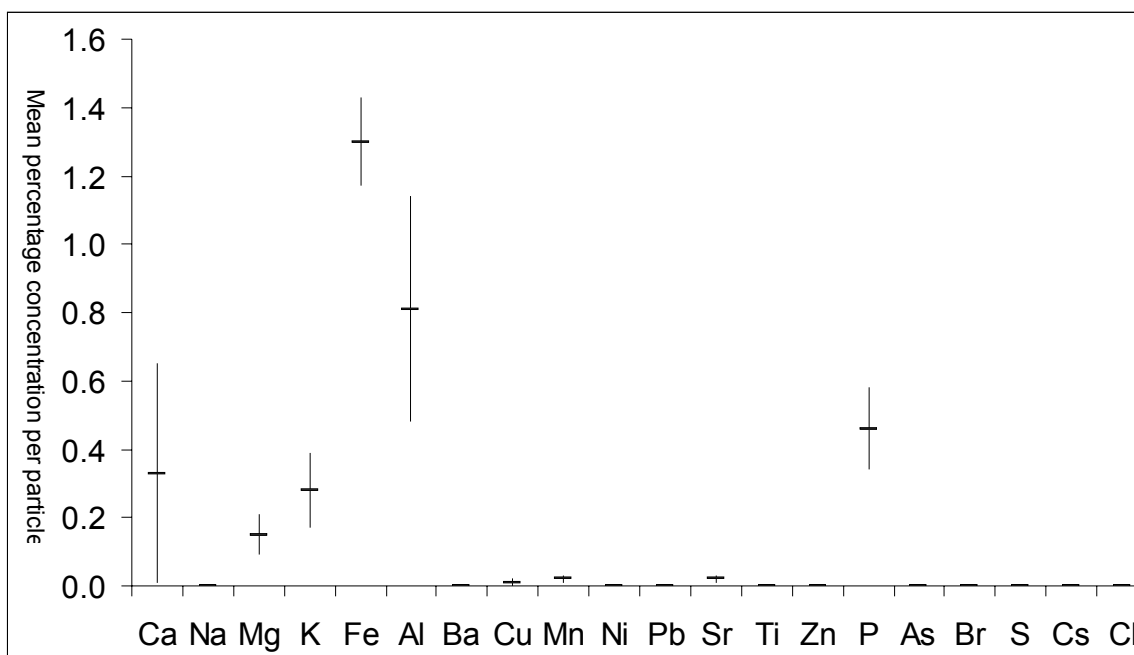


Figure 182, Mean percentage concentration of elements from soil groundmass samples from Caheratrant kaleyard (Error bars show 95% confidence interval of the mean)

7.5 DISCUSSION OF THE ELEMENTAL RESULTS IN BLACK CARBONISED PARTICLES IN KALEYARDS AND GARDENS FROM THE THREE FARMS

The elemental results from the amended inclusions in hortisols from the kaleyard and garden areas can be used to determine a number of key conclusions. On Fair Isle the three kaleyards at Shirva, Busta and Leogh all contain organic inclusions and soil groundmass with very similar elemental signatures and typically contain moderate percentage concentrations of Fe, Al, K, Mg, Na, Ca, Mn and P. These elements occur readily in the peat and turf organic manures as well as in the black carbonised particles and the natural soils. The soil groundmass contains only very small amounts of metals and pollutants compared to the black carbonised particles which by comparison contain higher concentrations of Pb, Zn, S, Ba, As, Cs and Cu, typical evidence of burning in occupation areas and settlement centres. The elemental transfer of metals between the black carbon particles, organic particles and the soil matrix appears to be minimal, as only small traces of S, Cu, Zn and As were found at Shirva and Busta. However, the micro black carbonised particles appear to be very resilient to post burial degradation and have an ability to retain high elemental concentrations. Elemental results in the soil groundmass, organic inclusions and even the large black carbonised particles are considerably lower and suggest that the inclusions are more susceptible to post burial chemical, biological and physical breakdown. In a wider context the elemental results from the black carbonised particles at Olthof indicate a different type of carbonised material, which because of the high acidity of the soil are present in fewer numbers than at any of the sites but results from the O:C ratio analysis suggest that the majority are more resistant charcoal and carbonised softwoods. At Caheratrant there is a predominance of carbonised peat and turf fragments mixed with calcareous beach sand and some charcoal fragments. The elemental results from Olthof show distinctive concentrations of Ca, Al, P and Fe in the micro black carbonised particles but unlike Fair Isle, higher values of Ba, Pb, As, Zn and S in the larger black carbonised particles. Considerable leaching in the plaggen soils at Olthof has resulted in rapid degradation of organic inclusions and a groundmass with very low elemental concentrations and contains only minimal amounts of Fe, Na, Al and P and no evidence of elements associated with settlement fire residue. It is therefore concluded that the majority of the black carbonised particles in the plaggen soils are

highly resistant charcoal fragments, able to retain elemental concentrations better than the less resilient organic fragments and the soil groundmass. At Caheratrant, like Fair Isle, the smaller black carbonised particles contain higher quantities of Fe and P than the large inclusions but very similar concentrations of Na, K and Mg and lower concentrations of Cu, Zn and S suggesting that there is similarity between the two size fractions. There is likely to have been more mixing of carbonised particles and organic fragments as the range of elements present are very similar which may derive from the reuse of organic and charcoal material in animal byres or from mixing in storage areas before being added to the garden soil profile.

7.6 DISCUSSION OF THE ELEMENTAL CONCENTRATION RESULTS FROM BULK SOIL ANALYSIS AND WITHIN BLACK CARBONISED PARTICLES IN KALEYARD AND GARDEN SOILS

The elemental concentration results from the bulk samples and the black carbonised particles (Table 29) illustrate some clear similarities and differences which may be attributable to manuring. As discussed in chapter 5, section 5.6 the elemental results from the bulk samples at Shirva (section 5.6.1) and Caheratrant (section 5.6.2) contain the highest amounts of P, Ca, Zn, Fe, Al and Na, whereas at Olthof the elemental values are considerably lower (section 5.6.3). From these results alone one might suggest that less manuring from organic and domestic waste occurring at Olthof but the historical and fieldwork data (chapter 3, section 3.5 and 3.6) indicate considerably deeper anthropogenic horizons manured over many hundreds of years as seen in plaggen soils across the Netherlands (Pape, 1970; Spek 1992; van Smeerdijk, et al., 1995; van Mourik 1997). Reductions in the elemental values must therefore have been occurring as a result of increased post burial degradation of the manuring components and leaching of key signature elements.

