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ANTHROPOGENIC SEDIMENTATION IN ORKNEY :
THE FORMATION OF DEEP TOP SOILS AND FARM MOUNDS

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ABSTRACT

The formation of two sediment types in Orkney is elucidated. Both are demonstrated to be the result of anthropogenic sedimentary processes, deep top soils the result of arable activity, farm mounds the result of habitation activity.

Deep top soils commenced formation c 1200 AD either as a spontaneous innovation due to increasing population pressure or as a new agricultural technique introduced with monastic settlement. Cessation of deep top soil formation is attributed to the 1800s agricultural improvements when new forms of land fertilizer were introduced. The land use associated with deep top soil formation was the tunmal, the most intensively cultivated part of the early township. The materials used to sustain this intensive cultivation resulted in deep top soil formation. These materials were dominantly turf from the hill land and grazing land together with variable quantities of animal manure and a little seaweed. Deep top soils are located in West Mainland on naturally less fertile soils, where seaweed was in short supply and where population density was relatively high.

Farm mound formation commenced over a thousand year period, between the Iron Age and late Norse period. The major impetus to farm mound formation was the Norse settlement commencing c 800 AD. Two farm mounds examined in detail indicate a mound core was deposited using primarily a turf and manure mixture. At one site this alleviated a flooding hazard. The core was then covered with turves and peat, creating a living surface upon which pathways and fertilized garden plots are evident. In the latter stages of farm mound formation their use was as a midden where toft wastes, dominantly ash, were deposited. Farm mounds are restrictedin their distribution to Sanday and North Ronaldsay where early population levels were greatest and where ample seaweed was available for land fertilization instead of toft wastes.

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CONTENTS

CHAPTER 1

DEEP TOP SOILS AND FARM MOUNDS IN ORKNEY : THE OBJECTS OF STUDY

1:1 Introduction

One theme of increasing concern to geographers is the impact of man upon the natural environment. This thesis relates to one aspect of that theme, namely the formation of anthropogenic landforms. Awareness that certain human activities could cause modification of the earth's surface is not new. In classical times Pliny acknowledged the problem of soil erosion which he attributed to the cutting of forests (reported by Nir, 1983). Of the modern scholars, George Marsh was the first to re-discover man as a factor in earth surface modification (Marsh, 1873). In his major work "Man and Nature, or Physical Geography as Modified by Human Action", he clearly identified the chain reaction of forest clearance, slope erosion, sedimentation in river beds and flooding. Despite Marsh's work, except for the work of Sherlock (1922), relatively little early attention within geography was given to the influence of human activity on earth surface evolution. This was primarily because of the dominating force of environmental determinism and the concern to develop a geomorphological model, the culmination of which was the geographical cycle model of W.M. Davis. The scientific community as a whole also tended to ignore this area of study, partly as a result of the systematic division of nature into a multiplicity of parts, each with its own discipline.

Soil erosion during the 1930s in America's mid-west forced public attention for the first time upon the impact of agriculture. From this came the wider realization that not just agricultural activity was responsible for earth surface modification, but also other activities such as urbanization, mining, construction of transport networks, damming of water and refuse disposal (Thomas, 1956; Brown, 1970). In 1964 it could be claimed that in terms of the amount of work done, man was beginning to operate at the same order of magnitude as natural forces in the landscape (Golemb and Eder, 1964). Today with man's nuclear capability, his capacity to modify the earth's surface is probably many times greater than natural landscape forces.

It is without question that the activities of contemporary high technology man rank alongside natural forces in importance for landscape evolution. It is also now recognised that prior to the invention and availability of power machinery and nuclear capabilities man could generate small but locally important landscape features. These occur in widely differing environments and time periods. The generation of such landscape features was often the result of accelerated sedimentary processes, for example soil creep. Alternatively, human energy was frequently responsible for these new landscape features with man or his domestic animals physically carrying material from one area of the landscape to another. Significant aggradation of sediments has resulted from activities such as the preparation of fields for cultivation, the construction and occupation of settlement sites, warfare and domestic and "industrial" waste production (Limbrey, 1975; Butzer, 1982; Eidt, 1984; Evans et al (eds), 1975 and Limbrey (ed) 1978).

From the brief discussion above it can be stated that anthropogenic geomorphology is a young but now widely accepted branch of geomorphology (Haigh, 1978). Man is clearly an important factor in landscape evolution, creating a considerable diversity of landscape features, both spatially and temporally, as a result of a wide range of activities. This thesis contributes to our understanding of anthropogenic geomorphology by identifying the constraints on and the processes of formation of two anthropogenic landscape features in Orkney. Deep top soils and farm mounds are the terms given to the two landscape features examined by this thesis. These phenomena had already been identified and briefly described prior to the commencement of the work presented in the following pages. From these earlier observations the hypothesis was advanced that both deep top soils and farm mounds in Orkney were anthropogenic in origin. By way of introduction to the deep top soils and farm mounds this earlier work is now reviewed.

1:2 Deep Top Soils and Farm Mounds in Orkney : The Early Observations

Recent surveys in Orkney, the islands lying off the north-east corner of Scotland (Fig 1:1), identified what may be the result of two distinctive forms of earth surface modification caused by man. The Soil Survey for Scotland (1981) drew attention to a "deep top soil of the Bilbster Series, usually in excess of 75cm" which, apart from two small pockets on the island of Stronsay, is confined to the West Mainland of Orkney (Fig 1:2). Secondly, an archaeological survey of two of the North Isles, Sanday and North Ronaldsay, revealed prominent mounds, now known as farm mounds, up to 160m in diameter and 7m in thickness, associated with habitation sites (R.C.A.M.S., 1980). These mounds also present a distinctive spatial pattern in that their distribution is thought to be confined to the North Isles of Sanday and North Ronaldsay (Fig 1:3). Earlier observations gave rise to the hypothesis of anthropogenic origins for these features and it is these observations that are now described to establish how much weight should be given to this hypothesis.

1:2:1 The Deep Top Soils

The Bilbster Series in Orkney is a freely or imperfectly drained podzol developed on drift derived from flagstones, sandstones, limestones and mudstones of the Stromness Flags and Rousay Flags of the Middle Old Red Sandstone. Within this Series is a deep top phase which, according to the Soil Survey for Scotland (1981), is distinguished by the depth of its top soil, the S or S/A horizon. The depth of the top soil is stated as being usually in excess of 75cm. Its mapped extent is approximately 6.94km^2 occurring on the West Mainland and Stronsay on gentle slopes. Plate 1:1 gives some indication of the profile morphology of a deep top soil.

One "bench-mark" soil profile description for the deep top soils of the Bilbster Series was available with supporting laboratory data

Figure 1:1 The Orkneys

Islands which have deep top soils and farm mounds are underlined.

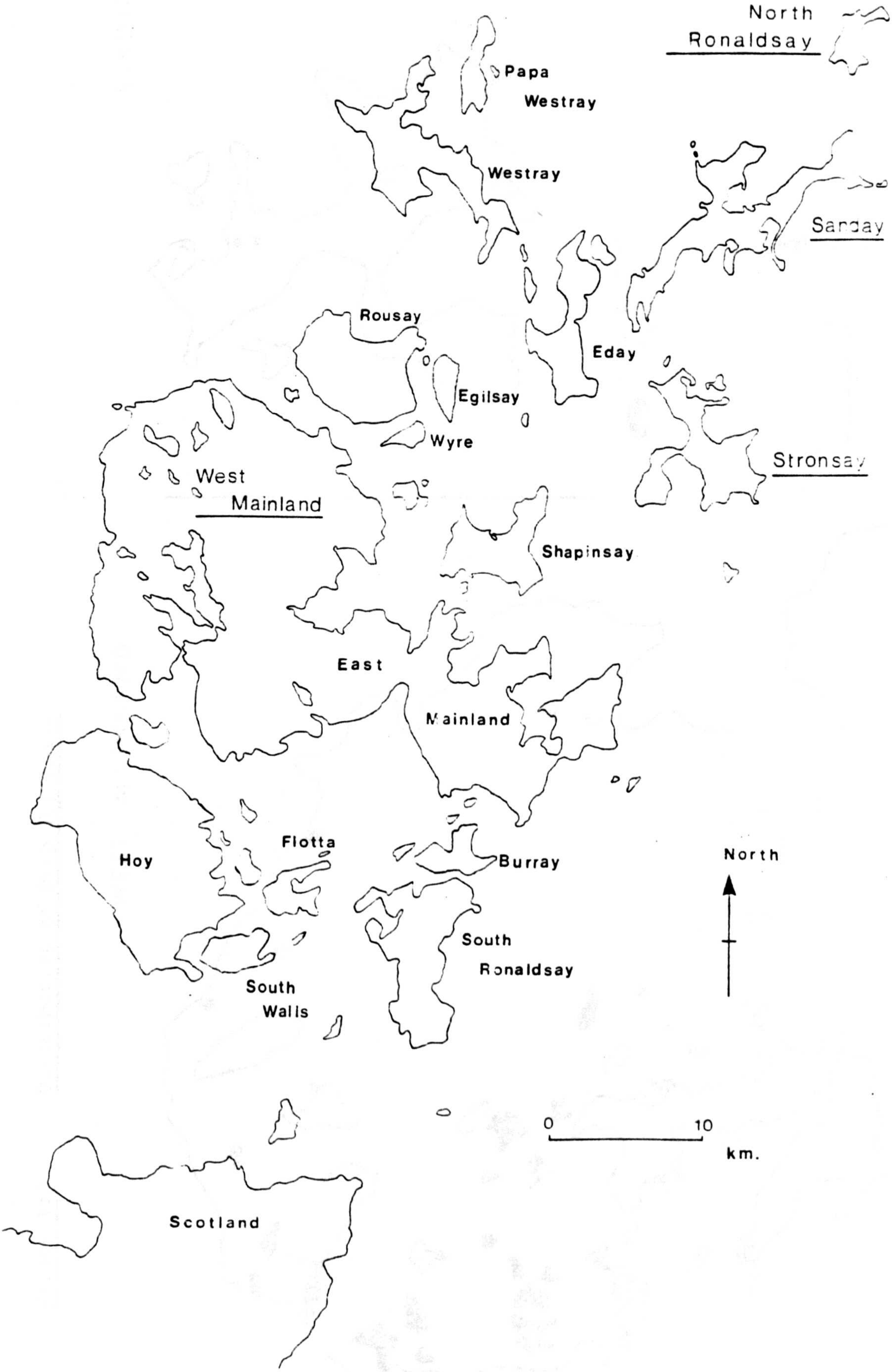


Figure 1:2 Distribution of Deep Top Soils

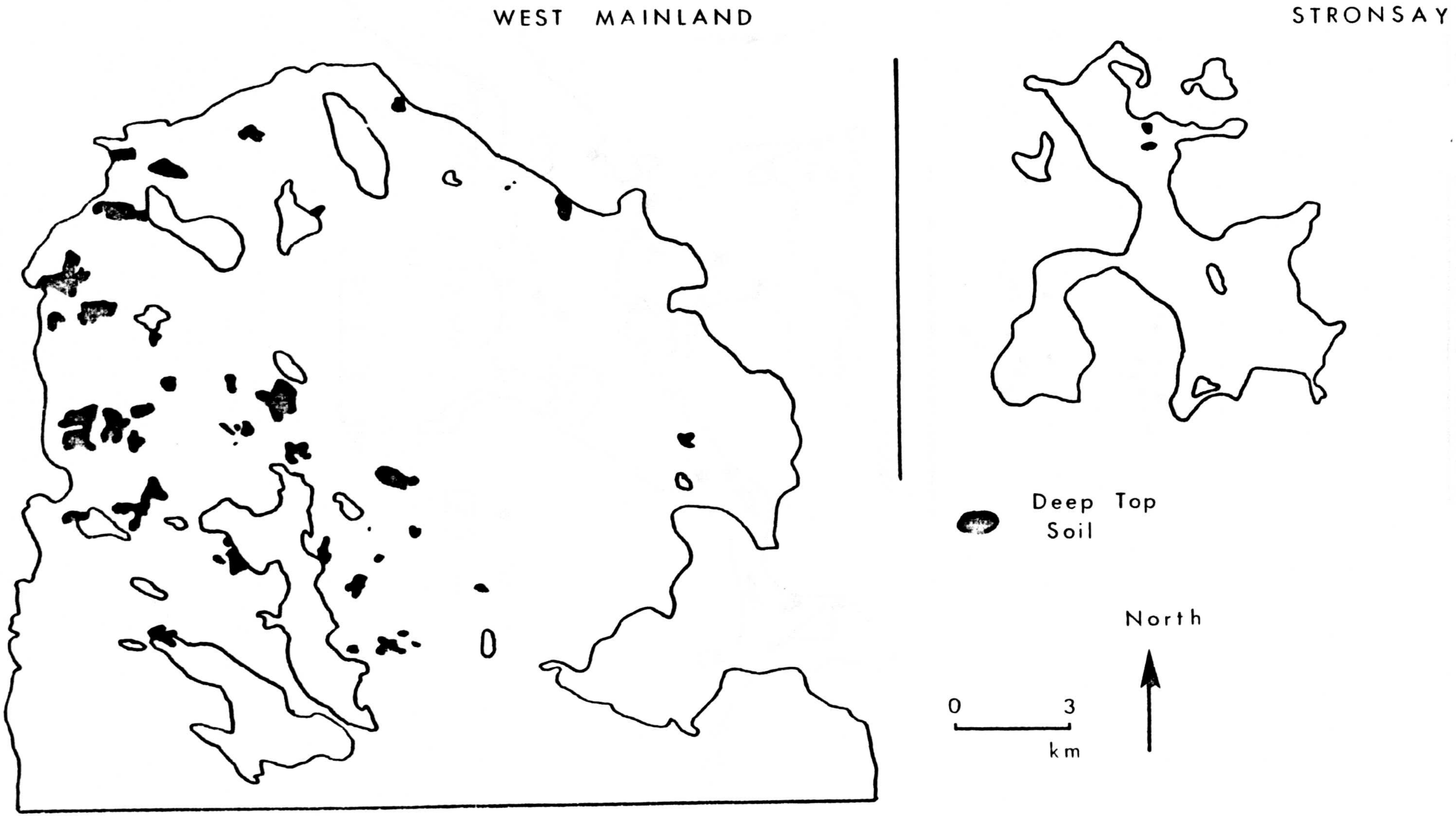


Figure 1:2

Figure 1:3 Distribution of Farm Mounds

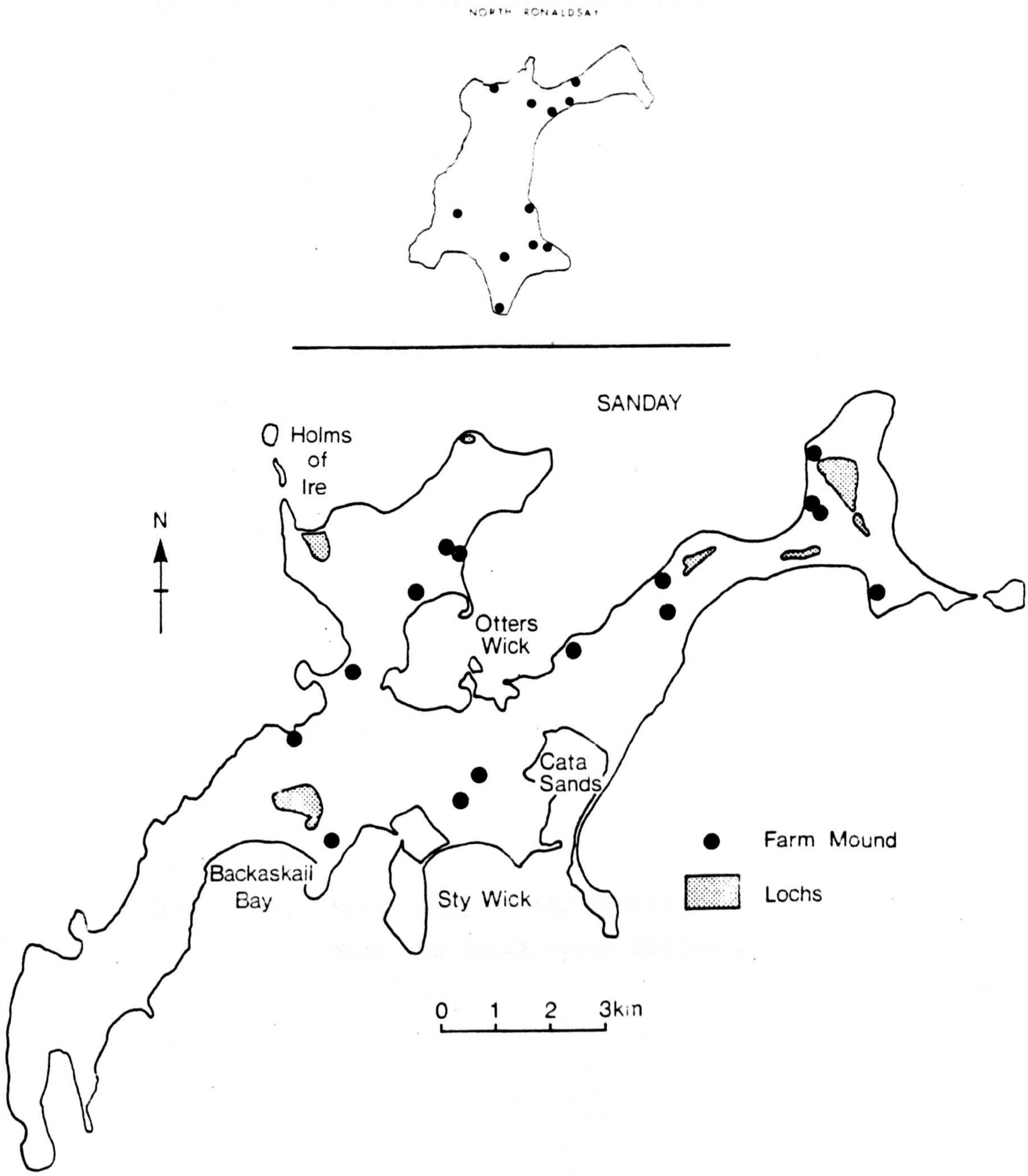
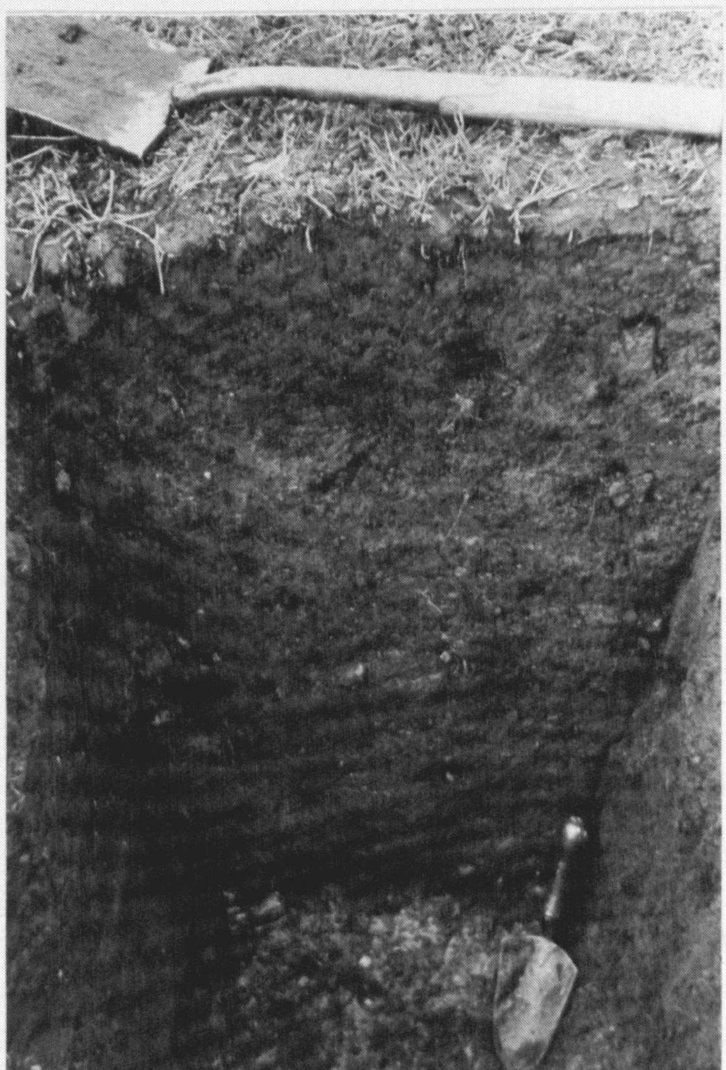


Plate 1:1 A Deep Top Soil Profile, Netherskail, Marwick

(i) Profile location close to farm.

(ii) Morphology of the profile.
Note the thick upper horizon.



(Table 1:1). This profile consists of a thick S (cultivated) horizon which grades from 10YR to 7.5YR in hue, with a clear change to a S/B horizon. These horizons overly a friable B_2 and stony indurated B_3 horizon. Laboratory derived data demonstrates a moderate to strongly acidic soil, apart from the upper S_1 horizon. Exchangeable magnesium, calcium and sodium are at their highest levels in the S_1 horizon. Potassium values are relatively constant throughout the S horizon. There is a general decline in exchangeable cation values down the profile, although magnesium shows a slight increase in the B_3/C horizon. Percent sand decreases to the S/B horizon and then increases to the B_2 and B_3/C horizon. Silt values exhibit a complementary trend while clay values increase gradually with depth. Values for the organic fraction and loss on ignition show a general decline with depth, although the S_2 horizon demonstrates a slight increase in carbon content relative to the S_1. Total phosphorous values are abnormally high, especially in the S horizon.

Examining the characteristics of this "bench-mark" deep top soil in relation to several systems of soil classification indicates the possible anthropogenic origin of this profile. The system of soil classification developed for England and Wales contains the following description of the thick man-made A horizon which is given as a diagnostic surface horizon. "This is a dark A horizon at least 40cm thick, that evidently results from addition of earth containing manure, incorporation of waste materials originating from former human occupations, or unusually deep cultivation of soil rich in organic matter. It has a colour value of 4 or less and contains at least 0.6% organic carbon throughout its depth. Organic matter is intimately mixed with the mineral fraction in all sub horizons and artefacts such as pieces of brick are commonly present." (Avery 1973; 1980).