The bulk elemental results also complement the results found from the micromorphology, zone counting and image analysis, in that the largest elemental signatures occur in the soils with the most organic inclusions. Table 29 also contains the elemental results from the black carbonised particles.

Elemental Concentrations							
Bulk Samples (chapter 5, section 5.7)				Black Carbonised Particles (chapter 7, section 7.6)			
Elements	S	O	C	Elements	S	O	C
P	xxx	xx	xx	P	xx/xxx	xx	x
Ca	xxx	xx	xxxx	Ca	xxx	xx	xx
Pb	xx	x	t	Pb	x	t	t
Ba	x	xx	x	Ba	t	t	t
Cu	x	x	x	Cu	-	-	x
Sr	xx	x	xxx	Sr	-	-	-
Cl	t	-	t	Cl	t	-	t
Cs	t	-	-	Cs	t	-	-
S	xx	-	t	S	x	-	x
Zn	xx	x	xx	Zn	t	t	t
As	-	x	xx	As	t	-	t
Mg	xxx	x	xx	Mg	x	t	x
K	xxx	x	x	K	xx/xxx	t	x
Fe	xxxx	xx	xxxx	Fe	xx	xx	xx/xxx
Al	xxxx	xx	xxx	Al	xxxx	xx	xx/xxx
Na	xxx	x	xxx	Na	xxx	x	x
Mn	xxx	xx	xxx	Mn	t	-	t
Ti	x	t	t	Ti	-	t	t

Key: Shirva – S, Olthof – O, Caheratrant – C

xxxx – v. high, xxx – high, xx – medium, x – low, t – trace, - no data.

Table 29, Table of elemental concentrations in the bulk amended and anthropogenic soils and the black carbonised particles from kaleyard and gardens at Shirva, Olthof and Caheratrant

At the three sites there appears to be an association between the most common elements (P, Ca, K, Fe and Al) found in the soils and the black carbonised particles, possibly because of better ionic binding and post burial transfer of elements between the organic soil groundmass and the black carbonised particles.

These common elements occur readily in the organic components used in the development of amended soils but can also occur naturally and may derive from external sources such as the atmosphere, sea water, soils and sediments. Patterns in the elements associated with human activity (Pb, Ba, Cu, Sr, Cl, Cs, S, Zn and As) are less common in the black carbonised particles than the bulk soil samples at each of the sites. This suggests that either carbonisation occurred away from any sources of human occupation or industry, leading to a lack of elemental enhancement, or the particles did contain larger levels of elements but they were leached out quickly into the soils and subsequently led to higher elemental results in the bulk samples.

Elemental analysis from black carbon particles from the terra preta soils have demonstrated similar high results of C alongside lower quantities of P, Si, Ca, and Fe (Liang, et al., 2006) and traces of Al, Si and P in smaller fragments from organic inclusions with a high mineral content (Glaser, et al., 2000). The results also mirror those gathered by Schaefer, et al., (2004) where distinctive concentrations of P, Si, Al, Fe, Mn, Ti and Mg in the were found in the soil matrices, however, Schaefer does not analyse the elemental concentration of the black carbon particles but the results from all three analyses show a very similar suit of elements. Experimental analysis by Lehmann, et al., 2003 showed that the inclusion of charcoal led to better retention of P, Ca, Mn and Zn in the soils alongside other anthropogenic inclusions of fish fragments (Lima, et al., 2002)

In Scotland the black carbonised particles at Nairn were related to higher P values in anthropogenic soils (Davidson, et al., 2006) and on St Kilda the black carbonised particles contained high concentrations of Pb, Cu and Zn and related to the widespread distribution of peat ash across the Village Bay arable farmland (Davidson, et al., 2007a). On Fair Isle the Pb, Cu and Zn results are considerably lower and indicate far less peat ash input into the kaleyard and is more akin to the manuring process seen on South Uist (Davidson, et al., 2007a). Alongside high results of Cu and Zn the particles also contained higher concentrations of Fe, O and Ti similar to many of the black carbonised particles from all three sites indicating distinctive elemental effect from the natural soils. The groundmass of the anthropogenic soils at St Kilda were very similar to the results from Fair Isle and other than being dominated by C and O also contains P, Al, Fe, Na, Ca and K related to manuring with organic inclusions (Davidson, et al., 2007a).

More detailed elemental mapping of the anthropogenic soils from St Kilda shows higher concentrations of Ca, Cu, Pb, Zn, Ba, Sr in the black carbonised particles and the results from the three sites illustrate considerably lower results which indicates a very different process of manuring. However, the results also show high Fe, Ca and moderate to low P levels which is similar to the garden and kaleyard soils (Wilson, et al., 2008). The low results may reflect the mobility of elements in the soils and to some extent the limits of the techniques used.

The limited elemental analysis of organic inclusions from the Netherlands have shown distinctive concentrations of Ca, Mg, K and Na in prominent soil inclusions associated with a small farm house (Oonk, et al., 2009a, 2009b and 2009c) and the results are directly related to the highest concentration of Ca, Cu, P and Zn in the bulk soil analysis. At Olthof the results of Ca, Mg, K and Na are also very similar between the bulk and black carbonised particles and are directly associated with anthropogenic additions to the soils, but, the results are lower than from the results taken directly adjacent from the house.

8 CONCLUSIONS

8.1 INTRODUCTION

The research themes developed in this project were undertaken in order to more fully understand the process by which humans develop soils for arable farming. The analysis was conducted in a range of geographical localities across Europe with particular focus on the quantification of black carbonised and black amorphous particles and their significance as cultural resources in the soil. The project design outlined in chapter 1 and summarised in table 30 was developed so that each chapter can be taken as an individual piece of research. Accordingly, each chapter contains separate summaries of analysis, interpretations and conclusions. The results are detailed in each chapter and summarised in table 31. This chapter draws upon the key developments chapters 2 to 7 in order to re-evaluate the site based aims outlined in section 1.11 and the to further understand the spatial distribution, character and history of manuring processes and the specific use of carbonised organic fragments.