The Soil Taxonomy of the U.S.D.A. (1975) describes a "plaggen" (plaggen = to cut sods) epipedon as follows; "The plaggen epipedon is a manmade surface layer that has been produced by long continued manuring. Sods or other materials used for bedding livestock in medieval times were spread with the manure on the fields being cultivated. Colour and organic carbon content depends

TABLE 1:1

PROFILE DESCRIPTION AND LABORATORY DATA FOR A DEEP TOP SOIL OF THE BILBSTER SERIES

Association: THURSO | Series: BILBSTER | Title: MIDHOUSE No 1 | Nat Grid: HY 340 181

Soil Type: PODZOL | Drainage: FREE | Alt: 180' | Slope/Aspect: 2^o S

Land Use Capability: 3 | Parent Material: DRIFT DERIVED FROM ROCKS OF THE MIDDLE OLD RED SANDSTONE

Horizon	Depth	% L on Ig	Soil Separates					Exchangeable Cations me/100g						% Base Saturation	pH H_2O	pH $CaCl_2$	Organic Fraction				Phosphorous mg P_2O_5/100g
			% Sand	% Silt	% Clay	U.S. % Sand	U.S. % Silt	Ca	Mg	Na	K	H	Σ				%C	%N	C/N	%OM	Total
S	5-15	14.0	47	42	11	35	54	15.1	1.54	0.44	0.22	9.6	26.9	64.3	6.4	6.0	5.73	0.79	4.9	9.9	660
S	30-40	11.2	41	45	14	31	55	3.09	0.35	0.23	0.21	15.8	19.7	19.8	5.6	4.9	5.98	0.53	11.3	10.3	700
S	50-60	8.6	39	44	17	24	59	1.69	0.18	0.23	0.27	16.6	19.0	12.6	5.4	4.8	3.65	0.40	9.1	6.3	1,024
B2	80-90	6.8	53	29	18	50	32	1.68	0.31	0.14	0.13	11.6	13.9	16.5	5.5	4.9	1.53	0.26	5.9	2.6	426
B3/C	125-135	3.8	53	28	19	44	38	1.65	0.43	0.09	0.08	4.8	7.1	32.4	5.8	5.0					140

DESCRIPTION

Horizon	Depth (cm)	
S_1	0-25	Very dark grey brown, 10YR 3/2; silt loam; moderate medium subangular blocky peds; firm and moist; moderate organic matter; frequent fine roots; few small stones; clear boundary
S_2	25-45	Dark brown, 7.5YR 3/2; silt loam; moderate medium subangular blocky peds; weakly firm and moist; moderate organic matter; frequent fine roots; few small stones; clear change to
S/B	45-70	Dark brown, 7.5YR 3/2 with brown 7.5YR 4/4; silt loam; moderate medium subangular blocky peds; weakly firm and moist; low organic matter; few fine roots; frequent small and medium stones; sharp change to
B_2	70-100	Yellow brown, 10YR 5/6; loam; massive - stone dominated; weakly firm but friable, moist; no organic matter; very few fine roots; many medium and large tabular fragstones; clear boundary
B_3/C	100-135+	Light grey brown, 2.5Y 6/2 and grey brown 2.5Y 5/2; loam; massive; very firm and indurated, moist; few yellow brown 10YR 5/6 mottles; no organic matter; no roots; many medium and large stones.

Source: The Soil Survey for Scotland

on the source of the materials. Commonly the epipedon contains artefacts such as bits of brick and pottery throughout its depth."

The system of soil classification for the Netherlands specifies three sub groups of plaggen soils with an artifically thickened A_1 horizon (de Bakker and Schelling, 1966). "Enk" earth soils, both brown and black, are very old arable fields, the A_1 horizon being thickened by the use of earth containing manure. "Tuin" earth soils are old horticultural soils of the alluvial districts raised as a consequence of the application of organic manure, mud from drainage ditches and sand. The Belgian (Tavernier and Maraechal, 1962), German (Mückenhausen, 1962) and French (see FitzPatrick, 1980) systems of soil classification also recognises the formation of thick manmade horizons by similar activities to those described above.

The point to be stressed is that the general characteristics of the Orcadian deep top soil (Table 1:1) closely resemble the criteria given as diagnostic for manmade surface horizons or "plaggen" soils by a number of soil classification systems. There are good grounds therefore for advancing the hypothesis that the deep top soils in Orkney are anthropogenic in origin. More specifically it seems likely that these soils arose by man physically transporting material into his arable areas to act as a fertilizer. That is, they were formed by anthropogenic sedimentary processes. This hypothesis is fully explored in Chapter 3.

1:2:2 Farm Mounds

Farm mounds are virtually exclusive to the islands of Sanday and North Ronaldsay. Some fifteen have been identified on Sanday and a further eleven on North Ronaldsay. A list of known mounds is given in Table 1:2. These mounds range from 50m to 205m in their longest axis although some have been severely cut into by coastal erosion. Plate 1:2 gives some indication of the morphology of these features. Deposits are apparently varied and may be up to 7m thick; they are consequently landscape features of major significance. The mounds would appear to be associated with the

TABLE 1:2

LIST OF FARM MOUNDS ON SANDAY AND NORTH RONALDSAY
BASED ON SITE SURVEY OF R.C.A.M.S.(1980) WITH REVISIONS
FROM PRESENT PROJECT

SANDAY

Farm Mound	Grid Reference
Westbrough	HY 663 424
Langskail	HY 684 444
Skelbrae	HY 676 437
How (A)	HY 661 393
Ayre	HY 652 412
Northskail	HY 681 445
Beafield	HY 687 405
Cleat	HY 704 427
Garbo	HY 721 434
Seater	HY 721 440
Tofts	HY 748 461
Lopness	HY 759 437
How (B)	HY 748 453
Sandquoy	HY 747 453
Geramont	HY 684 403

NORTH RONALDSAY

Ancumtoun	HY 760 555
Brae of Breck	HY 768 552
Brae of Sennabreck	HY 770 526
Cruesbreck	HY 762 524
Hooking	HY 767 534
Neven	HY 772 550
Quoybanks	HY 774 552
Sennes	HY 775 555
Southness	HY 768 526
Strømness	HY 761 513
Hill of Holland	HY 754 532

Plate 1:2 Farm Mounds on Sanday

(i) Tofts

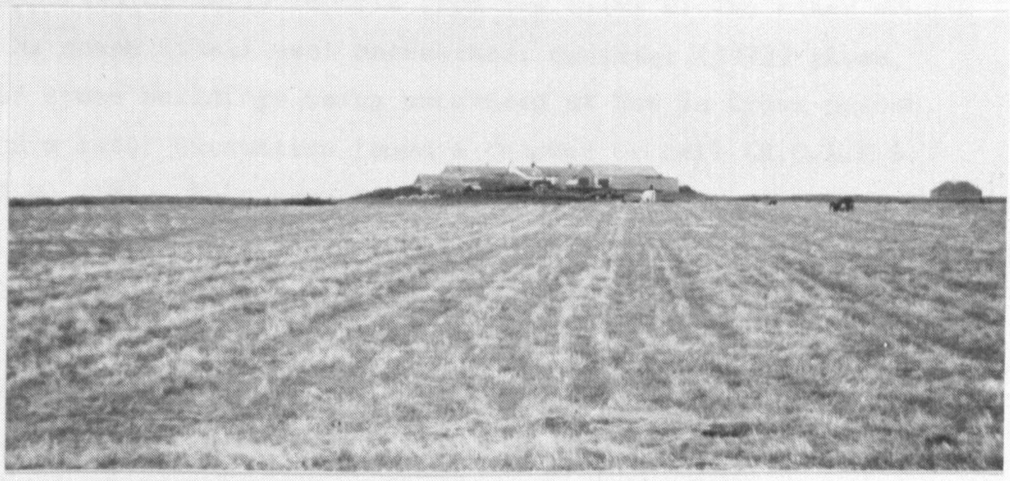
Note the farm buildings on top of the mound.

(ii) Beafield

Note the farm buildings on top of the mound.

(iii) Langskail.
(Eroded by the sea)

Note the dark coloured mound material in contrast to the lighter coloured dune sand.



areas of better soil from an agricultural viewpoint and hence their presence may reflect the agricultural value of the two islands on which mounds are found.

To earlier commentators on the mounds there was no doubting their anthropogenic origins, despite their varied composition. The R.C.A.M.S. report of 1980 originally postulated that the mounds were composed mainly of building debris with additional material being derived from wind blown sands. This is undoubtedly the case at some sites of which Hooking, North Ronaldsay (HY 767 534) is an excellent example. Here the only sedimentary material of direct anthropogenic origin is a thin band of some 45cm sandwiched in the dune complex. This hypothesis was further supported by early reports from the sites of two other mounds although the mound itself went unremarked. Cursiter (1923) gives evidence of stone buildings being uncovered at How in Cross parish, Sanday, and a later excavation found a chamber or cell (R.C.A.M.S. 1946 ii 40 No 158). This structure was referred to as a broch but it was noted that its true character had not been satisfactorily determined. At Tofts the late Dr F.T. Wainwright commented that there were "obviously many structures besides the farm" and an Ordnance Survey investigator reported the farmer as stating that he had found dry stone walling and numerous limpet shells in the vicinity of the farm buildings, suggesting an early occupation site (reported by Davidson et al 1983). Again however the mound itself was not commented upon. A second hypothesis postulates that the mounds consist mainly of farm manure (Fenton, 1978; Grant, 1843) or farmyard manure and house refuse (Pringle, 1874). Pringle, upon cutting into the mound at Westbrough, Sanday, (HY 663 423) revealed a mass of black soil intermixed with layers of ashes. He attributed the formation of the mound to the accumulation of farmyard manure and house refuse over many generations. Similar mounds exist at How (Sanday) and at other parts of the island, implying similar processes of accumulation. The R.C.A.M.S. report of 1946 (Item 138) also mentions the site at Westbrough which is described as a large featureless mound. One side had, at that time, been broken into revealing a deposit of dark coloured earth and stone intermixed with layers of limpet shells. There were no visible remains to suggest a broch. Finally the 1946

R.C.A.M.S. Report makes note of what is termed a kitchen midden along the seashore near Northskail on Sanday (HY684444, Item 143). No mention is made of any structure being apparent.

The third hypothesis combines certain elements of the previous two. An archaeological excavation at Pool, Sanday (HY619378) which commenced during the summer of 1983, revealed significant areas of stone structures within a matrix of "soil" material. Thus the mounds may have evolved through the construction of dwellings on top of farmyard waste and house refuse laid down before, during and after the settlement phase or phases. This site was first recognised in the R.C.A.M.S. 1980 Report as being unique in that stone structures were observable at various levels along an eroded shoreline section. These structures were considered to be either a Buckquoy type of Pictish house (see Ritchie, 1977) or an early Norse house. The importance and uniqueness of this site was emphasised by the first summer's archaeological field work of 1983 directed by Dr John Hunter. Pre-Pictish, Pictish and Norse structures were identified within the mound. (Hunter, unpublished manuscript).

The closest parallels to the Orcadian mounds would appear to be the farm mounds of the Helgøy region in north Norway (Bertelsen, 1979; Holm-Olsen, 1982). These Norwegian features are currently under archaeological investigation as a contribution to the analysis of the early economy and settlement pattern in this region. The majority of the known farm mounds cover an area of between 2,000 and 3,000m^2 with the depth of the cultural layers ranging between 1 and 8m. Simonsen, the first archaeologist to describe these features gave the following description: "A farm mound is not only a huge midden, it is in fact the old farmyard with long traditions. If one digs through the deposits one will find strata under strata, back to the initial phase of the farm. The mound has always grown because of household refuse, ruins of buildings, dung and other kinds of debris. Many of the farm mounds have given stray finds that show that the age of the deepest stratum is early medieval or even older". (Simonsen, 1954, translated by Bertelsen, 1979). Sixteen examples of farm mounds have been identified in the Helgøy region with dates of origin ranging from 940$\pm$80 to 1555$\pm$80 AD based on ^{14}C datings of the bottom cultural layers. In general however the farm mounds apparently go back no further than the second half of the 14th Century. This fits with resettlement in the Helgøy region due to growth of commercial fisheries in the 14th and 15th Centuries.

Excavation of these Norwegian mounds demonstrates that they are not simple unstructured accumulations of refuse. Six types of cultural deposits, based on origin, were used by Holm-Olsen (1981) for classifying the artifact and osteological material found during the mound excavations. These layers were as follows: (1) Top soil, which is often disturbed and/or mixed with midden material. (2) Refuse layers. (3) Buildings. (4) Outdoor constructions. (5) Fillings of sand or gravel. (6) General farm mound soil, which consists of mixed sandy soil and is considered as the general build-up of the mound between the houses.

Results of soil analysis from these excavations are not yet available (Holm-Olsen, pers comm) and therefore nothing can be said about the sedimentary/pedological characteristics of the Norwegian farm mounds. However, in view of the general morphological similarities between these and the Orcadian mounds, the term "farm mound" has now been ascribed to the Orkney mounds. It seems clear that the Orcadian mounds are anthropogenic in origin and are the result of anthropogenic sedimentary processes with man transporting material from one part of the landscape to another.

1:3 Thesis Objectives and Organisation

The task of the thesis is quite straightforward. It is to elucidate how and why deep top soils and farm mounds in Orkney formed. Section 1:2 has indicated that both are distinctive sedimentary landscape features and that there is good reason to believe that both are the result of anthropogenic sedimentation. Anthropogenic sedimentation is defined as the deposition in one part of the landscape of sedimentary materials, both inorganic and organic, that have been removed and transported from another part of the landscape by human effort. With this background in mind the thesis develops in the manner outlined in the paragraph below.

Chapter 2 provides the necessary natural sedimentary and pedological context within which the deep top soils and farm mounds are found. It is against this background that any statement on the nature and formation processes of the deep top soils and farm mounds must be evaluated. Chapter 3 examines in more detail the hypothesis of anthropogenic sedimentary origins presented in Section 1:2 above. With this hypothesis confirmed a conceptual model of anthropogenic sedimentation is developed in Chapter 4. This is based on the implicit approaches adopted by previous workers in this area of anthropogenic geomorphology. Chapter 5 tackles the first problem raised in the conceptual model by identifying the factors responsible for the initiation and cessation of deep top soil and farm mound formation. Chapters 6 to 9 identify the major processes of deep top soil and farm mound formation. The conceptual model would suggest that there are two key elements to anthropogenic sediment formation processes. One element is the land use activities associated with areas of the landscape receiving anthropogenic sediments. This dictates the movement of sedimentary materials by human effort. The second element is the materials used in the formation of anthropogenic sediments and the sources of these materials. Chapter 6 presents a set of multiple working hypotheses for these two elements based on the available historical literature on Orkney. Chapter 7 establishes the land use of areas receiving anthropogenic sediments while Chapter 8 identifies the materials of formation and their sources. Chapter 9 brings together the two elements of the anthropogenic sedimentary process which permits statements to be made about the evolution of deep top soils and farm mounds. Identification of the main spatial constraints on anthropogenic sedimentary processes in Orkney is the subject of the penultimate chapter. Here reasons are given for the distinctive distribution of the two anthropogenic sediments under consideration.

Taken together the chapters of this thesis represent a first approximation of the constraints and formation processes of the deep top soils and farm mounds. A summary statement on the formation of deep top soils and farm mounds in Orkney is presented in the final chapter.

CHAPTER 2

SEDIMENTATION AND PEDOGENESIS IN ORKNEY

2:1 Introduction

By outlining the sedimentary and pedological history of Orkney the context is provided within which it is possible to validate and evaluate the anthropogenic nature of the deep top soils and farm mounds. The chapter is essentially a review of the considerable body of evidence on Orkney's environment, past and present, which has bearing upon sedimentation and pedogenesis. Despite this considerable evidence, there are still major gaps in our understanding of the Orcadian environment. Thus the chapter must not be seen as a definitive work on sedimentation and pedogenesis in Orkney. Sufficient understanding can however be gleaned to establish the context of deep top soil and farm mound formation.

Major sedimentation has occurred in the area that is now known as Orkney since the lower Old Red Sandstone era. Much of the underlying Orcadian geology is comprised of sedimentary rocks. Thus the history of sedimentation in Orkney properly begins with a consideration of its geological formations. The chapter then moves on to identify the seven types of superficial deposits observable in Orkney today and to give reasons for their origins. Upon these deposits, given the relative landscape stability of Orkney over the Holocene period, soils will have formed. Consideration of the factors controlling soil formation (topography, vegetation, climate, parent material, man and time) together with the morphological characteristics of contemporary Orcadian soil profiles permits some inferences to be made about the pedogenic processes responsible for the mosaic of soil types seen in Orkney today. The chapter provides therefore the necessary understanding of sedimentation and pedogenesis in Orkney within which the deep top soils and farm mounds must be considered.

2:2 Sedimentation in Orkney; Geological Formations (After Mykura, 1975; 1976; Wilson et al 1935)

Subsequent to the emplacement of the basement geological complex, the environmental history of Orkney has been dominated by sedimentary processes (Fig 2:1 and Fig 2:2). Prior to the deposition of Old Red Sandstone sediments, a basement complex formed a range of low hills elongated in a north-north-west direction. Small outcrops of the underlying crystaline basement complex occur near Yesnaby and Stromness in West Mainland and on Graemsey, consisting of Moinian and Caledonian type metamorphic granites.

The oldest sedimentary rocks in Orkney are the lower Old Red Sandstone, represented by two formations. One, the Harra Ebb formation, rests unconformably on the basement rock. Part of its formation would appear to represent talus and alluvial fan deposits around the base of the complex hills. The Yesnaby sandstone formation consists of two distinct facies. Well graded sandstone with large scale tabular cross-bedding suggests aolian deposition in the lower formation. The upper unit consists of massive, ripplemarked, bioturbated and locally trough, cross-bedded sandstone. Thin beds of siltstone infill the fossil sun-cracks in the sandstones indicating that the sandstones are a water-laid sequence.

Large scale sedimentary processes continued into the middle Old Red Sandstone. Basal breccias of the lower Stromness Flags locally filled hollows in the old land surface. Their angular clasts are interpreted as a scree and talus deposit which was subsequently reworked and rounded. Above the basal breccias the Stromness Flags are made up of over 50 cycles of deposition formed by fluctuations in the level of a single large and generally shallow lake within the Orkney-Caithness area. Rhythmic sedimentation was regulated by the interplay of tectonic and climatic changes. Fine sediments were deposited first when the lake was at its deepest. Coarse sediments were later brought in by a river flowing from the north which pushed a delta out over the (by then) very shallow or dried up lake shore. The Rousay Flags are virtually identical to the Stromness Flags and so the comments concerned the environment of deposition of the latter apply equally well to the overlying Rousay Flag formation. Following the Rousay Flags in sequence of deposition are the Eday Beds. Essentially these deposits are fluvial in origin being deposited in the channels, alluvial fans and flood plains of relatively large rivers entering the Orcadian

Figure 2:1   The geology of Orkney (after Mykura, 1975).

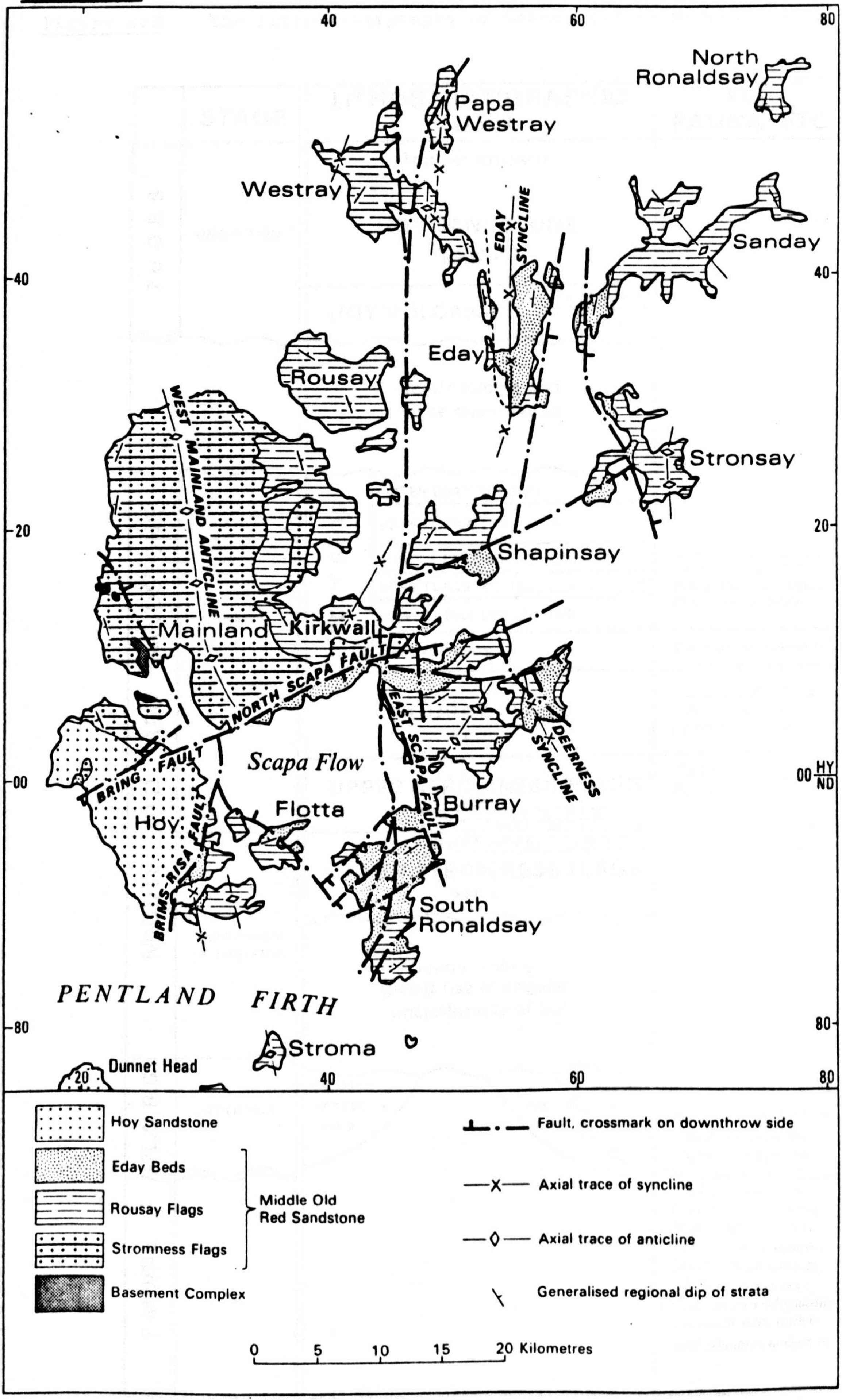
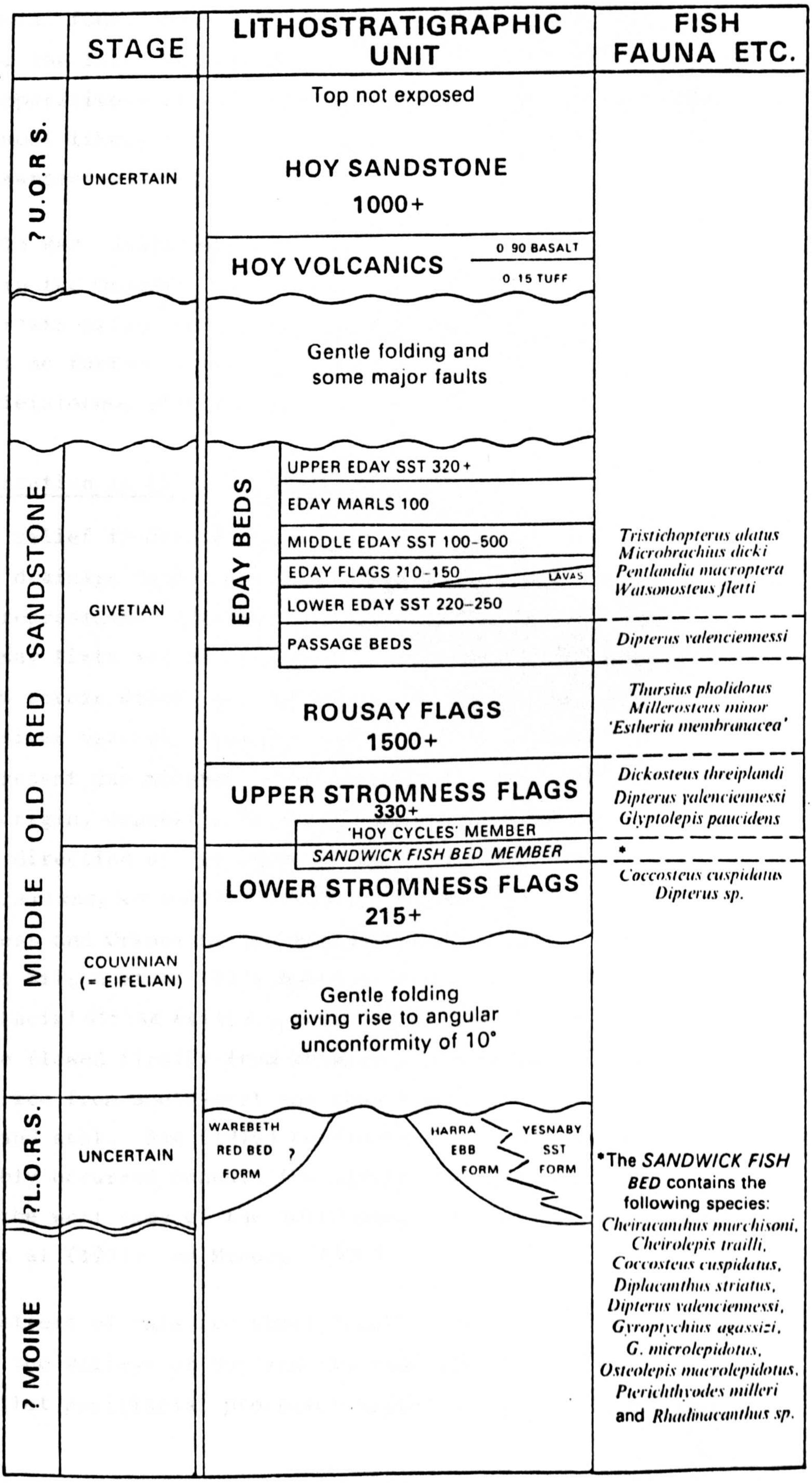


Figure 2:2 The lithostratigraphy of Orkney (after Mykura, 1975).