8.2 THE SPATIAL DISTRIBUTION OF AMENDED AND ANTHROPOGENIC SOILS ACROSS SMALL FARMSTEADS IN NORTH WEST EUROPE

- Macro and microscopic analysis of the soils from Fair Isle showed clear evidence of anthropogenic additions to the soil at Shirva, Busta and Leogh, but distinctive deepening of the topsoil horizons has not occurred as found on other Orkney and Shetland islands.
- At Shirva and Leogh the amended soil horizons deepen away from settlement centres as a result of the input of more organic manures (Peat) in the infield and outfield areas and post depositional soil movement.
- The oldest settlements on Fair Isle (Shirva and Leogh) have considerably deeper amended soil horizons than the farms developed to cope with population pressures in the 1860s (Taing).

Chapter 8	Aims	Methods	Site	Farm	Chapter	Section
8.2	1. The spatial distribution of soils	Auger survey	Fair Isle	Shirva	2	2.6.1
				Leogh	2	2.6.2
				Taing	2	2.6.3
			Netherlands	Olthof	3	3.5.1 to 3.5.4
			Ireland	Caheratrane	4	4.4.1 to 4.4.5
		Test pit excavations	Fair Isle	Shirva	2	2.7
			Netherlands	Olthof	3	3.6
			Ireland	Caheratrane	4	4.5
8.3	2. The physical and chemical state of soils	Soil pH.	Fair Isle	Shirva, Busta, Leogh	5	5.2.1
			Netherlands	Olthof	5	5.2.2
			Ireland	Caheratrane	5	5.2.3
		Loss on ignition	Fair Isle	Shirva, Busta, Leogh	5	5.3.1
			Netherlands	Olthof	5	5.3.2
			Ireland	Caheratrane	5	5.3.3
		Particle size	Fair Isle	Shirva	5	5.4.1 to 5.4.3
				Busta	5	5.4.1
				Leogh	5	5.4.1
			Netherlands	Olthof	5	5.4.4 to 5.4.6
			Ireland	Caheratrane	5	5.4.7 to 5.4.9
		Magnetic susceptibility	Fair Isle	Shirva, Busta, Leogh	5	5.5.1
			Netherlands	Olthof	5	5.5.2
			Ireland	Caheratrane	5	5.5.3
		Multi-element analysis	Fair Isle	Shirva	5	5.6.1
			Netherlands	Olthof	5	5.6.2
			Ireland	Caheratrane	5	5.6.3
8.4	3. Soil micromorphology of the soils	Soil micromorphology	Fair Isle	Shirva, Busta, Leogh	6	6.2
			Netherlands	Olthof	6	6.3
			Ireland	Caheratrane	6	6.4
8.5	4. The quantification of organic and inorganic inclusions	Zone counting	Fair Isle	Shirva, Busta, Leogh	6	6.6
			Netherlands	Olthof	6	6.6
			Ireland	Caheratrane	6	6.6
		Image analysis	Fair Isle	Shirva, Busta, Leogh	6	6.7
			Netherlands	Olthof	6	6.7
8.6	5. The elemental composition of black carbonised, black amorphous and organic inclusions	SEM-EDS analysis; O:C ratios	Fair Isle	Shirva	7	7.2.2 + 7.3
				Busta	7	7.2.2 + 7.3
				Leogh	7	7.2.2 + 7.3
			Netherlands	Olthof	7	7.2.3 + 7.3
			Ireland	Caheratrane	7	7.2.4 + 7.3
		SEM-EDS analysis; multi-elemental analysis	Fair Isle	Shirva	7	7.4.1
				Busta	7	7.4.2
				Leogh	7	7.4.3
			Netherlands	Olthof	7	7.4.4
			Ireland	Caheratrane	7	7.4.5

Table 30, Summary table of the broad aims, methods and result locations in the thesis

Site		Physical & Chemical State of the Soils																Micromorphology and Particle Quantification												Elemental Composition																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
		Soil Depth	pH	LOI (I)	Particle size	MS (II)	Multi Element (/no data, t-trace, *-low, **-medium, ***-high, ****-v. high)																Micromorphology & Zone Count										Image Analysis				SEM analysis in the kaleyards and gardens																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
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Shirva, Fair Isle	Kaleyard	400 – 500 mm	5.1 - 6.7	8 – 17%	60-1000µ m	88 – 278	*	*	*	*	*	*	*	*	*	/	/	*	*	*	t	t	t	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Table 31, Summary of the main results from the amended arable and anthropogenic soils at the three sites

- Black plaggen soils in the Netherlands are prolific across each landuse area but the brown plaggen soils are considerably shallower and are concentrated around the centre of Olthof and other archaeological settlement areas.
- Despite the distinctive depth both the black and brown plaggen soils contain very little macro evidence of anthropogenic input from settlement centres, as a result of post burial breakdown.
- Macro and microscopic evidence of the arable soils from Caheratrant illustrate clear evidence of human amendment, but distinctive deepening of the topsoil has not occurred and therefore the soils should not be termed “plaggen” soils.
- The amended arable soils at Caheratrant show distinctive increases in depth towards the settlement centre and clearly illustrate that manuring was being conducted over a wide area but focussed in the kaleyard areas.

The initial aim of the thesis was to analyse the distribution of amended and anthropogenic soils across a number of sites and landuse areas in order to test the theory that the deepest stratigraphies were located closest to settlement centres. This was conducted using a detailed archeo-historical and geoarchaeological methodology as a result of similar interdisciplinary studies from north west Europe and the results of which are discussed in chapters 2,3 and 4.

At each of the sites a well organised localised manuring technique was determined especially on Fair Isle where the limited peat resource was extracted and added to the soil through a careful recycling process similar to the island of Papa Stour (Bryant and Davidson, 1996). This interpretation was determined from the fieldwork results (chapter 2, sections 2.6 and 2.7) and micromorphological evidence (chapter 6, section 6.3). The deepest anthropogenic soils were found at Olthof and the soils had very distinctive mineragenic textures with far less organic inclusions suggesting less input of recycled domestic material (chapter 3, section 3.5.1 to 3.5.4 and 3.6). The fieldwork analysis highlighted the occurrence of both the black and brown plaggen soil across the entire site which complemented the work of Pape

(1970) as well as historical and archaeological research and suggests that the farm size has not changed considerably since its construction (Appels, 2003) . The fieldwork survey was also able to show that over the site the depth of the brown plaggen soil varied very little suggesting a similar level of organic addition to each of the landuse areas but that the manuring levels increased with the development of the black plaggen soils, especially in the garden area (chapter 3, section 3.6), a result which mirrored the results found by Dercon, et al., (2005). Localised manuring strategies could also be determined on Fair Isle where the soil profiles differed considerably from other marginal island areas. The kaleyard sequences at Shirva, Busta and Leogh (chapter 2, sections 2.7.1) are remarkably shallow compared to soil depths at Marwick (Davidson and Simpson, 1984), Papa Stour (Bryant and Davidson, 1996) and St Kilda (Meharg, et al., 2006) and indicated a limited manuring history, however, the inclusion of high quantities of macro-anthropogenic inclusions including charcoal and burnt peat fragments (chapter 6, section 6.6) indicated the addition of more domestic waste material possibly to reserve the peat material for fuel, as suggested by Fenton (1978), and for use in the infield and outfield areas. Manuring across the entire farm at Shirva and Leogh may have been developed because of the need to utilise as much space as possible for cultivation and increase yields. The fieldwork and historical documentation show that the amended arable soils at the older farms are considerably deeper than the amended arable soils at Taing (chapter 2, section 2.6.3), (occupied for a considerably shorter length of time) and the natural soils on the island. At Caheratrant the fieldwork revealed a distinctive localised manuring strategy which differed between landuse areas (chapter 4, section 4.5.1 to 4.5.4). In the kaleyards highly organic household waste was mixed with very large quantities of calcareous beach sand and was distributed in such a way that clear stratigraphical difference could be determined, reflecting the last addition before desertion (chapter 4, section 4.5.1). The inner and outer arable areas were characterised by the addition of far less peat and turf organics and beach sand and considerably less input from domestic sources, suggesting infrequent distribution of waste material (chapter 4, section 4.5.2). Past analysis on Irish anthropogenic soils indicated a development similar to the Dutch plaggen process and has even been called “*Irish Plaggen*” soil

(Conry, 1971). However the research conducted in this thesis suggests that the soils should be regarded as amended arable soils similar to those from Fair Isle and agrees with the comments put forward by Mackenzie, (2007, p33) that these soils do not constitute plaggen soils. Landuse changes throughout history have also been determined through the mapping of the soil horizons at the three sites. At Shirva and Caheratrant peat cutting for fuel led to the draining of naturally wet areas of land and in some areas agricultural soils were developed by initially ploughing the remnant organic horizon before the addition of more manuring components leading to the burial of the natural soil profile (chapter 2 and 4, sections 2.7.4 and 4.6.4). At Shirva the shrinkage of the domestic area and the demand for arable land led to the development of an amended soil above a once occupied area and this has preserved underlying archaeological features. A similar process has occurred at Olthof where prehistoric farms constructed directly upon the coversand ridges have been totally buried by the development of plaggen soils as a result of the increase in population and demand for agricultural land (Appels, 2003). It is therefore imperative that amended and anthropogenic soils be treated as cultural horizons which are interpreted alongside the structural evidence in order to determine the landscape history of a site.

8.3 THE PHYSICAL AND CHEMICAL STATE OF AMENDED AND ANTHROPOGENIC SOILS

- The overall soil pH results from the anthropogenic and amended soils were very similar at all three farms as a result of manuring with moderately acidic organic material (peat and turf). However, extensive sanding at Caheratrant across each land use area led to higher soil pH results.
- The loss on ignition results from Fair Isle and Caheratrant were considerably higher than at Olthof which considerably contrasted the spatial distribution of the soils discovered and indicates a high degree of post burial breakdown of organic inclusions.
- The soils analysed at all three farms contained very high fine sand contents as a result of mixing with natural soils and from the addition of

organic manures. At Fair Isle and at Caheratrant the soils also contained much larger sand sized particles which were a mixture of anthropogenic additions and natural inclusions.

- The magnetic susceptibility results indicate that alongside organic manure domestic waste, carbonised material and hearth ash were added to the soils at all three sites especially those on Fair Isle.
- Overall the multi-element results are very low especially the key elements associated with organic and inorganic manuring. Patterns of distribution could still be determined across landuse areas with a general decrease from settlement centres outwards at each site. On Fair Isle and at Olthof concentrations of the key elements P, Ca, Mg, K, Cu, Ni, Sr, Cs, Ba and Pb were considerably lower than results from previous analysis but at Caheratrant the results were much more consistent.

The physical and chemical state of the amended and anthropogenic soils at the three sites ranged considerably. At Shirva the soil pH results were very similar to other isolated Scottish islands including Skye (Entwistle, et al., 1998 and 2000) (chapter 5, section 5.2.1). At Caheratrant kaleyard the large quantities of calcium carbonate beach sand added to the anthropogenic soils led to distinctly higher soil pH results which mirrored the results determined by (Conry, 1971), (chapter 5, section 5.2.3). The deliberate process of sanding to increase the soil pH appears to be occurring on a much more sporadic basis outside the kaleyard. Micromorphology (chapter 6, section 6.5) and historical evidence illustrated by Conry and Mitchell, (1974) has clearly shown that it is occurring but the results may be directly affected by increased mixing by ploughing and biological action. The soil pH results gathered from Olthof were also very similar to the results gathered in past analysis (Pape, 1970) but this research has clearly shown that there are very subtle variations in results between the black and brown plaggen soils, as a result of modern ploughing and increased leaching (chapter 5, section 5.2.2) especially in the garden area. Similar patterns of results were also found on Fair Isle and this might indicate smaller additions of domestic waste material or acidic peat and turf organics (chapter 5, section 5.2.1). At Caheratrant the kaleyard sequence

contained clearly identifiable horizons of organic soils and beach sands which were identifiable by physical characteristics and the distinctive soil pH values. At each site the soil pH of the natural manuring components was determined (chapter 5, section 5.2.4). At Fair Isle and Caheratrant the peat soils contained low soil pH results and this may explain the decrease in results in the amended soil pH. However, unlike Caheratrant no direct evidence was found for the deliberate raising of the soil pH in the amended soils on Fair Isle as was suggested in the anthropogenic soils found by Chrystall (1994).