Thicknesses are given in metres

area from the south-west. The Eday sandstones were in all probability laid down by swift, braided and straight rivers which formed alluvial fans. Such a process of deposition has also been inferred for the later Hoy sandstones of the upper Old Red Sandstone, although comparatively little is known about this formation. Eday marls were most likely formed in the channels and alluvial plains of slower meandering streams.

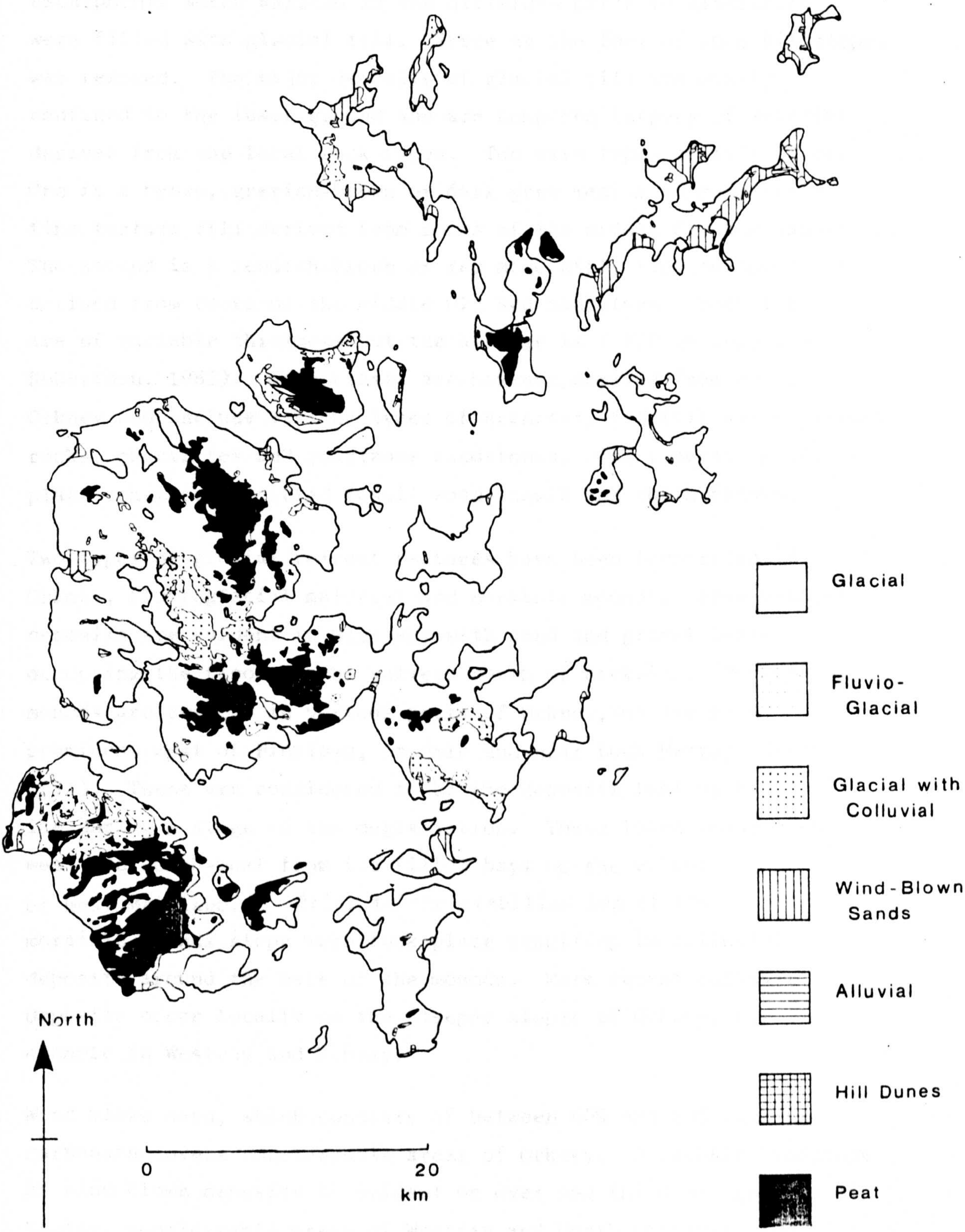
The upper Old Red Sandstone marked the end of major sediment deposition in the Orcadian area. Tectonic and volcanic activity has to a certain extent modified the original Old Red Sandstone deposits but no further evidence of major sedimentation occurs until the Pleistocene glaciations.

2:3 Sedimentation in Orkney; Superficial Deposits

Present day relief in Orkney began to evolve in the Tertiary period with drainage basins and river valleys draining towards a base level represented today by the concordant flows of Scapa Flow, Stronsay Firth and Westray Firth. The later Pleistocene glacial flow across Orkney was influenced by these drainage basins and river valleys. Present day superficial deposits, from which the present day mineral soils are derived, are predominantly glacial in origin, deposited by the Devensian glacial episode (Fig 2:3). The general direction of ice flow in north Scotland was eastwards from eastern Sutherland, but was deflected north-west and west north-west over Caithness and Orkney by the Scandinavian ice sheet (Peach and Horne, 1880; Wilson et al 1935; Mykura, 1976). Rae (1976) using primarily glacial striae evidence, identified three separate flows of ice. Ice flowed firstly from between south and south-east, followed by ice from south-east and then finally from between east south-east and east. Rae (1976) considers that these separate flows probably occurred beneath the single ice sheet with its origins on the west side of the North Sea, contrary to the findings of Wilson et al (1935) and Mykura (1976).

After the retreat of this ice sheet, local glaciers probably remained in the valleys of Hoy and the higher parts of Orkney mainland whilst periglacial processes operated over the remainder

Figure 2:3 Superficial sedimentary deposits in Orkney. (Based on the Soil Survey for Scotland, 1981).



of Orkney. The effect of the passage of the ice sheets was a smoothing out of the pre existing topography as a result of both deposition and erosion. Depressions between the small rocky escarpments which existed in the hillsides prior to glaciation were filled with glacial till. Scree at the foot of such hillslopes was removed. The major deposits of glacial till are mostly confined to the lower ground and are composed largely of material derived from the local rock types. Two main types of till occur. One is a brown, greyish-brown or dark grey medium to moderately fine texture till derived from rocks of the middle Old Red Sandstone. The second is a reddish-brown or red moderately fine textured till derived from rocks of the middle Old Red Sandstone. Both tills are of variable thickness but the average is c 120 cm (Dry and Robertson, 1982). Some clasts are, however, derived from outside Orkney and include various types of granitic, felsitic and schistose rocks, quartzites and quartzose sandstones, dark limestones with plant remains, calcified fossil wood, chalk and chalk flints.

Two types of glacial retreat features have been identified in Orkney, fluvioglacial material and morainic mounds. Fluvioglacial deposits are evident in West Hoy with sand and gravel lenses occupying the floor of the valleys north of Rackwick. Morainic mounds are evident in various parts of Orkney, but are most prominent west of Finstown, at Evie and near Loch Harray (Mykura, 1975). These are considered to be the deposits left by lobes of ice during a stage in the deglaciation. These lobes readvanced west and south-west from ice-filled bays up the valleys of West Mainland. Prior to the stabilisation of the morainic mounds, slope wash took place resulting in colluvial deposits around the base of the mounds. More recent colluvial deposits occur locally on the steeper slopes of Orkney, for example in Westray and Rousay.

Wind blown sand, which consists of between 60% and 90% calcium carbonate covers considerable areas of Orkney. A machair landscape of wind blown deposits is evident on over one third of the area of Sanday, considerable areas of Westray and North Ronaldsay and smaller areas of Mainland. Based on the analysis of fossilised land snail populations and pollen,there is a clear environmental change involving the destruction of birch-hazel scrub during the Neolithic period commencing c 5000 B.C. The destruction of this vegetation community can be correlated with the onset of sand-blow in and around the Bay of Skail (Evans, 1977; Spencer, 1975; Keatinge and Dickson, 1979). Exact processes of scrub woodland destruction are unclear but the main possibilities are (1) the accumulation of the blown sand itself, inferring some climatic change; (2) the increasing effect of salt spray as Flandrian sea levels reached their maximum; (3) the activities of Neolithic man and his grazing animals; (4) any combination of the above three. However, without fully understanding the origins of the blown sand,it is still possible to state that aeolian processes have played a major part in moulding considerable areas of the contempory Orcadian landscape.

Aeolian action of a different sort has combined with frost action to produce small areas of hill dunes in upland Hoy (Goodier and Ball, 1975). These are areas of vegetated ground within zones of erosion that stand above the surrounding deflation surface. The stratigraphy of the dunes represent a complex sequence of cyclic accretion and stability phases in the accumulation of the hill dune, in a manner similar to the formation of sand dunes. Contempory geomorphic processes in this area are not accretional except locally where redeposition occurs near the windswept dune faces.

To complete the review of the sedimentary history of Orkney,mention must be made of alluvial deposits. No studies of recent alluviation have, to the author's knowledge, been undertaken in Orkney. The primary reason for this is presumably the fact that there are today no large areas of alluvial deposits in Orkney. A process which has been so dominant in the sedimentary history of Orkney is now minimal.

Finally, although strictly speaking peat is not a sedimentary material, brief mention is made of these organic deposits to complete the picture of superficial deposits seen in Orkney today. Blanket peat covers extensive areas of West Mainland, Hoy, Rousay and Eday (Fig 2:3) and is considered to have commenced forming c 3400 B.P. A combination of climatic deterioration and the removal of tall herb and fern plant communities by man and his grazing animals may have initiated the more acid conditions required for peat formation (Keatinge and Dickson, 1979).

In conclusion, this review of superficial deposits in Orkney has identified six sedimentary processes as being of importance in the moulding and shaping of the contemporary Orcadian landscape. Organic peat deposits are also of importance, covering considerable areas of Orkney today. Some of the processes leading to the deposits described above appear to have been initiated by man. The question remains, however, as to whether man has created new landforms in Orkney by carrying and depositing sedimentary materials. Do the deep top soils and farm mounds represent this anthropogenic sedimentary process?

Because the deep top soils and farm mounds are essentially superficial sedimentary deposits, it is to be expected that the pedogenic processes of biological activity, mineral weathering and leaching, will be operating upon these sedimentary bodies (Duchafour, 1982). Similarly, pedogenic processes will be re-arranging and altering the constituents of the superficial sediments in Orkney described above (Section 2:3). The key to identifying the sedimentary processes of any sediment lies in the properties of that sediment. Thus consideration must be given to the processes of pedogenesis that alter sedimentary properties both during and after sedimentation if sedimentary processes are to be elucidated. The section that follows outlines the factors that control pedogenesis in Orkney. Knowing what the controls of pedogenesis are and were, assists with the attempt to reconstruct the more important pedogenic processes in the Orcadian landscape.

2:4 The Factors of Soil Formation in Orkney during the Holocene

According to the classical approach, processes of soil formation are controlled by five factors, viz, parent material, topography, organisms, climate and time (Jenny, 1941, 1980). These factors interact to produce a unique set of soil properties at any point in the landscape. Given that Orkney has been inhabited since the Neolithic some 5000 years B.P. (Miller, 1976), it is necessary to incorporate the activities of man into the factors of soil formation. This can be done in a number of different ways. Jenny (1941) originally considered the role of man in soil formation within the "organisms" factor. Bidwell and Hole (1965) gave evidence of how man had altered each of the classical five factors of soil formation thus influencing the development of a soil. Yaalon and Yaron (1966) considered it best if a new zero time for soil formation were identified with that new zero time identifying the commencement of human activity upon the soil. In this scheme the original soil becomes the parent material for the man-directed functions. For the purposes of this chapter, the mechanisms by which man can influence the five classical factors of soil formation are considered (Bidwell and Hole, 1965). The characteristics of the five soil forming factors in Orkney are now described. Parent materials, topography, organisms and climate are each considered separately within a temporal framework. Because these factors influence one another, there is inevitably some degree of overlap.

2:4:1 Parent Materials

An outline of the known sedimentary processes responsible for the formation of parent materials upon which the Orcadian soils have evolved is already given in Section 2:3. It is worth reiterating that the bulk of Orkney's mineral soils have evolved on glacial till deposits left by the last (Devensian) glaciation. Some characteristics of the glacial deposits in Orkney are now given.

The Soil Survey for Scotland use the term Association to denote areas of similar parent material. In Orkney two major associations, the Canisby and the Thurso, occur (Dry and Robertson, 1982). The

Canisby Association consists of drifts derived from flagstones and sandstones of middle Old Red Sandstone age. It is characterised by a compact, slowly permeable reddish brown or red moderately fine textured, moderately stoney till. This Association dominates East Mainland, South Ronaldsay, Flotta, Shapinsay, Stronsay and Westray. The Thurso Association also consists of drifts derived from sandstones and flagstones of middle Old Red Sandstone age. Characteristic of this Association in Orkney is a compact greyish brown or yellowish brown medium to moderately fine textured till and a stony brown, moderately coarse or medium textured till. Dominantly around Finstown, a morainic drift of coarse or medium texture occurs. The Thurso Association dominates the landscape of West Mainland.

Other Associations only occur locally; the Darleith Association derived from basalitic lavas and tuffs in north-west Hoy; the Dunnet Association derived from upper Old Red Sandstone drift also in Hoy; the Lynedardy Association in the Stromness area composed of drift from the middle Old Red Sandstone and granite and schists from the basement complex; and the Rackwick Association composed of the fluvioglacial sands and gravels found around Rackwick, Hoy.

More recent deposits which form parent materials for soil formation in Orkney are the calcareous wind blown sands, the Fraserburgh Association of the Soil Survey for Scotland, and the organic blanket peat deposits. The Fraserburgh Association is characterised by coarse textured, weakly structured calcareous sands high in pH. Blown sands cover considerable areas of Sanday, Westray and North Ronaldsay. It seems probable that such deposits began forming c 5000 B.P. possibly as a result of anthropogenic activity (see Section 2:3). Organic blanket peat formation is thought to have commenced c 3400 B.P. on West Mainland, Rousay and Eday. Again man or his grazing animals are thought to have provided the initial trigger for peat formation by destroying the tall herb-fern plant communities dominant in Orkney prior to this period (See Section 2:3).

2:4:2 Topography and Sea Level Change

Today the topography of Orkney with its origins in the Tertiary period, is a landscape of broad lowland and low gentle convex hills generally below 75m (Fig 2:4). On Mainland a number of smooth rounded hills rise to a maximum of 268m (Ward Hill). West Mainland consists of an extensive plain occupied in its lower parts by Lochs Harray and Stenness. This plain can be attributed to the West Mainland anticline (Fig 2:1) resulting in weakened rocks in this area more susceptible to erosion thus forming lower ground. An escarpment dominates the plain to the east and north and low hills dominate to the west. East Mainland, Burray and South Ronaldsay represent the remnants of a dissected plateau which today is of low level and low gradient. The northern isles of Sanday and North Ronaldsay are predominantly flat and low-lying being mostly less than 20m above sea-level except for the Spur Ness peninsula, Sanday, which represents a continuation of Eday. Lying in a syncline (Fig 2:1) rocks of Eday and the Spur Ness peninsula are resistant to erosion resulting in a slightly greater relief than their surroundings. Hoy, underlain by the comparatively resistant rocks of the upper Old Red Sandstone is a more rugged terrain with Ward Hill rising to 279m.

There is some evidence to suggest a post glacial rise in sea level around Orkney. Stratified beach deposits cover soils on the Deerness peninsula and a few undated structures are known to be now under water. Conversely there is little evidence for the isostatic adjustment of the Orcadian archipelago since being covered by ice which is evident elsewhere in Scotland. The result is that the Orcadian landscape has a "drowned" appearance. Convex slopes are dominant and rivers have been truncated leaving only small streams (Laing, 1974; Miller, 1976).

Clearly, despite the low relative relief of Orkney there is considerable diversity in topography throughout the archipelago Furthermore, with time, relative heights have been altered due to the post glacial rise in sea level and possibly also tectonic change. Both of these observations have implications for the formation of soils, influencing drainage conditions and climatic parameters by altering landscape positions relative to sea level.

3:4:3 Vegetation

Vegetational history, based on pollen analysis is comparatively

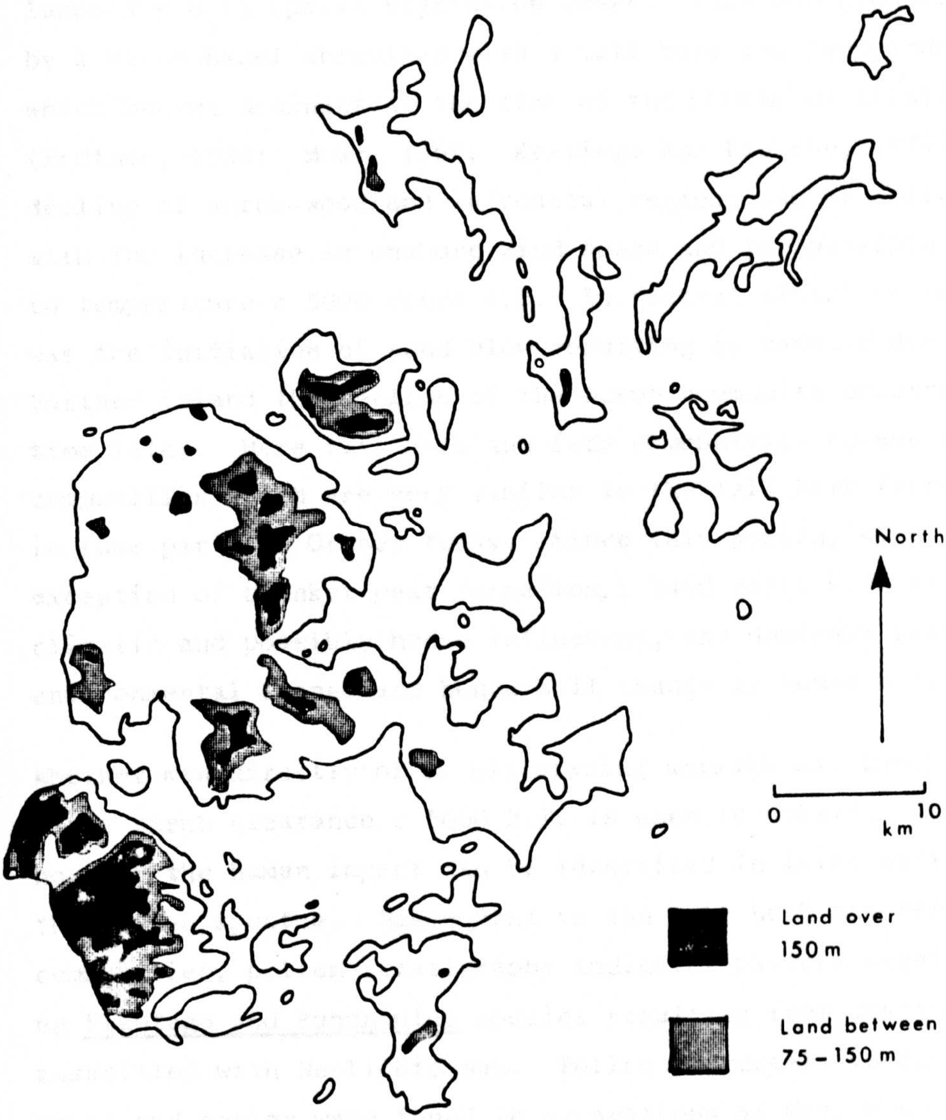


Figure 2:4 The topography of Orkney.

straightforward in Orkney (Table 2:1). The late post glacial Devensian period is considered to have produced a comparatively barren landscape with sparse vegetation cover. This was gradually replaced by a birch-hazel shrubland with a tall herb and fern understorey which became dominant at the time of the Flandrian climatic optimum (Erdtman, 1924; Moar, 1969; Keatinge and Dickson, 1979). The decline of scrub-woodland in coastal regions can be correlated with the increase in onshore wind speed and the possible drop in temperature c 5000 years B.P. In coastal districts the consequence was the initiation of sand blow resulting in machair development. Further inland the decline of the scrub community occurred some time later. Here tall herb and fern communities became dominant, communities which are very similar to the tall herb ferns seen in some parts of Orkney today. Since this period, with the exception of blanket peat formation, c 3400 years B.P. in response to climatic and possibly human influences, the dominant factor of environmental change and hence soil change is human activity.

Whether man directly or by his grazing animals was involved in the early shrub clearance c 5000 B.P. is open to debate. Certainly however the human impact can be identified in later sections of the pollen spectra. Subsequent to the tall herb and fern communities, pollen stratigraphy indicates pasture vegetation, eg Plantago and Rununculus species resulting from grazing pressure associated with Neolithic man. Pollen of cereals including oats, wheat and barley were found in excavations at Maes Howe and at Stenness(Jones, 1979; Godwin, 1956; Caseldine and Whittingdon, 1976). These landscape changes marked the beginnings of anthropogenic modification, although there appears to be a hiatus of human activity in Orkney between the late Neolithic c 3900 B.P. and the middle-late Bronze Age c 2900 B.P. (Renfrew, et al 1976; Huxtable et al 1976). After this hiatus it is generally accepted that gradual arable intensification occurred. From the Norse settlement (c 800 A.D.) to the 1830s,burning took place to clear heather and scrub for agriculture and seaweed, manure and parings of turf were known to be added to the arable land (Bullard, 1975). The abolition of the run-rig system of

TABLE 2:1 A vegetational history of Orkney (after Davidson and Jones, 1985).

British Pleistocene stage		Other sub-divisions		Radiocarbon date ad/bc Calendar date AD/BC	Nature of vegetation	
INTERGLACIAL	FLANDRIAN	LATE FLANDRIAN	POST-GLACIAL	Present	Agricultural land, machair, fen, tall herb and fern communities, dwarf-shrub heath dominated by heather, blanket peat with cotton grass	
				1000 ad 1030 AD		Blanket peat formation begins
				0 ad 60 AD	Pasture land with grasses and ribwort Arable land with mugwort, crucifers and cereals	
				1000 bc 1250 BC	Heathland dominated by heather Machair with sea plantain and bucks-horn plantain Tall herb and fern communities including umbellifers and polypody	
		MIDDLE FLANDRIAN		2000 bc 2530 BC		
				3000 bc 3785 BC		Scrub decline begins
				4000 bc 4845 BC		
		EARLY FLANDRIAN		5000 bc c 5900 BC	Birch-hazel scrub Tall herb and fern communities	
				6000 bc		Scrub development begins
				7000 bc		
				8000 bc	Denser heathland with juniper and crowberry	
GLACIAL	DEVENSIAN	LATE DEVENSIAN	LATE-GLACIAL		Open grass and with mugwort Heathland with crowberry	
				9000 bc	Denser grassland Better developed heathland with crowberry and juniper	
				10 000 bc	Open grassland with sorrel and mugwort Heathland with crowberry	

agriculture commencing in the 1830s was followed by the introduction of new species of cultivars including clover and turnip. Also, extensive drainage programmes were undertaken, artificial manures were introduced and reclamation of the Hill-lands was accelerated.

Today rearing of livestock(cattle) is the main pursuit taking place on the land with some oats and barley grown as cattle feed. Reclamation of hill land still continues today although at a slower rate than that which took place during the 1800s. A large proportion of the Orkney landscape is therefore either cultivated or under permanent pasture dominated by grasses such as rye grass and dogs tail. Less well drained soils have been altered to form a permanent pasture dominated by heath bedstraw and meadow grass. Considerable areas of semi-natural vegetation do however still exist, particularly where there is poor drainage, near the coast and in upland areas.

Upland areas are dominated by moorland communities. Dry and moist Atlantic heather moors (Carici bineruis-Erictetum cinereae) occur in areas of less exposure. As exposure increases northern Atlantic heather moor (Narthecio-Erictetum tetralicis) gains dominance. Oroartic plant communities such as Alectorio-Callunetum vulgaris and Festuco-Racomitrietum lanuginosi are found on the highest hills of Orkney, in Hoy. Mountain white bent grassland and bog whortleberry heath are found in seasonally wetter areas of this environment.

A clear zonal sequence of maritime plant communities is evident on exposed cliffs and headlands which carry a salt spray influenced vegetation. The buck-horn plantain community colonizes the cliff edges, is succeeded by pasture of the spring squill and fescue species which in turn are succeeded by a mosiac of squill/fescue species and a sea plantain - crowberry community. Zonal sequences of vegetation communities are also evident on the coastal links and dunes. Foreshore (eg Orache species), foredune (eg Twitch species) and yellow-grey dune (eg Marran grass) communities may all be recognised. To the rear of the dune systems on the dune slacks and flats, eyebright-red fescue pasture may have developed on the drier soils. Frequently however such sites have been agriculturally improved.

Areas of poor drainage, ie flushed peaty slopes, basins and alluvial channels, occur throughout the landscape. The presence of one particular community or another is dependent on the nutrient status of the habitat and the base saturation of the flush water. Dystrophic communities include common cotton grass and common sedge. Nutrient rich sites are colonized by mires such as flea sedge, bog rush and few-flowered spike rush. Natural woodland only occurs in Berriedale and the Segal burn valley, both on Hoy. Patches of common sallow scrub and dry grassy birchwood communities have colonized sheltered slopes (Dry and Robertson, 1982; Bullard and Goode, 1975).

It is apparent that both in space and time the vegetation of Orkney has changed considerably in response to climatic fluctuations and human interventions. Such vegetation changes have had repercussions for the sedimentary history of Orkney with for example the development of wind blown sand deposits. Inevitably vegetation changes with time and across the landscape will also influence soil development. How this might be so is discussed once the climatic characteristics of Orkney, past and present, are outlined.

2:4:4 Climate

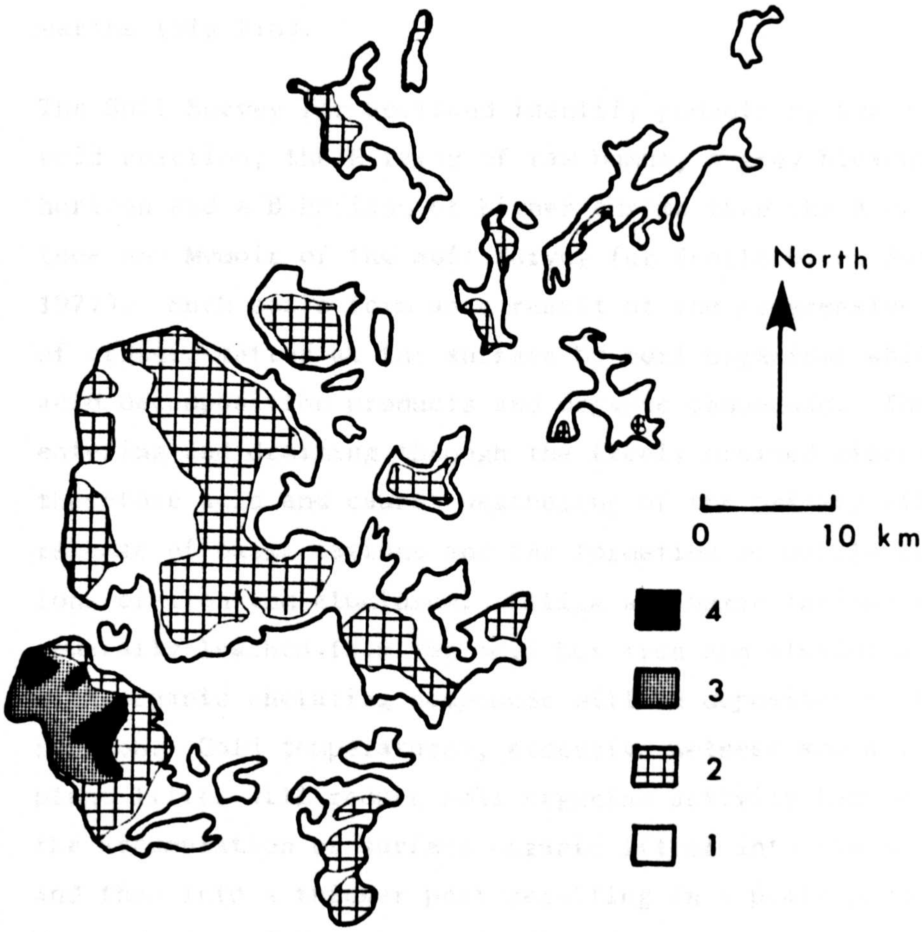
The climatic history of Orkney has been inferred from the palaeoenvironmental pollen evidence already described in Section 2:4:3. This evidence indicates that subsequent to the post glacial warming effect, climatic conditions have changed relatively little since the Fladrian climatic optimum (Davidson et al 1976; Moar, 1969). Keatinge and Dickson, (1979), based on pollen analysis, give evidence of an increased on-shore wind speed c 5000 years B.P. accompanied by a slight drop in temperature. This and the climatic deterioration c 3400 years B.P. has already been outlined above. Despite these slight climatic changes, it is possible to agree with Davidson et al (1976) that climate has changed very little in Orkney since the Flandrian. Consequently the climatic conditions in Orkney today can be taken as representative of at least the last 5000 years.

Climatic conditions in Orkney today are governed by the intimate relationship to the sea, the low lying gently sloping topography and the high latitude of the Archipelago(Dry and Robertson, 1982). The annual range of mean monthly temperatures is around 8.9°C with a minimum of 3.4°C in February to a maximum of 12.3°C in July. Thus it is evident that relative to the rest of Britain, summers are cool and winters mild (Plant and Dunsire, 1974). Rainfall is not excessive although a low evaporation potential associated with low summer temperatures and high relative humidities may make the average rainfall effectively greater. The average annual rainfall ranges from 890-1020mm over most of the Orkney archipelago, increasing to greater than 1020mm over the hills of Rousay, Mainland and Hoy. Along the western seaboard of Mainland the average annual rainfall is less than 890mm. Dry and Robertson (1982) have attempted to summarise this information in terms of climatic regions (Fig 2:5). It is apparent from this map that significant climatic gradients exist across Orkney thus varying the role of climate in pedogenesis.

The most noteworthy feature of the Orcadian climate is the high frequency of strong winds and gales. Wind directions are fairly evenly distributed around the compass with the highest frequency occurring from the quadrat between south and west. At Kirkwall the average number of gale days (days when wind speeds reach greater than 17.2 m/sec) is 30 (Plant and Dunsire, 1974). The implication of windiness to pedogenesis in Orkney is the salt spray that such winds carry and deposit throughout the island as well as the impact wind and salt spray has on vegetation communities.

This completes the review of factors controlling soil formation in Orkney. Soil types evident today in Orkney can be related to this evidence. Furthermore variation in the factors of soil formation with time can be used to infer the major pedogenic

Figure 2:5 The climatic regions of Orkney (after Dry and Robertson, 1982).



KEY:
1. Fairly warm moderately dry lowland and foothill.
2. Cool moderately dry lowland and foothill.
3. Cool wet lowland, foothill and upland.
4. Cold wet foothill and upland.

pathways of the Orcadian landscape.

2:5 Pedogenesis in Orkney

In mapping the soils of Orkney the Soil Survey for Scotland (1981) have classified soils of similar profile morphology according to a hydrological sequence. Soils so identified are tabulated in Table 2:2. Major soils groups which dominate Orkney today are the podzols, the gleys and the organic soils. Soil types of lesser extents are the calcareous soils and brown earths (Fig 2:6).

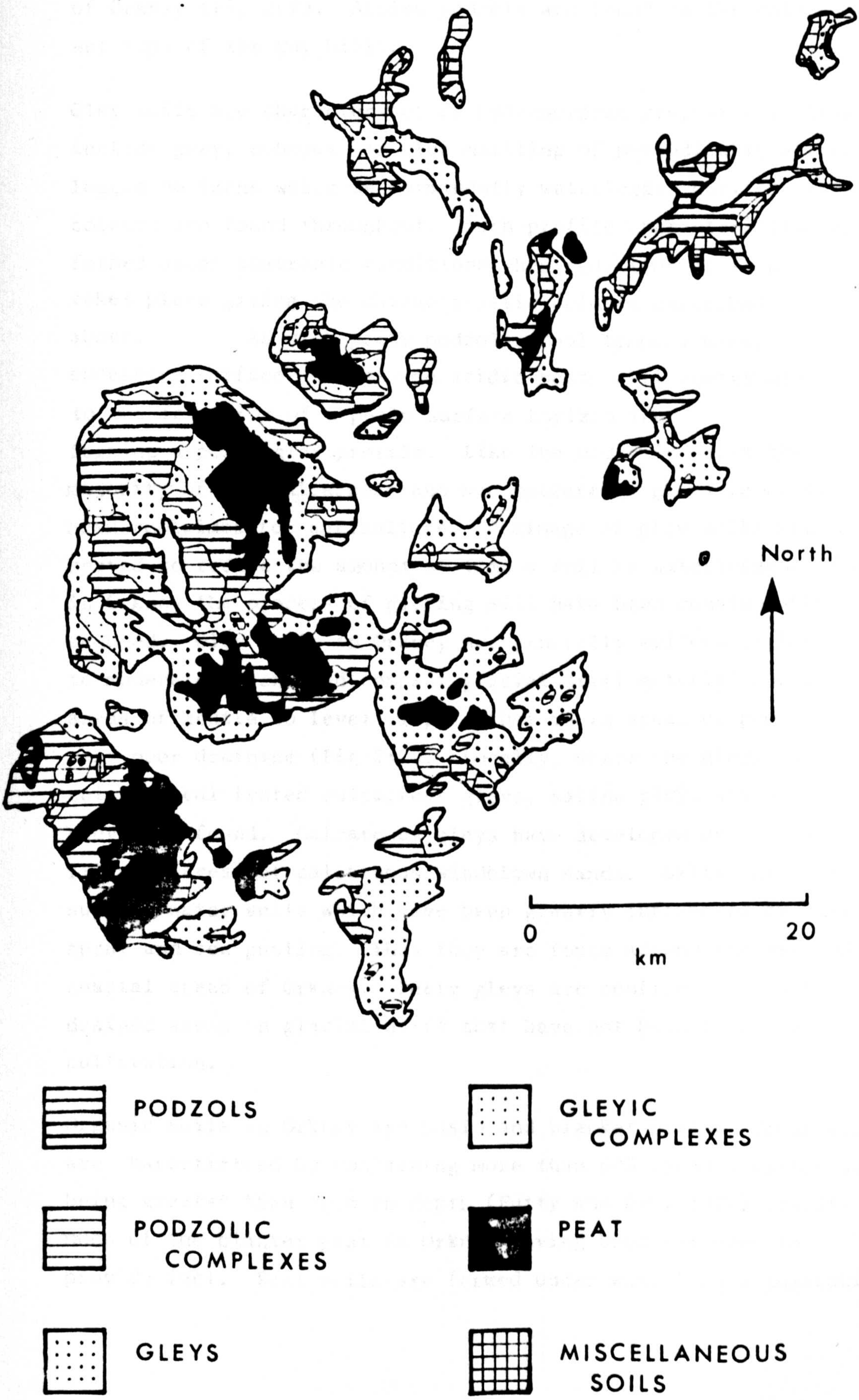
The Soil Survey for Scotland identify podzols by their strongly acid reaction, the H layer of raw humus, a grey bleached A_2 horizon and a B horizon of higher chroma than the A or C horizons (see any Memoir of the Soil Survey for Scotland, eg Futty and Dry, 1977). Such soils form as a result of the progressive decomposition of organic matter at the surface by soil organisms which releases acid decomposition products and organic compounds. The solution entering and draining through the freely drained mineral soil is therefore acid and causes weathering of the primary silicates, release of basic cations and the formation of mobile complex ions of iron and aluminium. Silica and basic cations are generally leached from the soil but iron and aluminium together with organic chelating compounds will be deposited in the B horizon. Cold temperatures, excessive wetness and acidic heath plant litter will reduce soil organism activity thus encouraging the accumulation of surface organic litter into raw mor humus and then into a thicker peat resulting in a peaty podzol profile. The majority of Orcadian podzols today are cultivated and this probably serves to reduce the podzolisation process. Application of fertilizers will replace cations lost by leaching and raise pH levels thus serving to reduce the rate of weathering. Fertilization will also serve to encourage soil organism activity as will tillage which increases the aeration of the soil. Peaty podzols will therefore not develop when soils are cultivated. Podzolic soils in Orkney are found on moderate to moderately steep slopes with generally uncompacted coarse

TABLE 2:2

CLASSIFICATION OF SOIL SERIES IN ORKNEY
(After Soil Survey for Scotland 1981)

MAJOR SOIL GROUP	SUB-GROUP	SERIES
Calcareous soils	Brown calcareous soils	Fraserburgh
Brown earths	Peaty brown soils	Tomtain
Podzols	Podzols	Bilbster, Ocklester, Boyndie
	Alpine podzols	Knitchen, Trowieglen
	Peaty podzols	Stromness, Millfield, Camster, Warth, Flaughton, Dunnet, Rackwick.
Gleys (Surface and groundwater)	Calcareous and non-calcareous gleys (poorly drained)	Midgarth, Thurso, Ness, Tresdale, Whitelinks, Sibster.
	Saline gleys (poorly drained)	Fletts, Mousland, Gessan.
	Peaty gleys (poorly drained)	Lynedardy, Olrig, Canisby.
	Non-calcareous gleys (very poorly drained)	Hunster, Gaira.
	Peaty gleys (very poorly drained)	Dalespot.
Organic Soils	Basin and valley peat	
	Blanket Peat	
Alluvial Soils	Poorly drained	Lochside
	Very poorly drained	Peat-alluvium, Innes
	Undifferentiated	AL
Soil Complexes	(A mapping unit used when the soil pattern on the landscape is too intricate for the component mapping lines which are listed above to be shown separately).	Croual, Ulbster, Frotoft, Sordale, Warehouse, Eskishold, Huntis, Aglath, Cuilags, Scarsa, Whitefowl Hill, Vow Randie, Heilan.
Miscellaneous Soils.	Hill Dunes Alluvial Fans Saltings Links	

Figure 2:6 Major soil groups of Orkney. (After the Soil Survey for Scotland, 1981)

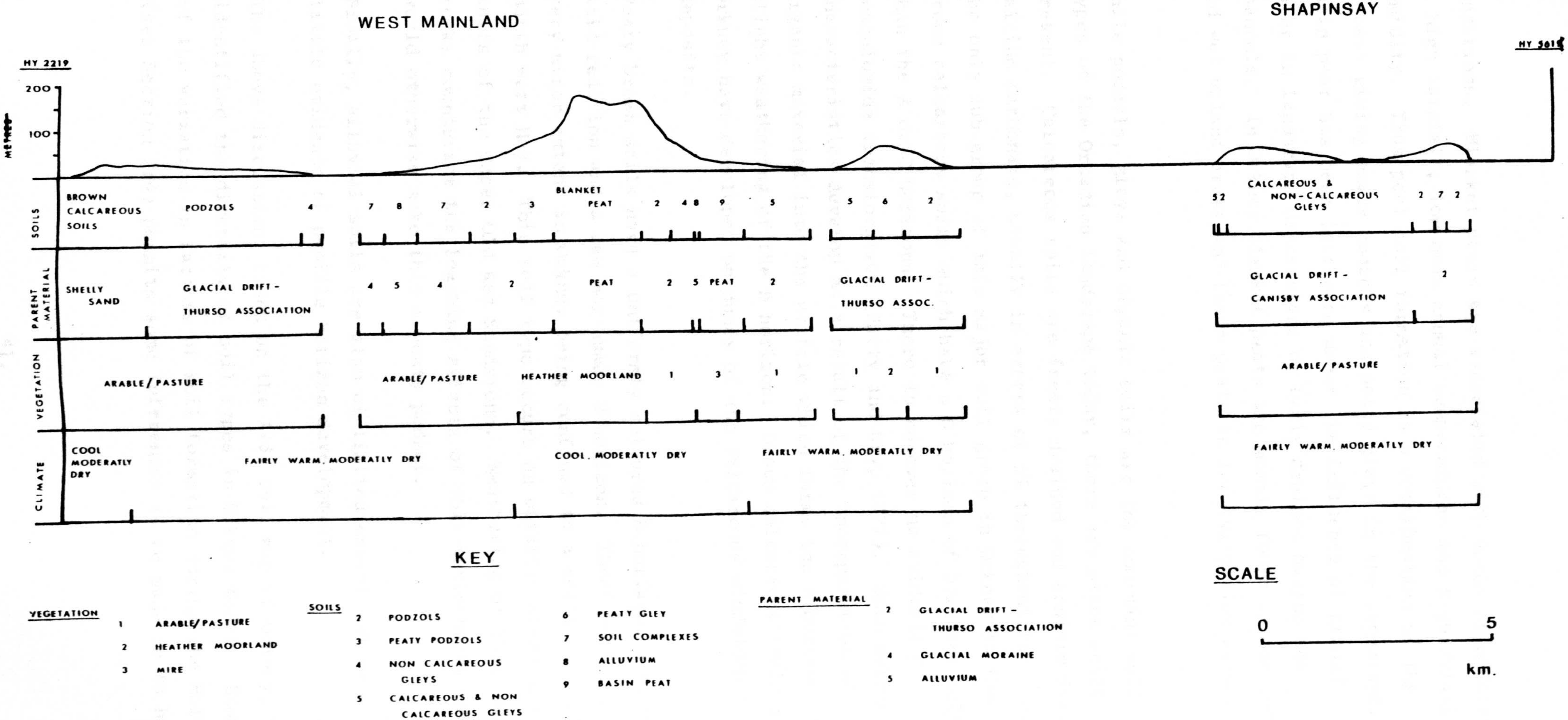


to medium texture freely or imperfectly drained parent material. Where the podzols are not cultivated peaty podzols are evident and are generally located in the slightly cooler, wetter areas of Orkney (Fig 2:7). Alpine podzols are found on the cold, wet tops of the Hoy hills.

Gley soils are characterised by hydromorphic properties. These include grey, ochrous or blue mottling of periodically waterlogged horizons while in permanently waterlogged horizons these colours are found throughout. Such profile characteristics are formed under anaerobic conditions when reduction of iron takes place giving the characteristic colours described above. As with peaty podzols, cool temperatures, excessive surface wetness and acidic heath will contribute to the formation of a peaty surface horizon thus forming a peaty gley profile. Like the podzolic soils the majority of the calcareous and non calcareous gleys in Orkney have been reclaimed for agriculture. Drainage of gley soils will have served to reduce the amount of time a soil is waterlogged. Thus in Orkney the process of gleying will have been considerably reduced. Gley soils in Orkney are generally evident on fine to moderately textured compact glacial drift material and in areas of gentle to level slope; that is in areas of poor and very poor drainage (Fig 2:7). Locally, where the gleys have not been cultivated calcareous gleys, saline gleys and peaty gleys are found. Calcareous gleys have developed on the sand flats of areas of calcareous windblown sands. Saline gleys are surface water soils which have been greatly influenced by salt spray and sea gusting. Thus they are found around the exposed coastal areas of Orkney. Peaty gleys are confined to poorly drained areas on glacial drift that have not been reclaimed for cultivation.