The amount of soil organic matter was also analysed in order to determine the level of amendment at each site. The results showed clear indications, along with other tests, of the amended and anthropogenic soils ability to retain organic additions since the abandonment of the farms. Overall, at each of the sites the loss on ignition results decreased with depth suggesting the input of less organic manure. The highest results were found in the kaleyard areas at Fair Isle and Caheratrant (chapter 5, section 5.3.1 and 5.3.3) with a gradual decrease away from the farm centres. At Olthof the loss on ignition results were considerably lower in all the landuse areas but a similar pattern of results could still be seen suggesting a higher input of organic matter in the area directly adjacent to the farm (chapter 5, sections 5.3.2). The quantity of organic material within the soils is however very reliant upon the modern landuse as suggested by Dercon, et al., (2005). At Fair Isle and Caheratrant the landscape is dominated by short grass and arable agriculture has not been conducted for over 100 years (chapter 2 and 4, sections 2.4.1 and 4.5.1) whereas at Olthof the continuation of arable farming and in particular deep ploughing may explain the low loss on ignition results (chapter 5, section 5.3.2). Low results were also found in the garden even though this landuse area was out of use today and this may be due to the amount of organic material in the heathland and grassland turves compared to the extremely high quantities in the peats used at the other sites. At Caheratrant the distinctive calcium carbonate horizons in the kaleyards had very low loss on ignition results which suggested that there was minimal mixing with organic material or that the organic content had been removed from the soil horizons by biological consumption and mixing (chapter 5, section 5.3.2). The results also illustrated clear variations with depth and can

be fundamentally linked with past and present landuse. At Fair Isle and Caheratrant the sites are covered by short grass but at Olthof there are a mixture of arable, wooded and grass environments and this has also led to distinctive variations in results as determined by Dercon, et al., (2005). Past changes in landuse were also found in an infield area of Shirva (chapter 2, sections 2.7.3). The soil sequence illustrated loss on ignition results very similar to those from Shirva and Busta kaleyards and suggested that in the past organic additions were considerably higher (chapter 5, section 5.3.1). Two buried peat soils were also identified at Shirva and Caheratrant with very high organic contents and these possibly indicate two areas of peat extraction which have been transformed into arable areas because of land pressures and due to the high organic content which would be ideal for the development of an amended soil (chapter 2 and 4, sections 2.4.1 and 4.5.1).

Particle size results from the soils of the three sites was very similar as a direct result of the local sandy geologies (chapter 5, section 5.4). But there are a number of other possible processes by which coarse particles may have entered the soil horizons. At each of the sites the natural soils have demonstrated high levels of sand sized particles and it is highly likely that mixing by ploughing and soil organisms has occurred but it is also very likely that the process of organic extraction from upland areas has also moved large quantities of sand particles into the arable soils as found on Orkney by Simpson, (1997). This process has been demonstrated at each of the sites through the micromorphological results (chapter 6, sections 6.2). Along with the sand it is also clear that silt and clay levels within the soils have derived from the addition of organic manures and it is these size fractions which are responsible for the storage of organic material. In Ireland the sand sized particles have also derived from the addition of calcareous sand and evidence from micromorphological analysis (chapter 6, section 6.5.1) demonstrated a dominance of calcite inclusions suggesting widespread addition across a number of landuse areas. On Fair Isle the low levels of calcite and dominance of quartz in the soils led to the suggestion that beach sand was not used on the island because of a lack of source material (chapter 6, section 6.3.1). The absence may also be due to the high soil pH results of the natural peats used for manuring compared to the more acidic peats used in Ireland. If this is the

case it is unusual for the Scottish Island area as past research has clearly shown that the addition of beach sand was a common occurrence (Fenton, 1978; Davidson and Simpson, 1984; Simpson, 1997). On Fair Isle the likely source of the fine mineral material is from wind blown sand and till which has also been shown to make up high levels of coarse particles in anthropogenic soils on Papa Stour (Carter and Davidson, 1998), (chapter 6, section 6.3.2). Across the Netherlands the process of plaggen manuring traditionally incorporates large quantities of sand inclusions present in organic heathland turves. But the use of the meadowland material has illustrated a small increase in silt and clay particles which are distinctive in the floodplain alluvial soils utilised in the early medieval period (Spek, 1992; Dercon et al 2005), (chapter 6, section 6.4.1 to 6.4.3). At Caheratrant and Fair Isle the amount of silt and clay particles in the amended arable soils may also derive from the natural till soils as demonstrated in chapter 6, sections 6.2 and 6.4, but they have been used to demonstrate differences between sites which may be due to anthropogenic amendment (Conry, 1971; Chrystall, 1994).

Elemental analysis of the soils was undertaken in order to determine the amount of human additions to the soils (chapter 5, sections 5.6.1 to 5.6.3). The results illustrate that at each of the sites there is far lower overall elemental concentrations than previous work has concluded illustrating either less input from settlement sources or the increase in post burial leaching by the movement of soil water through the soil profile. (Pape, 1970; van Smeerdijk, et al., 1995; Bryant and Davidson, 1996; Entwistle, et al., 1998 and 2000; Dercon, et al., 2005; Simpson, et al., 2005; Wilson, et al., 2005 and 2008; Davidson, et al., 2006; Meharg, et al., 2006).

Despite this, there were higher concentrations of P, Ca, Pb, Ba, Cu, Sr, Cd, Zn and As in the amended and anthropogenic soils than in the natural soils indicating either deliberate or accidental addition with time. At Fair Isle and Caheratrant the higher silt and clay levels in the soil has led to higher elemental concentrations whereas at Olthof the results were considerably less at each of the landuse areas (chapter 5, sections 5.6.1 to 5.6.3). The evidence also indicated a distinct reduction in P, Ca, Pb, Ba, Cu, Sr, Cd, Zn and As with the distance from the centre of settlements suggesting less input from hearths, fires and carbonised organic materials. At Shirva the amended

soils in the kaleyards and infield areas contained considerably higher amounts of phosphorus than the outfield area and although there were trace concentrations of other elements present these derived from the natural soils (chapter 5, sections 5.6.1 to 5.6.2). Past landuse changes at Shirva infield were detectable based upon the higher quantities of P, Ba, Cd, Cu, Ni, St and Ti in the Ap-4 horizon. The elemental evidence mirrored the organic content (chapter 5, section 5.3), soil pH (chapter 5, section 5.2) and magnetic susceptibility results (chapter 5, section 5.5) in suggesting that this was likely to have been an old kaleyard area within the proximity of a deserted farm house. Elemental variations from the black and brown plaggen soils at Olthof were remarkably similar but small variations were detectable in the black plaggen soils which mirrors the increase in rate of addition and change from the meadowland green turf to heathland turf. This pattern was most distinguishable in the garden area because of an increase in anthropogenic input with considerably less evidence of domestic waste in the inner and outer arable areas and increased elemental concentrations deriving from the natural coversands (chapter 5, section 5.6.2). At Caheratrant the most prolific element present was calcium as a direct use of calcareous beach sands and results from the kaleyards were particularly high and mirror the results determined by Conry and MacNaoidhe, (1999) (chapter 5, section 5.6.3). Results from the inner and outer arable areas were considerably lower and may derive from the natural till soils as well as from anthropogenic addition (chapter 5, sections 5.6.3). Overall despite the low results found during the multi-element testing at each of the sites it is clear that there are a number of elements which can be used to highlight the input of domestic waste and carbonised particles but in some places these elements have been found in small quantities in the natural soils making interpretation difficult. A number of elements were shown to increase with depth (Fe, Mg, Al, Mn, Ni, Ti) which suggested more influence from the natural soils and may have become included into the amended soils by heavy mixing as well as organic manuring components.

The results gathered from the bulk analyses have complemented the interpretations discussed in section 8.2 and although there are distinct similarities in manuring methods, the size of the farms, geology and pedology

the resultant anthropogenic soils have illustrated key differences across landuse areas and changes with depth

8.4 THE TEXTURE, COMPOSITION AND CHARACTERISTICS OF THE AMENDED AND ANTHROPOGENIC SOILS

- At each site the kaleyard and garden areas contain the most evidence of organic and inorganic manuring with a decrease away from the centre of the farmsteads.
- The amended arable soils from Shirva, Fair Isle and Caheratrant, Ireland contain more organic and inorganic evidence of the addition of manuring materials than at Olthof, the Netherlands, due to modern ploughing, soil organisms and leaching.
- Micromorphological evidence from Fair Isle suggests that the main organic component used in the arable soils is peat but that the manuring methods are on a considerably smaller scale to other sites on Orkney and Shetland.
- The black and brown plaggen soils of Olthof contain very similar micromorphological evidence with the main organic component consisting of meadowland and heathland turf.
- At Caheratrant micromorphological evidence shows that the calcareous sands were added to arable soils in a wide range of landuse areas but that the mixing with organic peat and turf occurred mainly in the kaleyard and inner arable areas.
- Micromorphological evidence of silty/clay laminations and excremental pedofeatures at each farm illustrates a higher biological and chemical breakdown of organic components than in natural soils as a result of manuring and cultivation.

8.5 THE IDENTIFICATION AND QUANTIFICATION OF MANURING COMPONENTS USED IN THE DEVELOPMENT OF AMENDED AND ANTHROPOGENIC SOILS

- Across each of the farms and landuse areas there is a reduction in the density and size of organic inclusions with depth especially peat, turf, and charcoal and carbonised organic inclusions due to natural post burial breakdown by organic and chemical processes.
- The kaleyard and garden soils contain the highest densities of black carbonised and black amorphous inclusions suggesting a greater input from settlement centres a pattern which mirrors the organic manuring process.
- The infield, outfield and arable areas contain considerably lower densities of organic inclusions and carbonised particles due to less anthropogenic addition.
- The void space results from Fair Isle and Caheratrant are larger than at Olthof suggesting more post burial breakdown of large carbonised particles.
- The use of zone counting and image analysis have complemented each other and highlighted similar patterns of the density and size of organic and inorganic manuring inclusions, especially black carbonised particles.

The description, identification and quantification of manuring components in the soil horizons was conducted by micromorphology (chapter 6, sections 6.2, 6.3 and 6.4) zone counting (chapter 6, section 6.6) and image analysis (chapter 6, section 6.7). The results have shown that the input of organic materials from Shirva and Caheratrant are very similar with distinctive concentrations of peat and carbonised peat inclusions alongside red and brown amorphous organics (chapter 6, section 6.2 and 6.4). These are similar results to past work conducted on Papa Stour, Shetland (Bryant and Davidson, 1996; Davidson and Carter, 1998; Adderley, et al., 2006). At Olthof, however, there are higher number of charcoal inclusions along with more turf and carbonised turf particles (chapter 6, section 6.3), results which develop

further the micromorphology of plaggen soils originally described by van de Westeringhe, 1988 and van Smeerdijk, et al., 1995. Across each landuse area large numbers of black amorphous particles were found and to assist the zone counting analysis a process of quantification by image analysis was conducted with particular focus upon the density and size of the particles and void spaces within the inclusions. At Fair Isle the greatest density of black amorphous particles were found in the kaleyard of the oldest and largest farmsteads (chapter 6, section 6.6.1) and the zone counting results illustrated a similar pattern (chapter 6, section 6.6.1 to 6.6.3). Of those amorphous particles identified there were also less distinctive patterns in the overall density and size of void spaces. In the kaleyard there was a clear link between the density of black carbonised particles with the density of void space (chapter 6, section 6.6.1 and 6.6.3) suggesting that a large number of particles thought to be amorphous black particles are likely to be small indistinct carbonised inclusions or heavily decomposed organic inclusions. In the infield and inner arable areas there was a decrease with depth in the number of black particles (chapter 6, section 6.6.2) however, the size of those particles increased with depth suggesting less breakdown and more conclusive evidence that there had been a change in landuse in the past. Complications in the image analysis methodology were clearly seen in the analysis of the buried peat soil horizons at Shirva and Caheratrant (chapter 2 and 4, sections 2.7.4, 4.6.4). The number of organic black fragments increased dramatically throughout the amended soil because of the very heavy mixing of the organic horizon but the analysis of the size of the inclusions and the void spaces present did highlight key differences between inclusions in the other landuse areas and acted as a partial experimental analysis by which other soils on Fair Isle could be compared (chapter 6, section 6.6). Difficulties did arise however with determining the differences between the deliberately added black peat organics and material deriving from the buried soil. This particular sequence of soils highlights clearly why analysis of the form and development of anthropogenic soils must be conducted using a range of qualitative and quantitative processes. Overall however, the combination of micromorphology, zone counting and image analysis (chapter 6, sections 6.2, 6.3, 6.4, 6.6 and 6.7) has successfully