Organic soils in Orkney are basin and blanket peats. These soils are characterised by containing more than 60% organic matter and being greater than 50cm in depth (Futty and Dry, 1977) despite much of the blanket peat in Orkney having been cut over to provide fuel. Peat soils are formed under waterlogged anaerobic

Figure 2:7 An environmental transect of Orkney.



conditions. Blanket peats are associated with areas of moderate to high rainfall, low mean annual temperatures and high relative humidity. Thus peat soil formation is a continuation of the process giving peaty podzols and peaty gleys in the landscape. Basin peat has been initiated under the influence of ground water in landscape depressions or badly drained basins and channels. In Orkney blanket peats are mostly found in the cool and wet upland areas and basin peats in low lying flat areas.

While podzols, gleys and organic soils are the dominant soil types of the Orcadian landscape today, there are other soils present. Calcareous soils are freely drained and contain free calcium carbonate, usually in excess of 5% throughout the profile. The only sub group of this major soil group in Orkney is the brown calcareous soils which have a B horizon of brighter colour than the A or C horizons. There is however no evidence of sesquioxide translocation (Futty and Dry, 1977). Such morphological characteristics develop as a result of the incorporation of organic material into the profile which forms the A horizon and slight weathering of the B horizon. Brown calcareous soils in Orkney have developed on dunes of the calcareous windblown sand deposits.

Peaty brown soils have a uniformly coloured B horizon, a moderately acid reaction and a raw mor humus H horizon. These soils are of very minor extent in Orkney being confined to a small area of north west Hoy. This soil type occurs on basaltic lavas and tuffs of the upper Old Red Sandstone. Weathering of these basic rocks counteract the leaching effects of this environment that would otherwise make this a peaty podzol.

Finally, alluvial soils are also of limited extent and show little evidence of profile horizon development.

The above discussion, based on the 1981 soil map of Orkney, has identified the diversity of soil types in Orkney today. Examination of the variation in factors of soil formation during the Holocene (see Section 2:4) permits some inferences to be made as to how this differentiation of soils came about. Changes in the Orcadian environment during the Holocene suggest that there have been four distinctive phases of pedogenesis since the end of glaciation.

Pedogenic Phase 1 lasted from the end of glaciation (c 10,000 years B.P.) to c 5,000 years B.P. With deglaciation of the landscape and the post glacial warming, raw parent materials will have developed through the immature soil phase to form the precursors of the podzol-gley pattern seen today. On better drained areas incompletely developed and slightly differentiated podzols will have formed while on areas of poor drainage gley soils would have developed. This reconstruction is based on the development of the birch-hazel scrub vegetation climax which by c 5,000 years B.P. was beginning to deteriorate. The scrub woodland would serve to keep the potential evapotranspiration level relatively high thus reducing podzolisation and gleying of soils. However, given that climatic conditions c 5,000 B.P. are similar to today (Davidson et al, 1976), the high relative humidity and low mean temperatures would mean that brown soils would not develop except at base rich sites. Instead the soil types associated with the climax vegetation communitity would be weakly developed podzols and gleys.

Phase 2 of pedogenesis in Orkney lasted between c 5,000 years B.P. and c 3,400 years B.P. This period saw the acceleration and further development of the podzolisation and gleying processes already evident. Destruction of the birch-hazel scrub by a cooler climate with greater wind speeds and/or by Neolithic man and his grazing animals would have the effect of reducing potential evapotranspiration. This in turn would result in increased wetness at poorly drained sites and increased through flow of water at well drained sites. In flat low-lying coastal bays destruction of the birch/hazel scrub was probably responsible for the initiation of calcareous sand blow and machair development. Upon this new parent material the brown calcareous soils and calcareous gleys formed. In highly localised areas cultivation by Neolithic man took place, mostly on podzolic soils. Although ploughing by Neolithic man would have done little more than scratch the land surface, this together with the use of organic fertilizer may have served to restrict the podzolisation process.

Phase 3 of pedogenic processes in Orkney can be associated with further climatic deterioration which occurred c 3,400 years B.P. The climatic deterioration at this point in time set the pattern of pedogenesis up until c 150 years ago. A lowering of mean temperatures and increased wetness served to destroy the tall herb/fern vegetation community thus further reducing biological activity in the surface horizons. Consequently blanket peat formed in the relatively wetter and cooler upland areas of Orkney with peaty podzols and peaty gleys developing beyond the small areas of cultivated podzol and calcareous sands.

Until the agricultural improvements of the mid-1800s, a peat layer of varying thickness covered much of the Orkney landscape. With the agricultural improvements, however, Orkney entered its fourth and latest phase of pedogenesis with soils being reclaimed for agriculture. Peaty podzols were ploughed and fertilized as were the peaty gleys once they had been drained. This brings us to the present day diversification of soil types seen in Orkney. Much of Orkney must be regarded as an agricultural landscape with most soils under cultivation of one form of another. Locally peaty podzols and peaty gleys still exist where land has not been reclaimed for agriculture. Peats are still found in the wetter and cooler areas of the uplands.

Having established the major sedimentary and pedogenic processes in the Orcadian environment both the deep top soils and farm mounds can now be set in context. This review has indicated that in the landscape evolution of Orkney man has not previously been considered as a direct agent of sedimentation in the manner outlined in Chapter 1, although he has been considered as an initiator of natural sedimentary processes. The review does present various natural sedimentary processes which may explain deep top soil and farm mound formation but if these features can be demonstrated as being anthropogenic in origin, then anthropogenic sedimentation will be an additional process of importance in Orcadian landscape evolution. Finally the review of pedogenic processes is important as it is from this that some indication of how sediment properties may have been modified since deposition is given. In attempting to identify anthropogenic sedimentary activities from sediment properties, how podzolisation and gleying have modified the properties of interest must be established. Thus this chapter has given the background within which deep top soils and farm mounds must be evaluated.

CHAPTER 3

THE ANTHROPOGENIC NATURE OF DEEP TOP SOILS AND FARM MOUNDS

3:1 Introduction

The first phase of field and laboratory work for this thesis concerned itself with providing descriptive information on the deep top soils and farm mounds. The data was then used to test the hypothesis that both the deep top soils and farm mounds were formed by anthropogenic sedimentary processes. The evidence presented in Chapter 1 provides some degree of confidence that the two landscape phenomenon under scrutiny are indeed the result of anthropogenic sedimentary processes. It was felt necessary however,to test this hypothesis more fully by considering the field and laboratory derived descriptions of deep top soils and farm mounds in relation to the surrounding soils and sediments of the Orcadian landscape (See Chapter 2). If the conclusion of this chapter supports the above hypothesis,then it is possible to develop further the theory of anthropogenic sedimentation to explain the formation of deep top soils and farm mounds. If it is concluded that the deep top soils and farm mounds are not the result of anthropogenic sedimentary processes, then the data of this chapter should go some way to assist the construction of alternative hypotheses.

As observed in Chapter 1 the deep top soils and farm mounds represent two quite distinct landscape features. It was therefore considered best that the two features were considered separately in this chapter. Deep top soils are examined first.

3:2 Examination of Field and Laboratory Data to Elucidate the Agents of Deep Top Soil Formation

This section is organised into five parts. The first part examines the procedures used to identify and describe the deep top soils and to verify or refute the hypothesis of anthropogenic sedimentation to explain their formation. Part two follows with a generalised description of the deep top soils. Parts three and four are a more detailed examination of the field and the laboratory derived descriptive data. The data from the deep top soils are considered in relation to other soils and sediments of the Orkney landscape as well as other soils throughout the world known to have been formed by anthropogenic sedimentary processes. This forms the crux of the section. Finally and fifthly, by considering the deep top soils in this manner it is possible to arrive at some conclusion as to the main agents of deep top soil formation in Orkney.

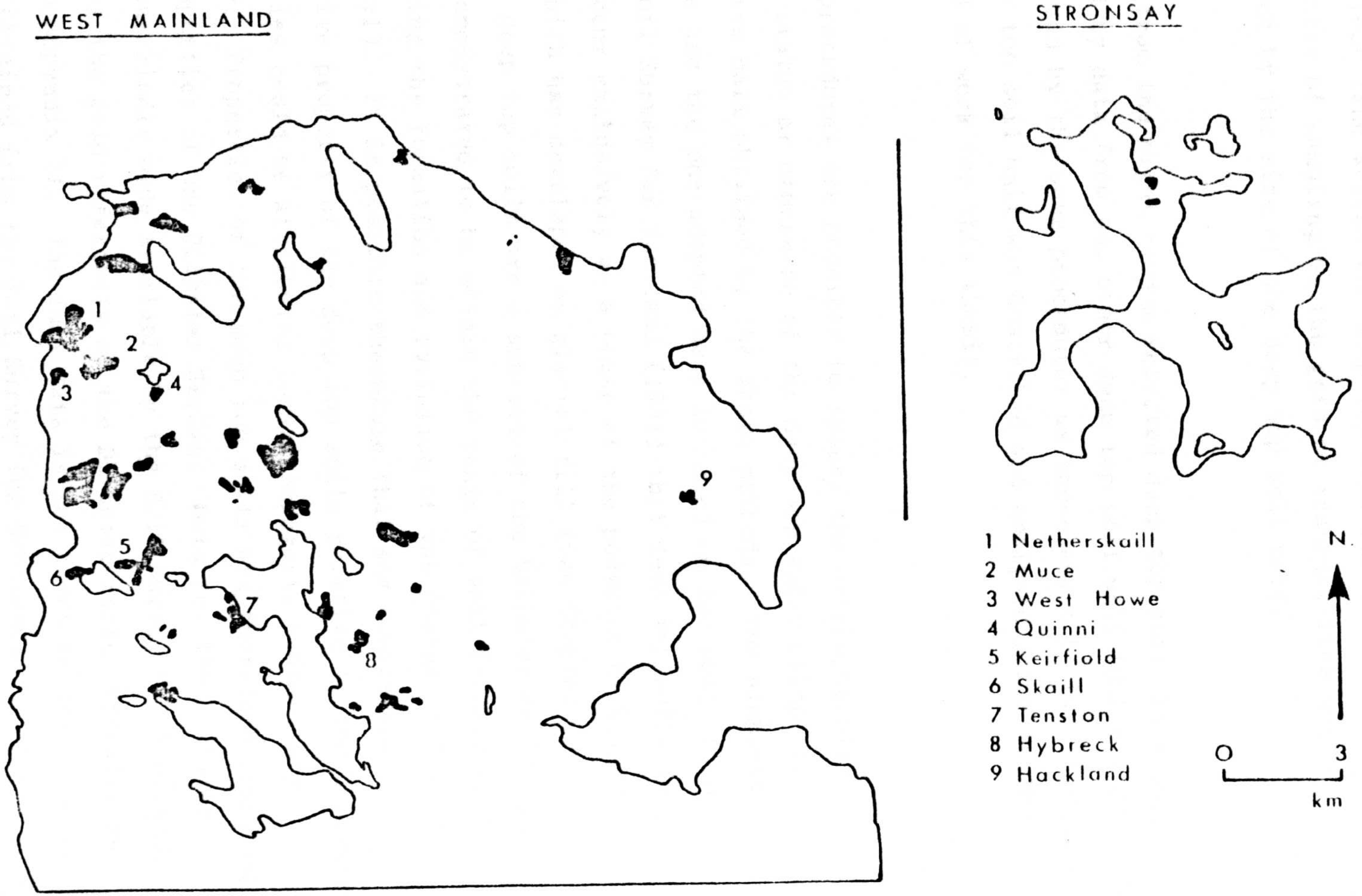
3:2:1 Materials and Methods

Eight of the deep top soil units in Orkney as mapped by the Soil Survey for Scotland (1981) were selected on the basis of random four figure grid references. The location of these units is given in Fig 3:1. The variation in thickness of the deep top soil unit was assessed by free survey augering using a Dutch auger. One profile was dug in each selected unit where the top soil was thickest. Once the profile was exposed to the B/C horizons, it was described in the terms of the Soil Survey for Scotland (see Futty and Dry, 1977). Descriptive field information on colour, mottling, texture, organic matter status, structure, degree of induration, root characteristics, stoniness, horizon boundary characteristics and horizon thickness were thus obtained.

Sampling of the profile for laboratory analysis was generally carried out at 20cm intervals to provide samples of all observed horizons, taking the first sample from the base of the exposed profile. There was some deviation from this sampling strategy on occasions but in every case each observed horizon was sampled at least once. Laboratory analysis was undertaken in the University of Strathclyde Department of Geography laboratory. Properties determined were those routinely assessed by the Soil Survey for Scotland which could be readily carried out in the Department of Geography laboratory. These properties were percentage sand, silt and clay, percentage loss on ignition, pH, exchangeable bases (Na, K, Ca, Mg) and total phosphorus. The analytical procedures used for the determination of these properties are given in Appendix I.

As well as describing and sampling the exposed profile in the

Figure 3:1 Location of deep top soil units selected for examination.



field, the relationship between deep top soil thickness of the selected units and the distance from the associated farm(s) was examined. This was achieved by using a Dutch auger and sampling on a grid or transect line centred on the farm site, following the maximum slope line across the deep top soil unit.
The intensity of sampling on the grid or transect line was conditioned by the size of the deep top soil unit.

The data from the eight random selected deep top soil units were augmented by data from one other deep top soil unit (Quinni) described and analysed by the same procedures as those above by D.A. Davidson. This deep top soil unit was described and analysed prior to the commenced of work for this thesis.

Several procedures are possible to assess the anthropogenic sediment status or otherwise of the deep top soils using the descriptive data obtained by the above methods. The simplest procedure and the one adopted here is based on the observation of the Soil Survey for Scotland (1981) that deep top soils in Orkney occur exclusively as a phase of the podzolic Bilbster Series which has developed on glacial till (See Chapter 2). Thus the deep top soils are a sub-set of the Bilbster Series and can be demonstrated to be within the range of soil forming factors controlling the formation and evolution of the parent soil series (Table 3:1). It is possible therefore that any consistently distinctive property of the deep top soils relative to the Bilbster soil series could be attributed to anthropogenic sedimentary activity. Properties of the deep top soils are therefore compared with properties of the Bilbster Series. Data for the Bilbster Series was kindly made available by the Soil Survey for Scotland. A list of the grid references of the Bilbster Series profiles is given in Appendix II. The full data is not given as this can be readily obtained from the Soil Survey for Scotland.

Having established with which profiles the deep top soils are to

TABLE 3:1

ENVIRONMENTAL DATA FOR THE BILBSTER MAIN SERIES AND BILBSTER DEEP TOP PHASE IN ORKNEY

ENVIRONMENTAL RANGE

Soil Series	Altitude (m)	Slope°	Aspect (Compass Points)	Vegetation
Bilbster Main Series	6-107	0-11	N.E.	Ploughed arable
			E.	Permanent pasture
			S.E.	Permanent grass-land
			S.	Pasture
			S.W.	Grassland
			W.	Rough grazing
			N.W.	
			N.N.W.	
Bilbster Deep Top Phase	7-43	0-7	E.	Arable ploughed
			S.E.	Permanent grassland
			S.W.	Grassland
			N.W.	
			N.N.W.	

Both soils are cultivated and are formed on drift derived from flagstones, limestones and mudstones of the Stromness Flags and Rousay Flags of the middle Old Red Sandstone.

Sources: Bilbster Main Series - Soil Survey for Scotland.

Bilbster Deep Top Phase - Authors field work.

be compared, the question arises as to what part of individual profiles can be validly compared. As soil profiles normally exhibit several soil horizons as well as anisotropism of properties down the profile this question is narrowed to whether similar horizons or similar depths within soil profiles should be compared. In practice this decision is conditioned by the available data. The Soil Survey for Scotland have based their profile description and sampling strategy upon profile horizons. Description is given for each horizon and sampling for laboratory analysis is also on a horizon basis. Thus it is most appropriate to compare the horizons of deep top soils with the equivalent horizons of the Bilbster Series on the principle that equivalent horizons in different soil profiles are homologous, ie are the result of broadly similar pedogenic processes (FitzPatrick, 1976). Any differences between the equivalent horizons of the compared profiles may possibly be attributed to anthropogenic sedimentation processes.

Establishing differences in properties between the deep top soils and the Bilbster Series was straightforward. Field properties for each of the two soil types were recorded on a presence or absence basis. These two sets of results were then compared to identify the differences in field properties. Each laboratory derived property from the two soil types was compared graphically and statistically by the Mann-Whitney U Test to identify any differences between the two soil types (Hammond and McCullagh, 1978). Having established differences it was necessary to attempt to ascribe these differences to anthropogenic sedimentary processes. This was done by an examination of the literature to identify soil properties and levels of soil properties which are thought to be indicative of anthropogenic soils and sediments in other parts of the world. If a degree of similarity in properties exists between the deep top soils and known anthropogenic soils and sediments then it may be inferred that the deep top soils are the result of anthropogenic sedimentary processes. To balance this, consideration is also given to properties that are similar in the deep top soils and Bilbster Series. Such similarities can arise because of the inability of the deep top soil to retain a particular anthropogenic signal, or that a particular property is not influenced by anthropogenic sedimentation, or simply that there has been no anthropogenic sedimentation.

It needs to be pointed out that there are inherent dangers with the comparative approach that has been adopted. What is being compared are two different soil types each of which has been described and analysed by two different observers and by different laboratory techniques (See Appendix I). Clearly this may mean that the two soil types cannot validly be compared. It is necessary to assume, however, that different observers and different laboratory techniques do not influence to major extents the results obtained for the two soil types. Thus by considering both the dissimilarities and the similarities of properties in the deep top soils and Bilbster Series soils it will be possible to arrive at some conclusion as to what the agent(s) of deep top soil formation was.

3:2:2 A Generalised Description of Deep Top Soils in Orkney

Profile descriptions of the nine profiles together with supporting laboratory data are given in Appendix III. An example is given here in Table 3:2. The deep top soils examined are found on level to moderately steep slopes over an altitude range of 7m to 43m. They are cultivated with their use today being grassland or permanent pasture with some ploughed areas. There are several salient features to be noticed in these profiles. The dark brown to very dark greyish brown S_1 horizon is effectively the present day top soil. Commonly the only differentiating feature between the S_1 and the S_2 horizons are subtle colour changes and, on occasion, changes in soil structure and occurrence of charcoal flecks. The S_2 horizon may therefore be, despite its thickness, considered as a top soil. No general pattern emerges as to the occurrence of field characteristics in the B horizon except that within each profile it is always lighter in colour than the overlying top soil. Certain profiles deviate from this general outline of the deep top soils notably, that of Keirfiold.

TABLE 3:2

DESCRIPTION AND ANALYTICAL DATA FROM A DEEP TOP SOIL

SITE INFORMATION

Soil Type: Bilbster Series Deep Top Soil.

Locality: Hackland

Grid Ref: HY 396202

Observer: Ian A Simpson

Date: 30/3/82

Rock Outcrops: ---

Relief:

Local:	Valleyside Foot slope
Micro:	Flat
Slope$^{(o)}$:	2^o
Aspect:	220^o
Slope Form:	Concave
Altitude:	30m

Land Use and Vegetation: Ley grassland.

Soil Surface: Flat

FIELD DESCRIPTION

Horizon	Depth (cm)	
S1	0-50	Very dark greyish brown (10YR 3/2) silt loam, no mottles, moderate organic matter, few fine black (10YR 2.5/1) charcoal flecks, few small subangular stones, strongly developed medium granular peds, many fine fibrous roots, clear smooth change to
S2/A1	51-58	Dark brown (10YR 3/3), silty clay loam, no mottles, low organic matter, few small subangular stones, strongly developed medium granular peds, frequent very fine fibrous roots, abrupt clear change to
B2	58-78	Dark yellowish brown (10YR 4/4) silty clay loam, no mottles, no organic matter, many large sub-angular stones, strongly developed medium angular blocky peds, no roots.

LABORATORY DATA

Horizon Depth (cm)	S1 0.15	S1 0.25	S1 0.4	S2/A1 0.55	B2 0.7
Loss on ignition	9.6	7.7	6.9	3.6	1.4
% sand	40.7	43.2	37.6	35.1	34.3
% silt	34.3	31.9	36.2	37.3	39.2
% clay	25.0	24.9	26.2	27.6	26.5
Ca (exchangeable me/100g)	7.72	4.84	4.63	3.90	3.64
Mg (exchangeable me/100g)	1.40	1.21	1.04	1.75	2.21
Na (exchangeable me/100g)	0.25	0.19	0.25	0.35	0.23
K (exchangeable me/100g)	0.06	tr	tr	tr	tr
pH (H_2O)	5.92	6.20	6.13	6.15	6.15
Phosphorous (total mg P_2O_5/100g)	472	377	235	93	23

tr = trace

In this profile the sandy loam cultivated horizon extends only 36cm to the sandy loam A_1 horizon. There is some doubt therefore as to whether this is an example of a deep top soil although mapped as one.

Data derived by laboratory analysis demonstrates the generally consistant loamy texture of the S horizon of the deep top soils. The profiles of Skaill and Keirfiold are different from the other deep top soil profiles in that a sandy clay loam texture is evident. This is indicative of wind-blown calcareous sand being involved in the build-up of these soils. B horizons of the deep top soils are wider ranging in their textural classes. Silty loams, loams and clay loams are present in the profiles analysed. Moderate (3-8%) loss on ignition values occur in the S horizon showing a general decline with depth and a sharp break to low values in the B horizon. Very high values for exchangeable calcium occur in the S horizon of Skaill and Keirfiold, attributable to the presence of wind-blown calcareous sand. This supports the observations of textural analysis. Generally the deep top soils demonstrate moderate exchangeable calcium levels which decrease with depth grading into the B horizon. The moderate exchangeable magnesium levels fluctuate down the profiles and no apparent pattern emerges. Similarly, exchangeable sodium levels fluctuate but levels are high, perhaps reflecting the maritime nature of Orkney. The moderate to low exchangeable potassium levels also fluctuate down the profile. pH levels are moderately acidic throughout the profiles with the exception of the Skail and Keirfiold profiles which are basic reflecting the calcareous sand components of these profiles. Total phosphorous values of the S horizons are, with the exception of the Keirfiold profile, abnormally high ranging from 315mg P_2O_5/100g to 1148mg P_2O_5/100g. There is normally a marked drop in P_2O_5 value into the B horizon which may range from low (less than 100mg P_2O_5/100g) to high (greater than 300mg P_2O_5/100g) levels. Of the analytical results it is the phosphorous levels that are distinctly unusual.

3:2:3 The Comparison of Deep Top Soils and the Bilbster Soil Series : Field Data

Table 3:3 identifies the different field profile characteristics in

TABLE 3:3

HORIZON THICKNESS CHARACTERISTICS

Soil Name	Horizon	Centimetres																						
		0-4	9-5	14-10	19-15	24-20	29-25	34-30	39-35	44-40	49-45	54-50	59-55	94-60	69-65	74-70	79-75	84-80	89-85	94-90	104-100	109-105	114-110	119-115
Bilbster Series Deep top Phase	S/A	-	-	-	-	-	-	-	-	-	-	+	+	+	-	+	+	-	-	-	-	-	-	+
	B	-	+	+	+	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bilbster Main Series	S/A	-	-	-	+	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	B	-	+	-	-	+	+	+	+	+	+	+	+	+	+	-	+	+	-	-	-	-	-	-

FIELD COLOUR CHARACTERISTICS

Soil Name	Horizon	Hue							Value							Chroma							
		10R	2.5YR	5YR	7.5YR	10YR	2.5Y	5Y	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
Bilbster Series Deep Top Phase	S/A	-	-	-	+	+	-	-	-	+	+	-	-	-	-	-	+	+	+	-	-	-	-
	B	-	-	-	-	+	+	-	-	-	+	+	-	-	-	-	+	+	+	+	-	-	-
Bilbster Main Series	S/A	-	-	-	+	+	+	-	-	+	+	+	+	-	-	+	+	+	+	-	-	-	-
	B	-	-	-	+	+	+	-	-	-	+	+	+	-	-	-	+	+	+	-	+		

Key: + occurrence noted

- occurrence not noted

TABLE 3:3 Cont'd

MOTTLING CHARACTERISTICS

Soil Name	Horizon	Hue							Value							Chroma								Abundance				Size		
		10R	2.5YR	5YR	7.5YR	10YR	2.5Y	5Y	2.5	3	4	5	6	7	8	1	2	3	4	5	6	7	8	Not Evident	Few	Frequent	Many	Fine	Medium	Coarse
Bilbster Series Deep Top Phase	S/A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
	B	-	-	+	-	+	-	-	-	-	+	+	+	-	-	-	+	+	-	-	+	-	-	+	+	+	+	+	+	-
Bilbster Main Series	S/A	-	-	+	+	+	+	+	-	+	+	+	+	+	-	+	+	-	+	-	+	-	+	+	+	+	-	+	+	+
	B	+	+	+	+	+	+	-	-	+	+	+	+	-	-	-	+	+	+	-	+	-	+	+	+	+	+	+	+	+

ORGANIC MATTER STATUS AND PARTICLE SIZE CLASS CHARACTERISTICS

Soil Name	Horizon	O.M. Status					Field Texture Class											
		None	Low	Mod-:erate	High	Very High	Sands	Loamy Sands	Sandy Loams	Loams	Silt Loams	Silts	Clay Loams	Sandy Clay Loams	Silty Clay Loams	Sandy Clays	Silty Clays	Clays
Bilbster Series Deep Top Phase	S/A	-	+	+	-	-	-	-	+	-	+	-	-	+	+	-	-	-
	B	+	-	-	-	-	-	+	-	+	+	-	-	-	+	-	-	-
Bilbster Main Series	S/A	+	+	+	-	-	-	-	+	+	+	-	-	-	-	-	-	-
	B	+	+	-	-	-	-	+	+	+	-	-	-	-	-	-	-	-

TABLE 3:3 Cont'd

TABLE 3:3 Cont'd

STONE CHARACTERISTICS

Soil Name	Horizon	Size: Very small	Size: Small	Size: Medium	Size: Large	Size: Very large	Size: Boulders	Abundance: Absent	Abundance: Few	Abundance: Frequent	Abundance: Many	Abundance: Very many	Shape: Rounded	Shape: Sub-round-:ed	Shape: Sub-angul-:ar	Shape: Angular (tabular)
Bilbster Series Deep Top Phase	S/A	+	+	+	-	-	-	+	+	-	-	-	-	-	+	+
	B	+	+	+	+	-	-	-	-	+	+	-	-	+	+	+
Bilbster Main Series	S/A	+	+	+	-	-	+	-	+	+	+	-	-	-	+	+
	B	-	+	+	+	+	+	-	+	+	+	+	-	-	+	+

ROOT CHARACTERISTICS

Soil Name	Horizon	Root Size: Very fine	Root Size: Fine	Root Size: Medium	Root Size: Coarse	Root Abundance: Absent	Root Abundance: Few	Root Abundance: Frequent	Root Abundance: Many
Bilbster Series Deep Top Phase	S/A	+	+	-	-	+	+	+	+
	B	-	-	-	-	+	-	-	-
Bilbster Main Series	S/A	-	+	-	-	-	+	+	+
	B	+	+	-	-	+	+	+	+

TABLE 3:3 Cont'd

STRUCTURE CHARACTERISTICS

Soil Name	Horizon	Ped Size					Ped Shape							Ped Grade				
		Very fine	Fine	Medium	Coarse	Very coarse	Platy	Prismatic	Columnar	Angular rock	Subangular blocky	Granular	Crumb	Weak	Moderate	Strong	Massive	Single grain
Bilbster Series Deep Top Phase	S/A	-	+	+	+	-	-	-	-	-	+	+	-	+	+	+	-	-
	B	-	+	+	-	-	+	-	-	+	+	+	-	+	+	+	+	-
Bilbster Main Series	S/A	-	+	+	-	-	-	-	-	+	+	-	+	+	+	+	-	-
	B	-	+	+	-	-	+	-	-	+	+	-	+	+	+	+	+	-

Soil Name	Horizon	Inclusion Type	Colour	Abundance	Size
Bilbster Series Deep Top Phase	S/A	Charcoal	10YR 2.5/1	Not evident and few	Very fine and fine
	B	-		Not evident	
Bilbster Main Series	S/A	-		Not evident	
	B	-		Not evident	

TABLE 3:3 Cont'd

the S/SA and B horizons of the deep top soils and Bilbster Series soils on a presence or absence basis. Inspection of this table permits the derivation of a second table, Table 3:4, in which the few field characteristics which uniquely distinguish deep top soils from the Bilbster Soil Series are listed. These characteristics are considered to be potentially indicative of the anthropogenic sedimentary process.

Many field properties of the two soil types compared are in the same range. Thus, soil organic matter status suggests that there are similar rates of input, incorporation and loss of organic matter in the two soil bodies. Soil structure, which is one of the least permanent properties of soils, is also similar in range over the two soil types. This reflects similarity in pedogenic processes - freeze-thaw, pedoturbation, wetting-drying - responsible for soil structure development. Soil colour similarities may reflect the common origin of the materials of the two soil bodies, both organic and inorganic. This is particularly relevant to Orkney where a comparatively uniform geology exists. The general indicators are therefore of a similar pedogenic regime and a similarity in the materials of these two soil types.

Of the discriminating field characteristics (Table 3:4), the most useful would appear to be the S/A horizon depth. This characteristic consistently discriminates deep top soils from the Bilbster Soil Series. Also of use are charcoal inclusions, the absence of mottles and root characteristics in deep top soils. Unfortunately charcoal flecks do not always occur in deep top soil profiles thus limiting their value as diagnostic characteristics. Similarly, while some Bilbster main series soils do have mottles, others do not. Thus the absence of mottling in deep top soils is limited as a distinguishing soil property. Limitations are also placed on the use of the presence or absence of roots in the B horizon. Roots are consistently absent in the B horizon of the deep top soils and are often, but not always, present in the B horizons of the Bilbster Soil Series.

The major field characteristic which discriminates the deep top soils from the Bilbster Series is the S/A horizon depth, as already

TABLE 3:4

FIELD CHARACTERISTICS WHICH DISCRIMINATE DEEP TOP SOILS FROM SOILS OF THE BILBSTER SOIL SERIES

S/A HORIZON

Horizon thickness

Charcoal inclusions (when occurring)

Absence of mottling (where applicable)

B HORIZON

Root absence (where applicable)

suggested by the Soil Survey for Scotland (1981). Can this property be ascribed to anthropogenic sedimentary processes? In the Netherlands, field studies have established that in areas of man-constructed plaggen soils the greatest thicknesses and oldest soils are usually found near the villages and the lesser thicknesses in areas of later reclamation (Pape, 1970). Similarly, in Ireland, the thickest plaggen soils are in areas that had the greatest population density (Conry, 1971). An examination of the relationship between top soil depth and distance from associated farm building(s) may therefore go some way towards supporting or refuting the anthropogenic sedimentary nature of the deep top soils. The procedure for this has been outlined in Section 3:2:1 and the results are plotted in Fig 3:2 and Fig 3:3.

By simple visual observation it is reasonably apparent that there is a tendency for top soil depths to increase within the vicinity of the farm buildings. Frequently the increased soil depth is greater than the 40cm maximum top soil thickness of the Bilbster Series (Table 3:3). Such increases may be equal distances on either side of the farm building, alternatively the increase in top soil depth may only be on one side of the building, for example West Howe and Hybreck. Where several farm buildings are comparatively close to one another, the increased top soil thickness may be continuous between them, for example at Tenston. Offsets from the main transect lines of the Hackland, Hybreck, Skail and Keirfiold demonstrate the gradation of deep top soils and Bilbster Series soils into other sedimentary materials, namely alluvial and calcareous wind-blown sand deposits (Fig 3:2). In the examples of Hackland, Skail and Hybreck, the offsets serve to demonstrate the distinctiveness of the deep top soils and Bilbster soils from alluvial deposits. There is no contribution of alluvium to the deep top soils. Textural classes within the Skail and Keirfiold transects and offsets indicate that calcareous sand makes up an observable proportion of the top soil. As these two mapped deep top soil units lie adjacent to calcareous wind-blown sand deposits, it is likely that the sand has been blown into the zone of the deep top soils. Thus, in these areas, there may

Figure 3:2:1 Top soil depths at Hackland deep top soil.

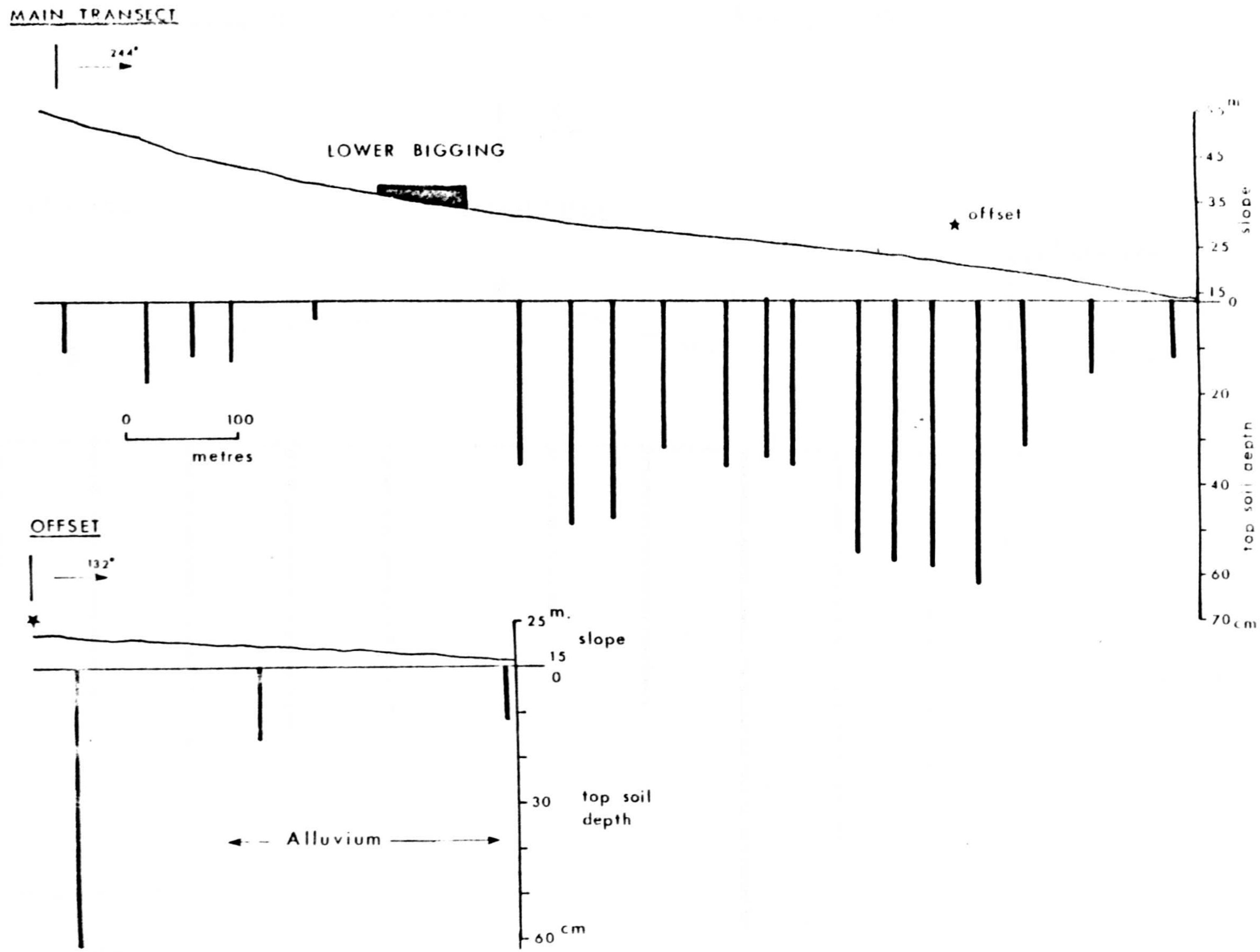


Figure 3:2:2 Top soil depths at Tenston deep top soil.

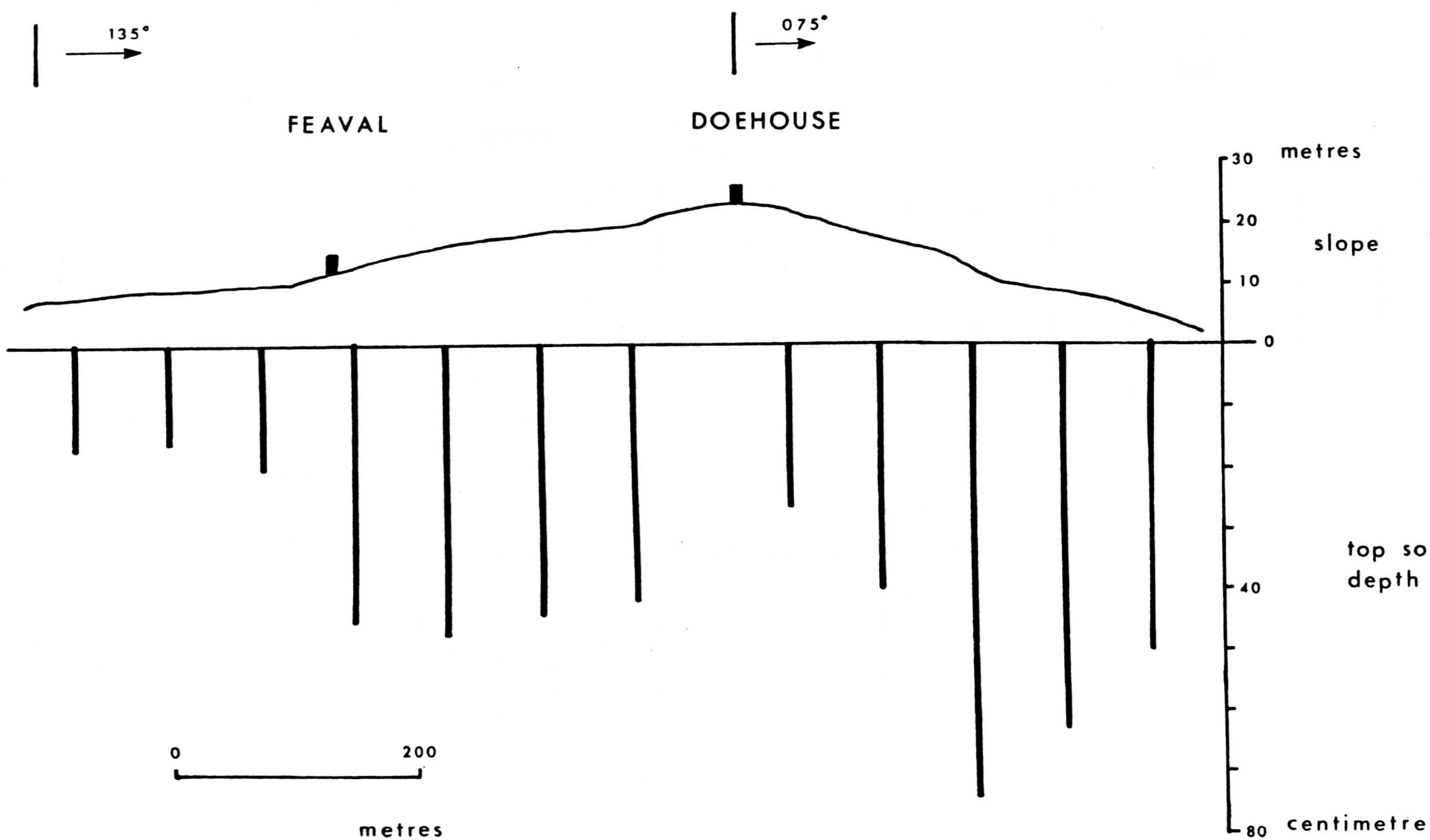


Figure 3:2:3 Top soil depths at Hybreck deep top soil.

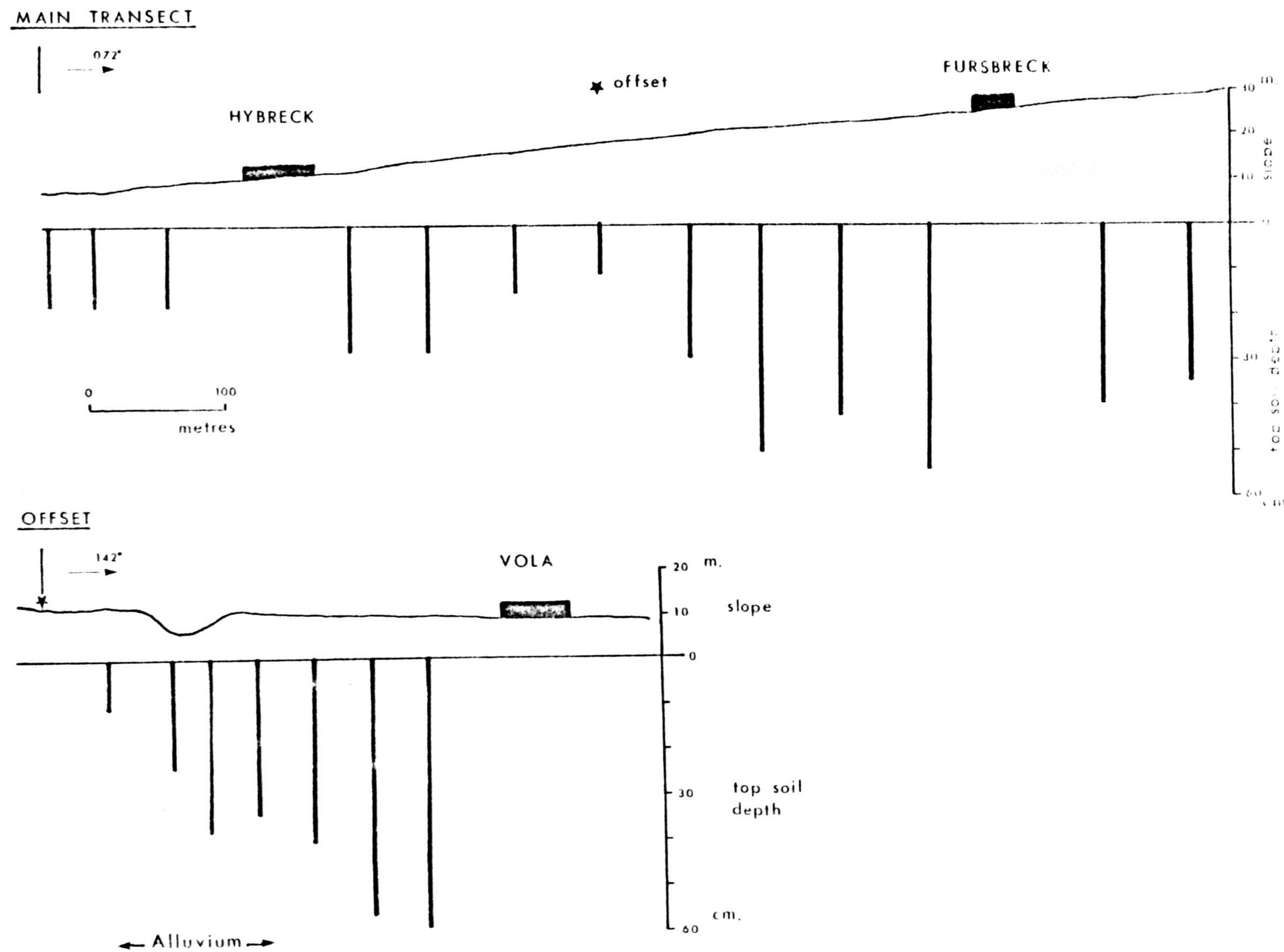


Figure 3:2:4   Top soil depths at Skaill deep top soil.