highlighted the range in organic inclusions within the amended soil horizons. The black particles identified by the image analysis were different from other particles as they clearly contained heavily rubified edges from biological, physical and chemical breakdown and therefore represent highly humified peats not black carbonised particles, a process used to identify laboratory produced carbonised inclusions (Simpson, et al., 2003). At Olthof and Caheratrant the number of black amorphous particles were considerably lower than on Fair Isle which goes directly against the hypothesis that the farms with deeper anthropogenic soils would contain more carbonised particles and this must be due to the use of carbonised peat as a main manuring source alongside the soils ability to retain organic and carbonised particles. At each site however, there does seem to be a clear reduction in density and size of amorphous black particles with distance from the centre of the farms suggesting that the focus of deposition was in the garden hortisols (chapter 6, section 6.8.1 to 6.8.3). This complemented the zone counting analysis which also illustrated differences between the number and size of inclusions in the plaggen soils (chapter 6, section 6.7.1 to 6.7.3). At each landuse area there was a clear decrease in size with depth in the black plaggen horizons as a result of very heavy modern ploughing which has resulted in the increased breakdown of a large number of black inclusions, mirroring the results found at Valthe, Drenthe by van Smeerdijk, et al., (1995). In the brown plaggen soil however there appears to be a slight increase in number either because the carbonised particles, added during the medieval period, have been less affected by post-medieval ploughing or because heavy mixing of the black plaggen soil has created increased downwards movement of black amorphous particles. A similar pattern was also witnessed in the infield and outfield areas when addition was historically less abundant and particle degradation seems to have been affected to an even greater extent by biological, physical and chemical action. In contrast to this, the mean density and size of voids from Olthof suggested that in the garden the little variation between the results in the black amorphous particles could indicate the addition of charcoal material with very similar rates of decomposition indicating addition and mixing by spade rather than deep ploughing (Conry, 1971). At Caheratrant kaleyard the zone counting and image analysis both

illustrated a distinctive decrease of carbonised particles and black amorphous particles with depth which showed that traditional Irish spade techniques (Gailey, 1970) were in part preserving the smaller black amorphous inclusions (chapter 6, section 6.6 and 6.7). Unlike the other two sites the infield and outfield areas at Caheratrant revealed relatively high numbers of black amorphous particles but the sizes and number of void spaces were very small and may result from the addition of beach sand and heavy mixing with the natural.

8.6 THE ELEMENTAL COMPOSITION OF BLACK CARBONISED, BLACK AMORPHOUS AND ORGANIC INCLUSIONS IN AMENDED AND ANTHROPOGENIC SOILS FROM KALEYARD AND GARDEN SOILS

- Elemental analysis has shown that at each farm over 80% of black amorphous inclusions tested may be classed as black carbonised particles; Shirva, Fair Isle 99%, Olthof, Netherlands 89%, Caheratrant, Ireland 83%.
- At each site the O:C ratios of black carbonised particles ranged from 0.00 to 0.49 illustrating organic source materials including carbonised peat and turf at Shirva and Caheratrant (0.20-0.49) and charcoal and carbonised softwoods at Olthof (0.00-0.49).
- Overall the mean elemental concentrations in the black carbonised particles is very small and reflects the low results determined in the multi-elemental results from the bulk soil analysis but there are concentrations of P, Ca, K, Fe and Al which have not been identified in any other organic inclusions.
- At Fair Isle and at Caheratrant the larger black carbonised particles contain higher concentrations of P, Ca, K, Fe and Al as a result of less post burial decomposition. At Olthof the increase breakdown of black carbonised particles has resulted in considerably lower elemental concentrations.
- Concentrations of elements associated with human settlement and activity including the disposal of food and household debris, animal and

human faeces and industrial waste(Pb, Ba, Cu, Sr, Cl, S, Zn, and As) are considerably lower at all three sites suggesting burning away from industrial and settlement centres or that the elements were not prevalent in the organic fuel material.

The utilisation of multi-element analytical techniques has proved to be extremely useful in determining the difference between black amorphous and black carbonised fragments (chapter 7, sections 7.2 and 7.3). The overall soil elemental composition at each of the sites was identified using ICP-AES and this revealed a suit of elements which were comparable with other anthropogenic soils to indicate possible human additions and natural concentrations. More detailed elemental concentrations were gathered from specific inclusions within the anthropogenic soils with the SEM-EDS analysis to aid identification of black carbonised particles and their roles in loading and post-depositional retention of specific elements. The multi-element results (chapter 7, section 7.2.2 to 7.2.4) illustrated that at each of the sites the number of amorphous black particles was very small once the quantity of carbon was determined and indicates that in the kaleyard areas the addition of carbonised material in the past was likely to have been a major additional factor (chapter 7, sections 7.4.1 to 7.4.5) The density and size of carbonised particles identified today is therefore a result of addition and post depositional breakdown and this varies at each of the sites. This work has concluded, however, that because of the range of formation processes, the assumption is that black inclusions within the soil horizons are “carbonised” and this can lead to erroneous conclusions regarding formation. Elemental analysis of black inclusions was restricted to the kaleyard areas because of the high numbers identified by the micromorphology, zone counting and image analysis (chapter 6, sections 6.2, 6.3, 6.4, 6.6, 6.7) but more detailed analysis of the buried peat horizons at Shirva and Caheratrant would have aided the distinction between manuring materials added from settlement centres. The use of the scanning electron microscope has clearly proven to be a highly successful method to identify the elemental concentrations in black carbonised particles and organic inclusions within amended and anthropogenic soil horizons and more work is needed to separate natural

background elemental levels and concentrations associated with manuring. Oxygen to carbon ratios (chapter 7, section 7.3) have aided the identification and interpretation of possible source materials from each site and the results complement the micromorphological results (chapter 6, sections 6.2, 6.3 and 6.4). The results suggest that the majority of black particles are carbonised derivations of peat and turf fragments with larger numbers of charcoal at Olthof because of the increased availability of wood. The elemental results from the bulk soil samples illustrated small increases in elements associated with anthropogenic additions (chapter 5, section 5.6) and the SEM-EDS analysis suggested that the increases were being retained by a range of organic inclusions including the black carbonised particles possibly as a result of post burial elemental cycling. Small patterns could however be seen in the range of elements present in the black carbonised particles across the different landuse areas at each of the sites indicating a reduction of settlement and carbonised waste with distance from the farm centres and mirroring other bulk soil analyses.