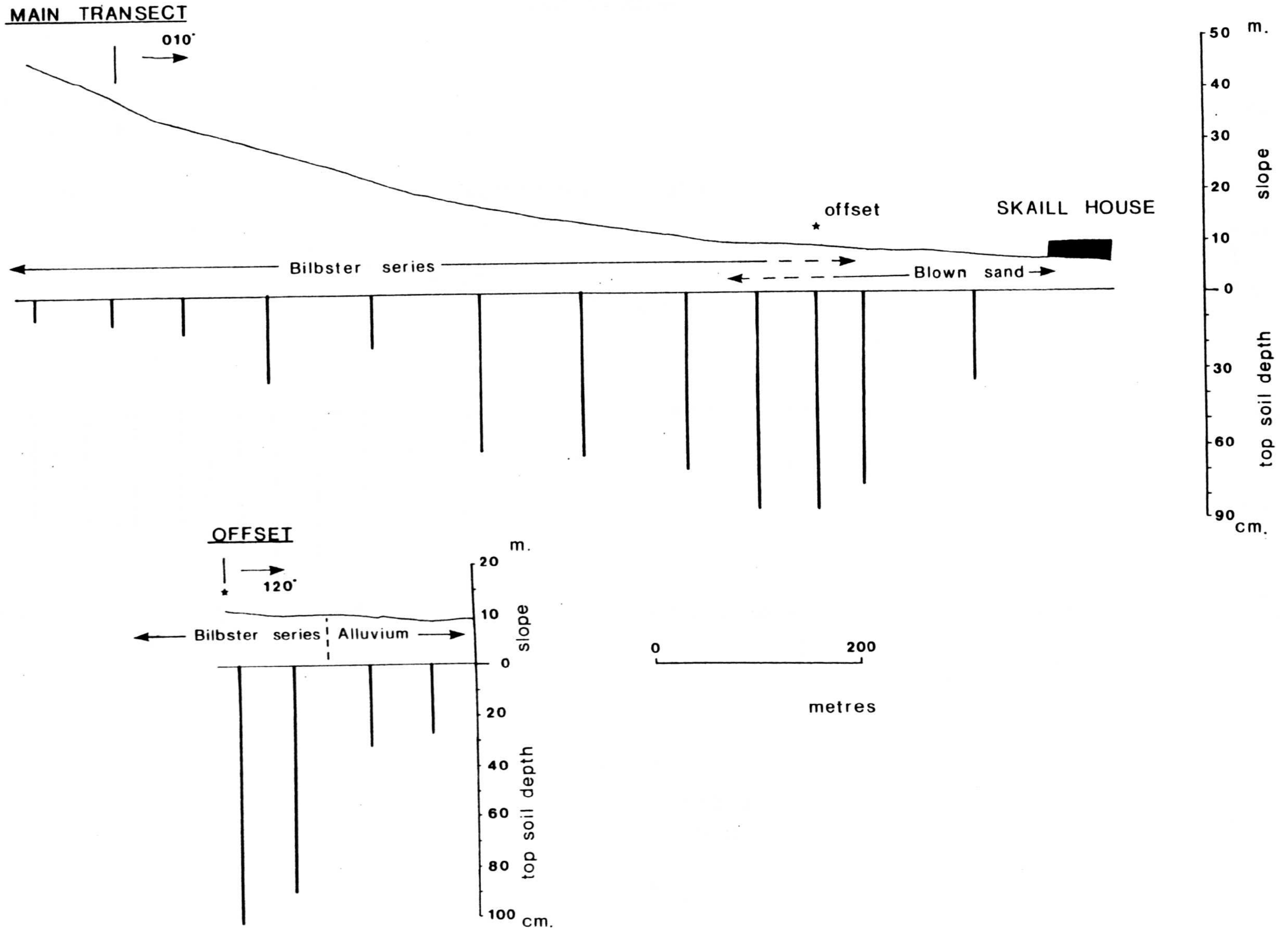
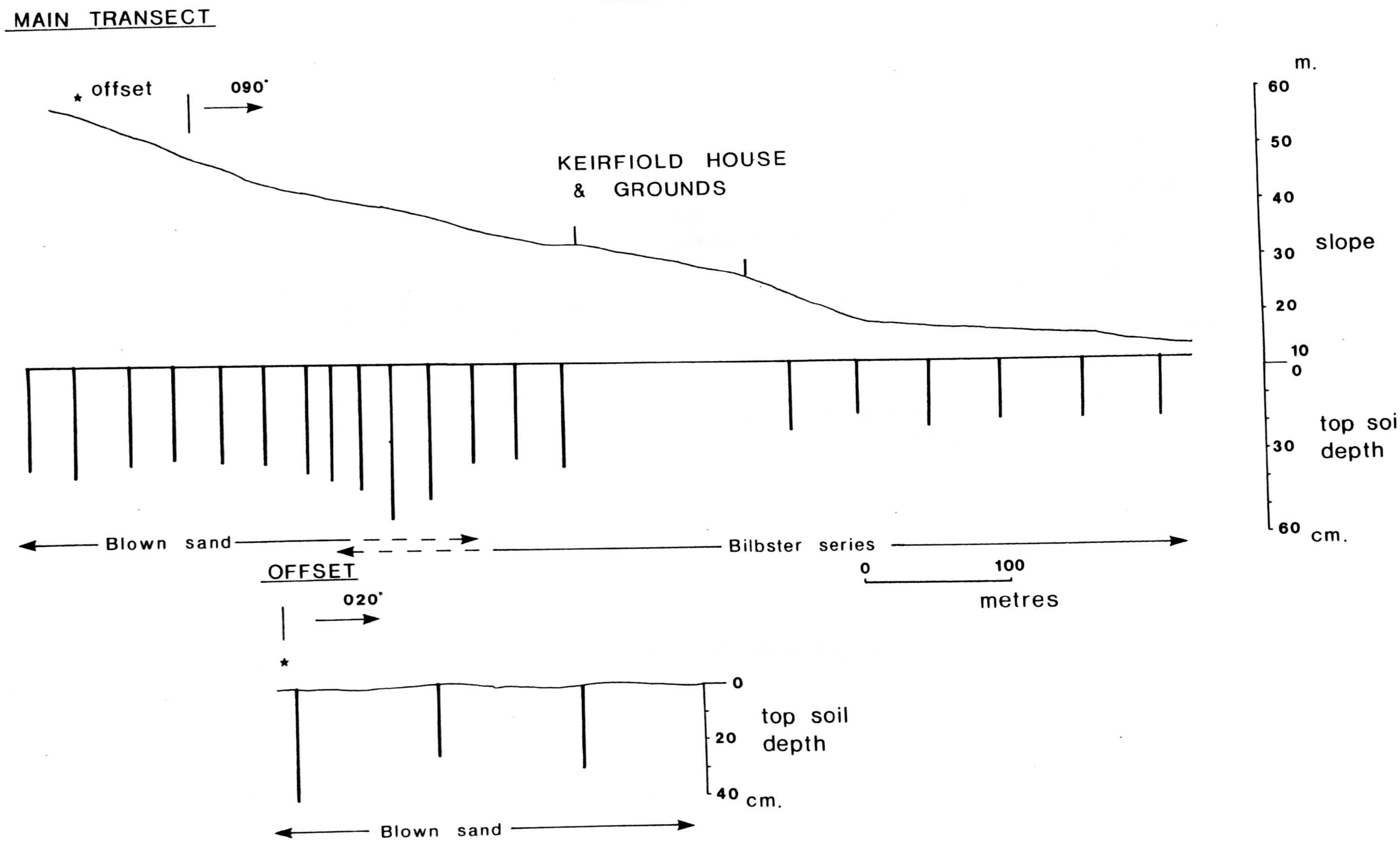


Figure 3:2:5 Top soil depths at Keirfold deep top soil.



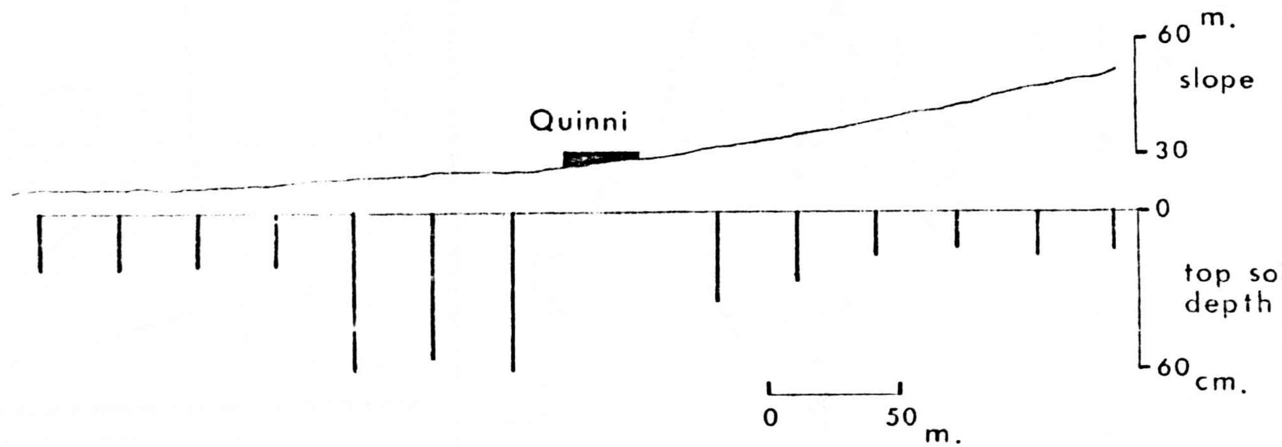
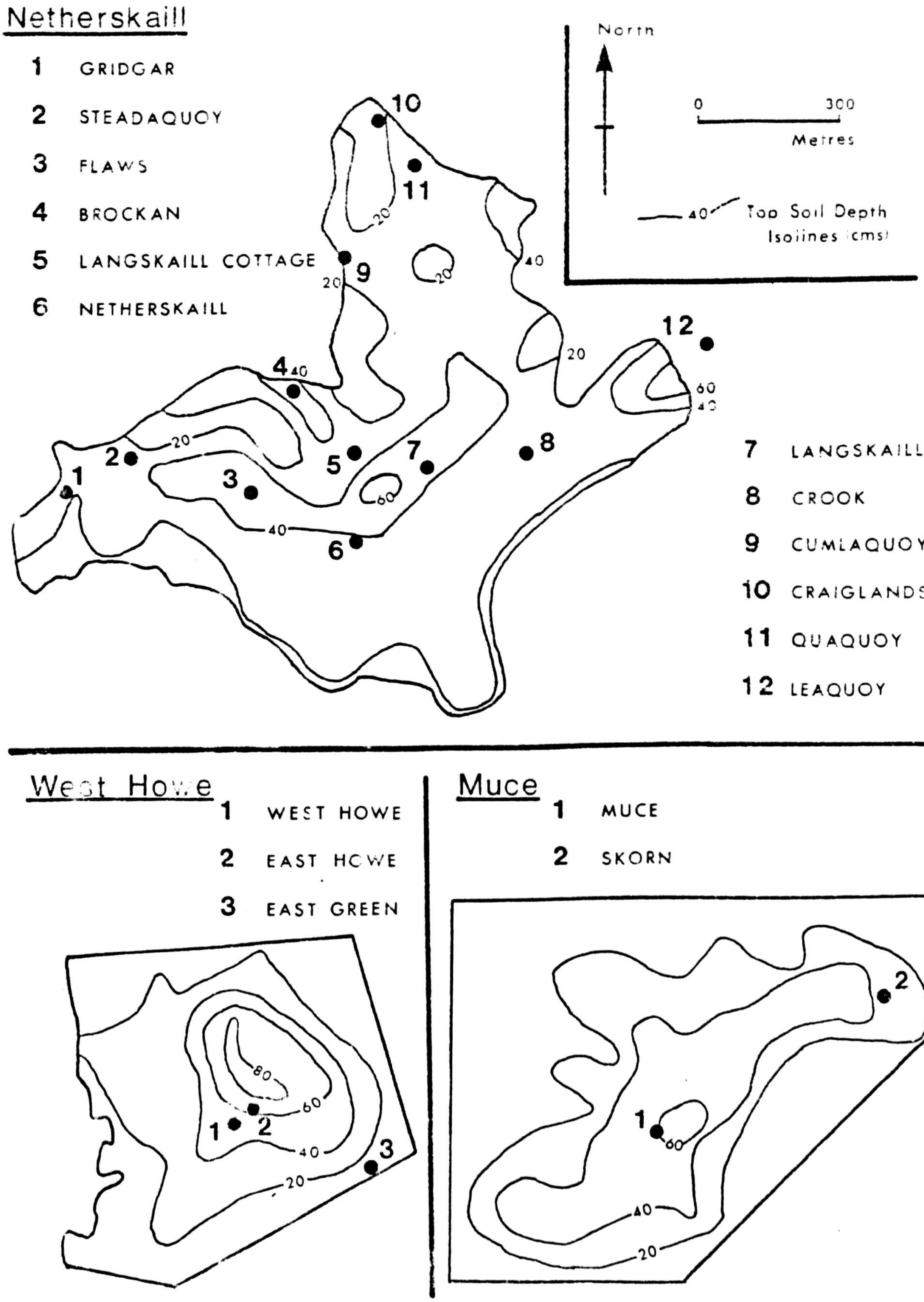


Figure 3:2:6 Top soil depths at Quinni deep top soil. (after D.A. Davidson)

Figure 2:3 Top soil depths of deep top soils in the Marwick Drainage Basin.
(based on a 50m sampling grid)



be more than one sedimentary process contributing to deep top soil formation. Despite this the general pattern of increased top soil depth around farm sites is strongly suggestive of anthropogenic sedimentation in a manner similar to the plaggen soils of the Netherlands.

Elsewhere in Orkney top soil thicknesses comparable to those of the deep top soils occur on colluvial deposits (Table 3:5). It is possible to postulate,therefore,that with the deep top soils occupying middle and lower slope positions of gentle to moderate gradient (Appendix III), that they are a result of mass movement or solifluxion processes (Gerrard, 1981). Thus the question is whether the farm came after the deposition of the deep top soil or,as another possibility,whether early ploughing activity has accelerated mass movement processes. Field evidence would tend to support the hypothesis of anthropogenic sedimentation for the formation of deep top soils. While the deep top soil horizon is cultivated throughout its entire depth, alluvial deposits usually exhibit a polygenetic profile (Table 3:5). Furthermore colluvial soils in Orkney are found only where they infill hollows between steep morainic deposits and as local flushes on the steeper hill slopes. More plausible is the hypothesis that the deep top soils are the result of early ploughing activity in the down slope direction. This is certainly a process that cannot be discounted. Immediately above the deep top soil however there is no evidence of truncated profiles,(see Figs 3:2 and 3:3) indicating that early ploughing activity was not a major factor of significance in deep top soil formation.

In discussing the above evidence several possible processes of deep top soil formation have emerged. Colluvial and alluvial deposition can be discounted as formation processes. Wind-blown sands in some areas, notably at Skaill and Keirfiold do contribute in a small way to the build-up of deep top soils but the major cause of formation must be attributed to anthropogenic sedimentation. Analysis of laboratory derived data from the deep top soils is now undertaken in an effort to further substantiate or repudiate the hypothesis that deep top soils formed as a result of anthropogenic sedimentary processes.

TABLE 3:5

FIELD DESCRIPTION OF A COLLUVIAL DEPOSIT, BILBSTER COMPLEX, ORKNEY

Depth (cm)	
0-30	10YR 3/2 loam; moderate medium subangular blocky; friable; moist; no mottles; moderate organic matter; frequent fine roots; few small subangular and tabular stones.
30-32	10YR 2/1 humose loam; moderate medium subangular blocky; high organic matter; zone of intense organic staining.
32-42	10YR 5/2 with frequent coarse dark brown 7.5YR 3/2 patches or organic staining; loam to silty loam; moderate medium subangular blocky; friable; moist; low organic matter; very few fine roots; frequent small subangular stones (flagstones); clear change to
42-60	Brown 10YR 5/3 with frequent coarse dark brown 7.5YR 3/2 patches of organic staining; sandy loam; moderate medium subangular blocky; weakly firm and crisply friable; moist; moderate organic matter; very few fine roots; frequent small subangular stones; clear change to
60-75	Greyish brown 2.5Y 5/2 and frequent brown 10YR 5/3 and 4/3 patches with fine streaks; silt loam; fine crisp and weakly indurated; moist; no organic matter; frequent small stones, some strongly withered; no roots; clear change to thin iron pan at 75cm.
75-95	10YR 5/4 with many fine and medium dark brown 7.5YR 4/4 patches and streaks; silt loam; weak medium subangular blocky; weakly firm and friable; moist becoming wet; no organic matter; very few fine roots; frequent small stones; sharp change to thin iron pan at 95cm.
95-108	2.5Y 5/2 with few fine brown to dark brown 7.5YR 4/4 root channels; fine sandy loam; weak medium subangular blocky; friable; moist becoming wet; no organic matter; very few fine roots; very few fine stones; sharp change to thin iron pan at 108cm.
108-128	10YR 5/4 with frequent medium patches of 10YR5/8; frequent coarse 2.5Y 6/2 gley patches; loam to sandy loam; massive structure dominated by stones; no organic matter; no roots; many stones.
128	Bedrock ?

Source: The Soil Survey for Scotland

3:2:4 The Comparison of Deep Top Soils and the Bilbster Series : Laboratory Data

Data from the nine deep top soil profiles examined during the first phase of field laboratory work were compared with data from the Bilbster Series supplied by the Soil Survey for Scotland (Appendix II). The procedure was to establish differences between the laboratory derived properties of these two soil types and to attempt to ascribe any differences to anthropogenic activity.

1. Soil Separates

The results of the Mann-Whitney U Test comparing the percentage sand,silt and clay in the deep top soils with the Bilbster Series demonstrate that, with the exception of percentage silt in the S/A horizon, the two soil types are significantly different thus rejecting the Null hypothesis (Table 3:6).

Table 3:6

Probability Values for the Mann-Whitney U Test Comparing Deep Top Soils with Bilbster Series Soils in Orkney

	S/A Horizon	B Horizon
% Sand	0.001 *	0.000 *
% Silt	0.193	0.000 *
% Clay	0.000 *	0.009 *

* = Significant to 0.05 level (Two tailed test)

Deep top soils are of a loam/clay loam texture (Fig 3:4). Thus they are less sandy, contain more clay and slightly more silt than the Bilbster Series. It is clear that the deep top soils are of a different textural class in comparison to "parent" Bilbster Series. Such differences include the underlying B horizon. Explanation has therefore to be made for the general increase in clay with the parallel decrease in sand and the similarity in silt content of the S horizon of the deep top soil relative to the Bilbster Series. Given that all other factors of soil formation are similar and assuming that communiation by accelerated weathering and/or cultivation of the deep top soil has not altered the textural class, then the implication of the results is that man has

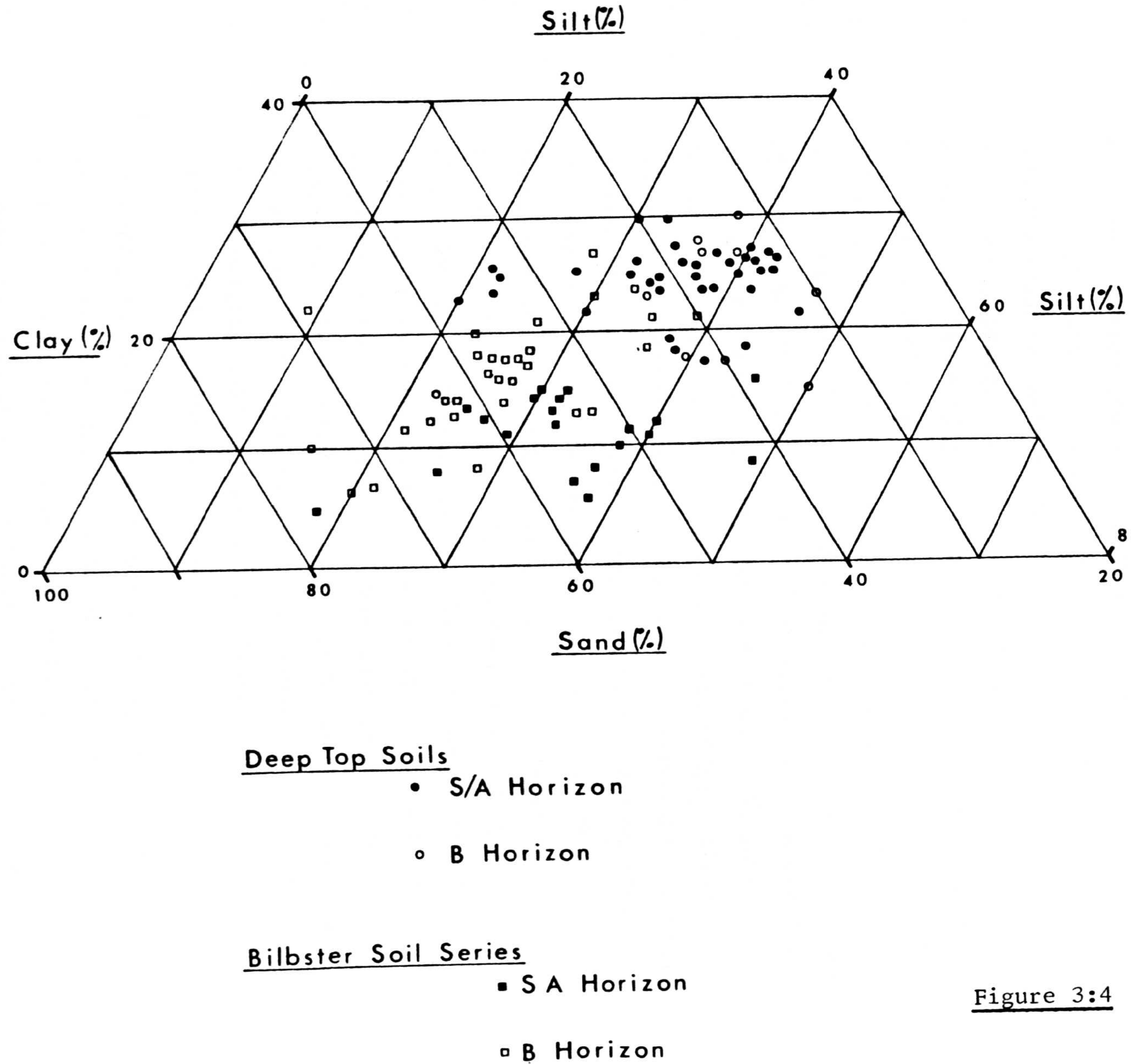


Figure 3:4 Textures of the deep top soils and the Bilbster Soil Series.

deposited inorganic materials which are different in textural composition from the "parent" soil. Such inferences from textural analysis have been made in areas where plaggen soils are known to occur. Particle size analysis of the Maori plaggen soils demonstrated a gravelly silt loam to very gravelly sand texture of these soils, (McFadgen, 1980). Such textures are in sharp contrast to the underlying and overlying sediments which have a wide range of textural classes ranging from silt through loamy sand to sand. Thus using particle size data,McFadgen was able to demonstrate the borrow pit origin of the Moari plaggen soils. In the Netherlands dune sand can be identified as having contributed to a number of plaggen soils (de Bakker, 1979). A soil buried by a plaggen horizon contains 23% clay and 9% coarser than 150um, material characteristic of recent marine sediment. The overlying plaggen horizon as a consequence of dune sand application,has a clay content of 6% while the sand separate has increased from 9% to 67%. Differences of texture can also be identified within the plaggen class of soils in the Netherlands. Brown plaggen soils which result because of the use of grass sods from brook valleys have slightly more clay than the black plaggen soils which result because of the use of heather sods. Clay differences arise because of differences in clay content of the original material (Pape, 1970; de Bakker, 1979). The deep man-made plaggen soils in Ireland originated as a result of the addition of large quantities of sea sand. Consequently one outstanding characteristic of this soil is the textural range of loamy coarse sands to light coarse sandy loams. The texture of the underlying soil influences the texture of the plaggen layer only to a limited extent.

Returning to the Orcadian deep top soils, the question arises as to where the material of formation originated. While this question is tackled more fully in Chapter 8, it is worth presenting some preliminary observations here. Compared with soils formed on other sediments in Orkney, the deep top soils have the highest clay content and the lowest sand content (See Appendix II). The deep top soils are, within

Orkney, unique in their texture. In an effort to explain this, two hypotheses may be presented. Firstly, it may be postulated that the materials involved in deep top soil formation were subject to some process before finally being deposited. These processes may have involved the production of ash, or an intensive trampling of turf sods by cattle in a confined space (Romans, pers comm.) Secondly, the turf sods themselves may have had a high clay content.

Similarity of silt content of the S/A horizons relative to the Bilbster Series can best be attributed to the use of Bilbster Series soil in the construction of deep top soil. In the Bilbster Series clay content frequently increases in the B horizon but not to the levels normally found in the B horizons of deep top soils. The implication of such an observation is that the texture of the B horizons have been influenced by anthropogenic sedimentary processes. The exact processes of clay incorporation into the B horizons cannot be given with any certainty. Illuviation into the B horizon in increased volume because of the greater amount of clay above in the S horizon is the most likely possibility.

Notwithstanding the difficulties in identifying the origin of the inorganic material, it is reasonably certain that human activity has introduced a new material into the area identified today as deep top soil. This is the most obvious explanation of the differences in texture between deep top soils and the Bilbster Series.

2. Loss on Ignition

The weight loss in an ignited sample is primarly due to the oxidative destruction of organic matter to carbon dioxide and water, the loss of structural water from clay minerals and the loss of carbon dioxide if free calcium carbonate is present (Futty and Dry, 1977). Thus values for loss on ignition give a reasonable estimate of the organic content of a soil sample.