The low elemental results gathered in both the bulk soil samples (chapter 5, section 5.6) and the black carbonised inclusions (chapter 7, section 7.4) are unlike the results gathered from other settlement sites. At Fair Isle the physical depth of the amended arable soils in the kaleyards (chapter 2, section 2.7.2) is directly contradictory to the density and size of black carbonised particles and the elemental concentrations within the soils and the carbonised inclusions is very different to the anthropogenic soils identified on Shetland (Wilson, et al., 2005; Davidson, et al., 2007). However, it is clear that the isolated island communities had very individual methods of developing arable soils. On Fair Isle the limited peat resource appears to have been used mainly as a for fuel in domestic fires resulting in large quantities of black carbon in all landuse areas but with limited elemental concentrations such as P, Al, Fe, Na, K, Ca unlike the organic and carbonised peat inclusion in the anthropogenic soils at Olligarth, Papa Stour (Wilson, et al., 2005), Nairn (Davidson, 2006) and St Kilda (Davidson, et al., 2007).

A similar process appears to have occurred at Caheratrant where amended arable soils were developed using peat and turf (chapter 6, section 6.3) and mixed with black carbonised particles which like Fair Isle contained

low elemental concentrations (chapter 7, section 7.4.5). The results determined in this thesis mirrored closely the results from soils analysed by Conry and MacNaeidhe, (1999).

The elemental results in the black carbonised particles mirrored the results from the Dutch plaggen soils and demonstrated a reverse relationship with depth to the farms on Fair Isle (chapter 3, section 3.5). Past elemental analysis has however shown that post burial breakdown and leaching has occurred even around the centre of settlement areas leading to almost a complete loss of elemental information (Oonk, et al., 2009a; Oonk, et al., 2009b). The elemental results do however correspond with the interpretation that charcoal particles are able to retain elemental data better than other black carbonised particles (Lehmann, et al., 2003) as the majority of black carbon particles identified at Olthof were of charcoal origin.

Despite the low elemental concentrations at all three sites the elemental results suggest a decrease in manuring with carbonised particles away from settlement centres as predicted and the ability for the black carbonised particles to retain small traces of elements over long periods of time.

8.7 SUMMARY

This thesis set out to determine similarities and differences between a range of anthropogenically amended and created soils from across north west Europe, and to analyse their role in determining the occupation and agrarian history in a variety of marginal geographical locations. The results ascertained in this thesis have illustrated clear differences between the type and distribution of soils at the three sites and the variations are directly associated with the availability of manuring material, traditional agrarian processes and natural soil processes acting upon the horizons and inclusions within them. Despite the clear differences there were also distinctive similarities in the soil distribution across landuse areas and geochemistry, which make these horizons exceptionally important to the complete understanding of the history of a site and this thesis has emphasised that only with a clear multidisciplinary analysis of sites and landscapes can a more complete understanding of

human influence be fully understood. Table 31 illustrates the major analytical findings of this thesis and each of the aims are discussed in chapter 8, sections 8.1 to 8.6 but the key aims illustrated in chapter 1, section 1.12 require summarising. This project has clearly shown that on Fair Isle there is a highly unique method of agrarianism being conducted which has created highly distinctive anthropogenically amended soils. Unlike other Shetland and Orkney islands they are not particularly deep, but compared to the shallow podzolic natural soils and unsuccessful occupation sites there is clear evidence of organic and inorganic inclusions which have created distinctive horizons. Deep anthropogenic soils were encountered at Olthof, the Netherlands where a considerably larger supply of meadowland and heathland turf was available to 'create' an organic horizon to grow crops. The distribution of these soils mirrored that of Shirva and Caheratrant with an emphasis on the manuring of areas directly around the farm centre. However, the geochemistry of the Dutch soils displayed surprisingly low pH and organic levels as well as fewer organic and carbonised inclusions. This was clear evidence of the distinctive post burial removal of manuring evidence and the reversion back to a podzolic soil indeed the exceptional depth of plaggen soils in the Netherlands may be a direct response by humans to dealing with extremely poor soils which lose added organic material very quickly. The soils at Olthof illustrated no clear way in which the farmers had tried to raise the pH which was in complete contrast to the soils analysed at Caheratrant, Ireland. This coastal site had a long tradition of the addition of calcareous sand to arable and garden soils resulting, once again, in deepened soil horizons around the farmsteads. There was also distinctive evidence to suggest that a similar manuring process to that of Fair Isle was being conducted, by which, the soils were regularly amended but not deliberately deepened other than in the kaleyards. The location of both Fair Isle and Caheratrant on the very edge of inhospitable environments would have required expert farming skills and it seems likely that the nurturing of crops within well sheltered kaleyards containing deeper organic and nutrient rich soils would have been essential to the survival of populations. One of the most important inclusions added to the soils at all three sites alongside organic material was a range of carbonised inclusions. Whether deliberately or accidentally added to the soils this thesis

has clearly shown that the highest density and area of inclusions actually derive from the shallowest soil sequence which in turn must have a direct relationship with the ability of the soils to retain nutrients and evidence of manuring. At Olthof historical documentation has shown clearly that material from settlements was often added to the soils and the absence of evidence does not indicate a lack of domestic addition. However, the current intensive arable activity on the site has increased the post burial decomposition of inclusions and therefore evidence of historic agrarianism.

The final contribution that this thesis has made is in furthering the understanding of the elemental composition of manuring components especially the carbonised particles. These inclusions are a frequent constant to both anthropogenically amended soils and archaeological horizons and it has been demonstrated here that there are distinctive patterns between the landuse history of a site, the geochemistry of soils and of the carbonised inclusions. Despite being small, the elemental concentrations within the burnt turf, peat and charcoal inclusions at Shirva and Caheratrant were enough to illustrate subtle landuse variation and even in the poorly preserved fragments at Olthof smaller reductions in elemental concentration could be seen. The low results may represent typical background results for marginal rural sites and further analysis on carbonised particles in urban and industrial areas might illustrate higher concentrations.

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