The source of organic matter is soils is plant and animal tissue, materials which are decomposed and reconstituted as humus in the soil system. Climatic conditions exert a dominant influence on the amounts of organic material found in soils under natural ecosystems but such influences may be nullified in soils which are cultivated (Brady, 1974). Large quantities of organic materials were involved in the construction of the Dutch plaggen soils. Heather sods, grass sods, forest litter and peat litter were used in the byre to soak up liquid components of the manure. This litter and manure was then applied to the arable land (Pape, 1970). In Ireland as well as manure, seaweed was frequently ploughed into the arable land, contributing to the plaggen horizon. Turf may have been involved in the formation of the deep top soils in Aberdeenshire (Glentworth, 1944). Based purely on the information available for the materials that formed man-made plaggen horizons, it might be expected that plaggen soils would have a higher loss on ignition value than comparable surrounding soils. This however need not necessarily be the case. Despite the increased input of organic materials, soil organic levels may return to an equilibrium level dictated by climate, once the additional organic inputs ceased. Furthermore land use for intensive arable purposes is frequently much lower in organic matter than comparable non-arable areas (Eidt, 1984). In cultivated areas the bulk of the plant material is removed for human or animal food and little is returned to the soil. Soil tillage serves to break up any organic residues and brings them into contact with soil organisms thus increasing the rates of decomposition. Depletion in soil organic matter content because of such practices is frequently reflected in the upper horizons of cultivated soils. Conry (1971) has noted that in surface horizons the organic matter status of plaggen soils in Ireland has declined relative to unreclaimed soils. The cause of such a decline is partly attributed to arable activity. Thus when interpreting the results of the loss on ignition results for the deep top soils,consideration must be given to both the question of input of organic material and to the depletions caused by arable activity and ongoing biological processes.

Results of the Mann-Whitney U Test comparing horizons of the deep top soils with the Bilbster Series,indicate that the two soil types are significantly different, thus rejecting the Null hypothesis that there is no statistical difference between them (Table 3:7).

Table 3:7

Probability Values for the Mann-Whitney U Test Comparing Deep Top Soils with Bilbster Series Soils in Orkney

	S/A Horizon	B Horizon
% Loss on Ignition	0.000 *	0.000 *

* = Significant to 0.05 level (Two tailed test).

The graphs indicate that values for the deep top soils are lower than those for the Bilbster Series (Fig 3:5). Thus assuming that the results are statistically comparable, they indicate the anthropogenic nature of the deep top soils as the deep top soils developed. Whether the deep top soils were constructed with material that contained little organic matter or whether cultivation activity on these soils was particularly intensive resulting in organic matter depletion is not clear. Further laboratory information is required to resolve this question.

3. pH

pH values represent the hydrogen ion concentration of the soil solution. For anthropogenic activity to be manifested in soil pH values, the factors controlling the concentration of hydrogen ions must be altered in such a way that the natural buffering capacity of the soil is overcome. Soil pH can be markedly altered by human activity for a large number of different reasons. Land clearance, cultivation practice, change in vegetation cover, soil drainage and the use of various fertilizers have all been documented as causing significant and permanent pH changes in soils. Glentworth (1944) notes that 80% deep top soils of the Insch Series in Aberdeenshire had a pH greater than 6, while of the undeepened counterparts, only 20% had a pH greater than 6. This increase

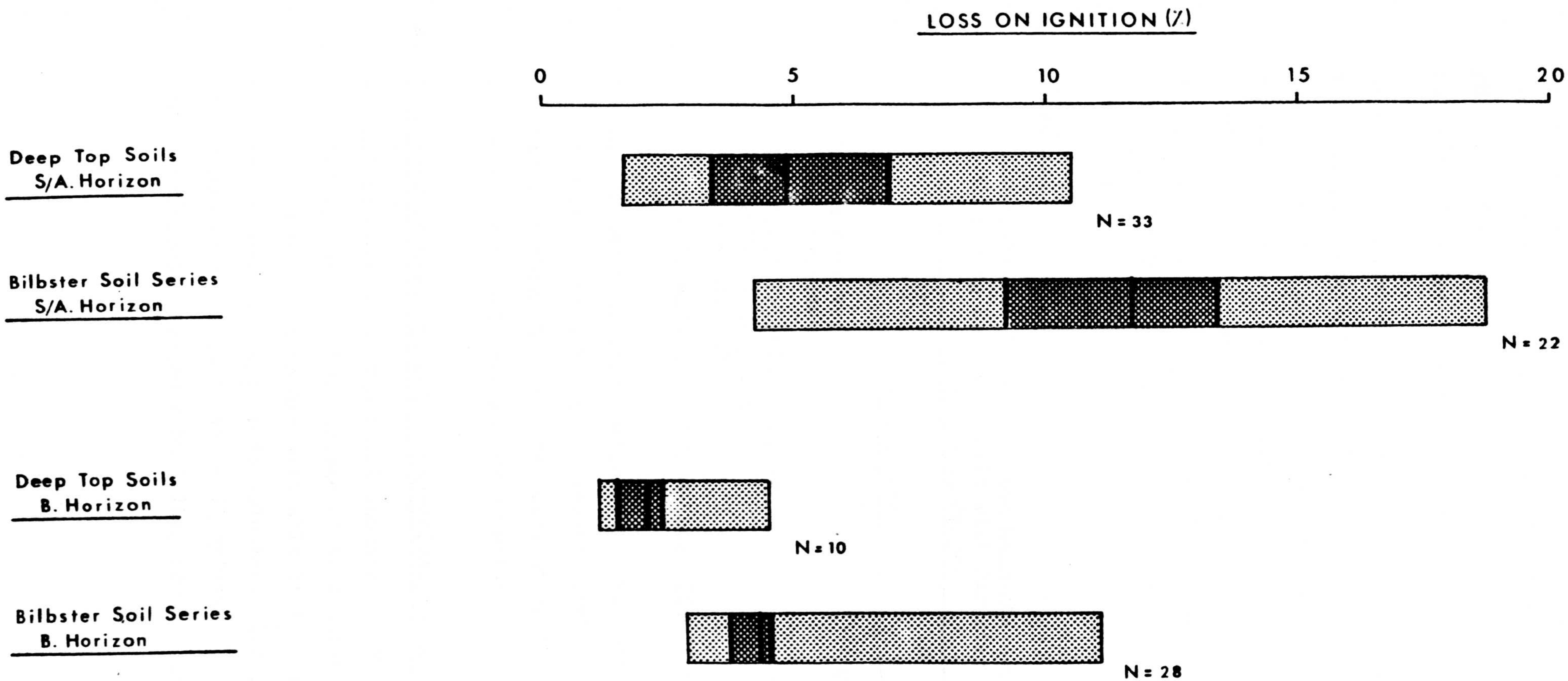


Figure 3:5 The percentage loss on ignition value ranges from deep top soils and the Bilbster Soil Series. Also shown are the median (central black bar), the upper quartile (black bar on right) and the lower quartile (black bar on left).

in pH status was attributed to arable activity. The Irish plaggen soils which are largely constructed out of calcareous sand have, not surprisingly, strongly alkaline reactions. pH values can range from 7.3 to 8.3 within these soils. The unsanded counterpart varies from 5.8 to 6.0 (Conry, 1971).

Statistical analysis demonstrated that when the two deep top soil profiles with a significant blown-sand input were taken out of the analysis,there was no significant statistical difference between the deep top soils and the Bilbster Series (Table 3:8). Even when these two profiles were included in the analysis, there was still no significant difference in the S/A horizon. The B horizon had however been significantly altered (Table 3:8).

Table 3:8

Probability Values for the Mann-Whitney U Test Comparing Deep Top Soils with Bilbster Series Soils in Orkney

	S/A Horizon	B Horizon
pH (All deep top soil profiles)	0.617	0.028 *
pH (Without Keirfiold and Skail deep top soil profiles)	0.549	0.317

* = Significant to 0.05 level (Two tailed test).

Because of the similarity between the two soil types (Fig 3:6) it is not possible to make any statement about anthropogenic activities within the deep top soils other than they do not influence in a long-term manner pH values.

4. Exchangeable Bases (Calcium, Magnesium, Sodium and Potassium)

A small proportion of the total amounts of these elements in the soil is held on the surface of soil colloids as adsorbed cations. These cations are available to the plant roots, entering either directly or in solution. The adsorbed cations can be easily released to the soil solution by exchanging with other positively charged ions. This process of release can be

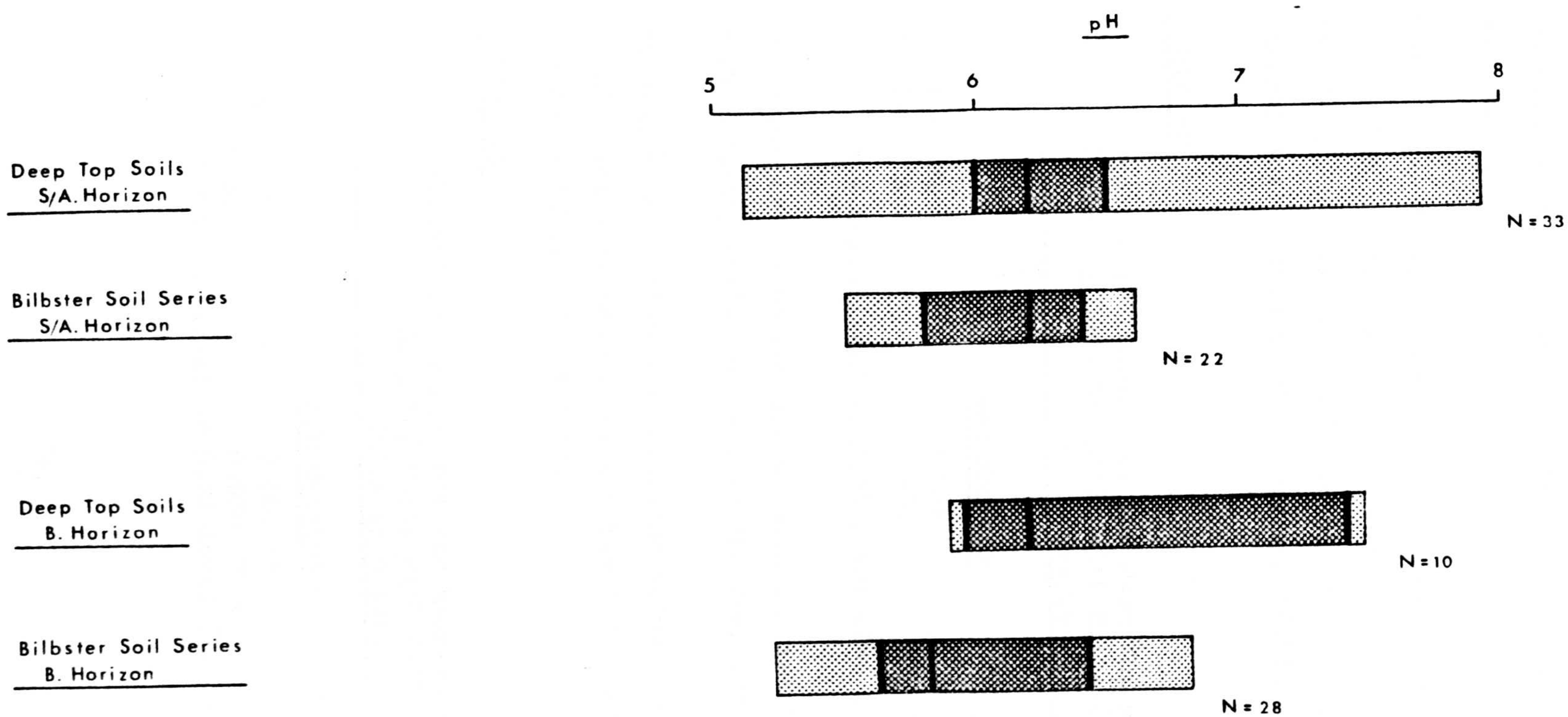


Figure 3:6 The pH value ranges from deep top soils and the Bilbster Soil Series. Also shown are the median (central black bar), the upper quartile (black bar on right)and the lower quartile (black bar on left).

reversed,as for example when soluble compounds of these elements are added to the soil.

Calcium and potassium are easily depleted in soils by leaching and by vegetation uptake. On the other hand, calcium is contained in significant amounts in food wastes and faecal material. Similarly, manure and ash contains significant amounts of magnesium (Eidt, 1984; Cook and Heizer, 1962). The values obtained,therefore,for exchangeable bases from Orkney soils represent the current balance between inputs and removals.

Statistical analysis demonstrates that there is no significant difference in exchangeable sodium and potassium content between the deep top soils and Bilbster Series with the exception of exchangeable sodium in the B horizon (Table 3:9).

Table 3:9

Probability Values for the Mann-Whitney U Test Comparing Deep Top Soils with Bilbster Series Soils in Orkney

	S/A Horizon	B Horizon
Exch.Na	0.841	0.005 *
Exch. K	0.424	0.368

* = Significant to 0.05 level (Two tailed test).

These properties do not assist with the interpretation of anthropogenic activities within the deep top soils.

Exchangeable calcium and magnesium values do exhibit significant differences between the two compared soil types (Table 3:10) (Fig 3:7 & 3:8).

Table 3:10

Probability Values for the Mann-Whitney U Test Comparing Deep Top Soils with Bilbster Series Soils in Orkney

	S/A Horizon	B Horizon
Exch. Ca	0.009 *	0.424
Exch. Mg	0.000 *	0.021 *

* = Significant to 0.05 level (Two tailed test).

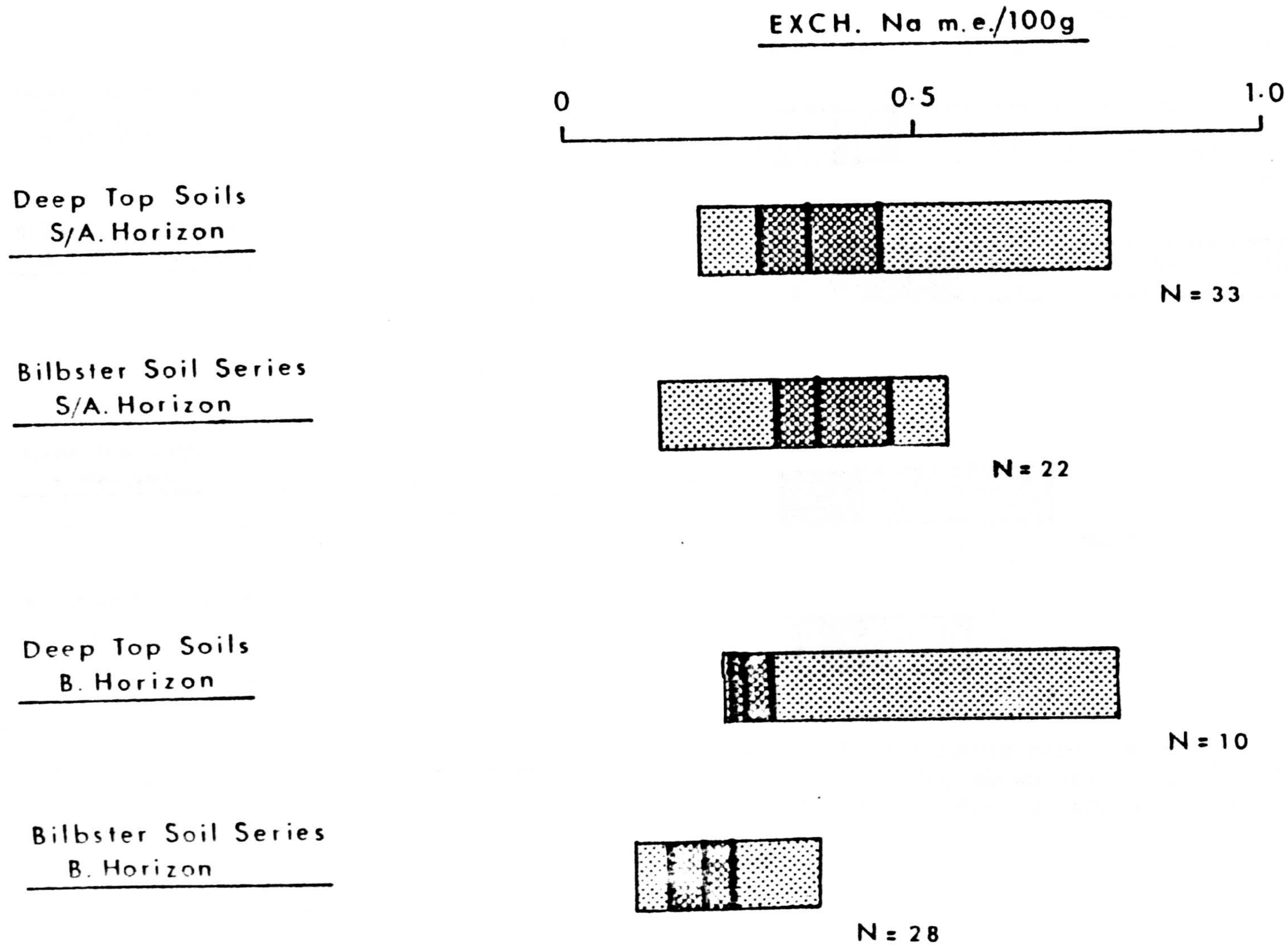


Figure 3:7 The exchangeable sodium value range from deep top soils and the Bilbster Soil Series. Also shown are the median (central black bar), the upper quartile (black bar on right) and the lower quartile (black bar on left).

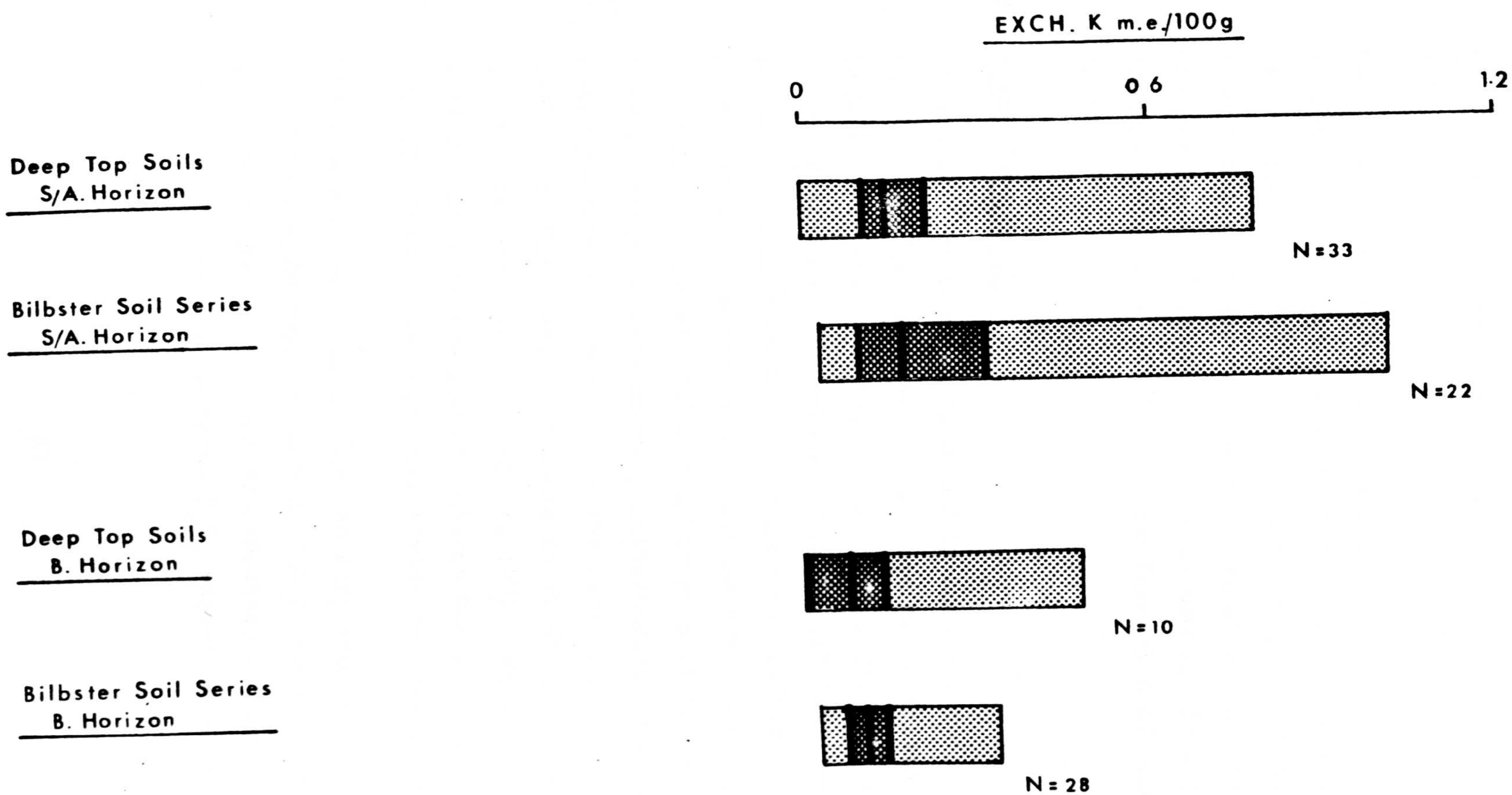


Figure 3:8 The exchangeable pottasium value range from deep top soils and the Bilbster Series. Also shown are the median (central black bar), the upper quartile (black bar on right) and the lower quartile (black bar on left).

Differences in calcium levels are not maintained in the B horizon. From the graph (Fig 3:9) it is evident that exchangeable calcium values are lower in the deep top soils as compared with the Bilbster Series. Major anthropogenic activity of some form is clearly evident, but again however the question that cannot be resolved is whether introduced material was genuinely low in calcium ie lacking in food waste and faecal material, or whether there has been intensive agricultural activity depleting the easily removed calcium cation.

Based on the available literature it would appear that the increase in the less mobile exchangeable magnesium cation (Fig 3:10) in the deep top soil relative to the Bilbster Series may be attributed to an input of manure and/or ash material. This observation is indicative of the anthropogenic sedimentary process being responsible for the formation of the deep top soils.

5. Total Phosphorus

Of the soil properties examined in anthropogenic soils throughout the world, phosphorus values are demonstrated to be always high to very high (Conry, 1974). The major source of phosphorus in these soils is considered to be faecal material, plant and animal remains, food waste and domestic refuse. All organic materials contain relatively high amounts of phosphorus as it is one of the essential constituents of DNA molecules. Of further value in interpreting anthropogenic activity in soils using phosphorus nalysis is the fact that when phosphorus is applied to the soil, it accumulates at its point of application due to its low solubility (Eidt, 1977; Proudfoot, 1976). Thus analysis of soil phosphorus values may give an indication of anthropogenic activity, in particular the use of organic materials.

Total phosphorus values for the deep top soils of Orkney indicate a wide range from 93mg P_2O_5/100g to 1148mg P_2O_5/100g (Fig 3:11). Results of the Mann-Whitney U Test demonstrate the distinct difference in total P_2O_5 values between the deep top

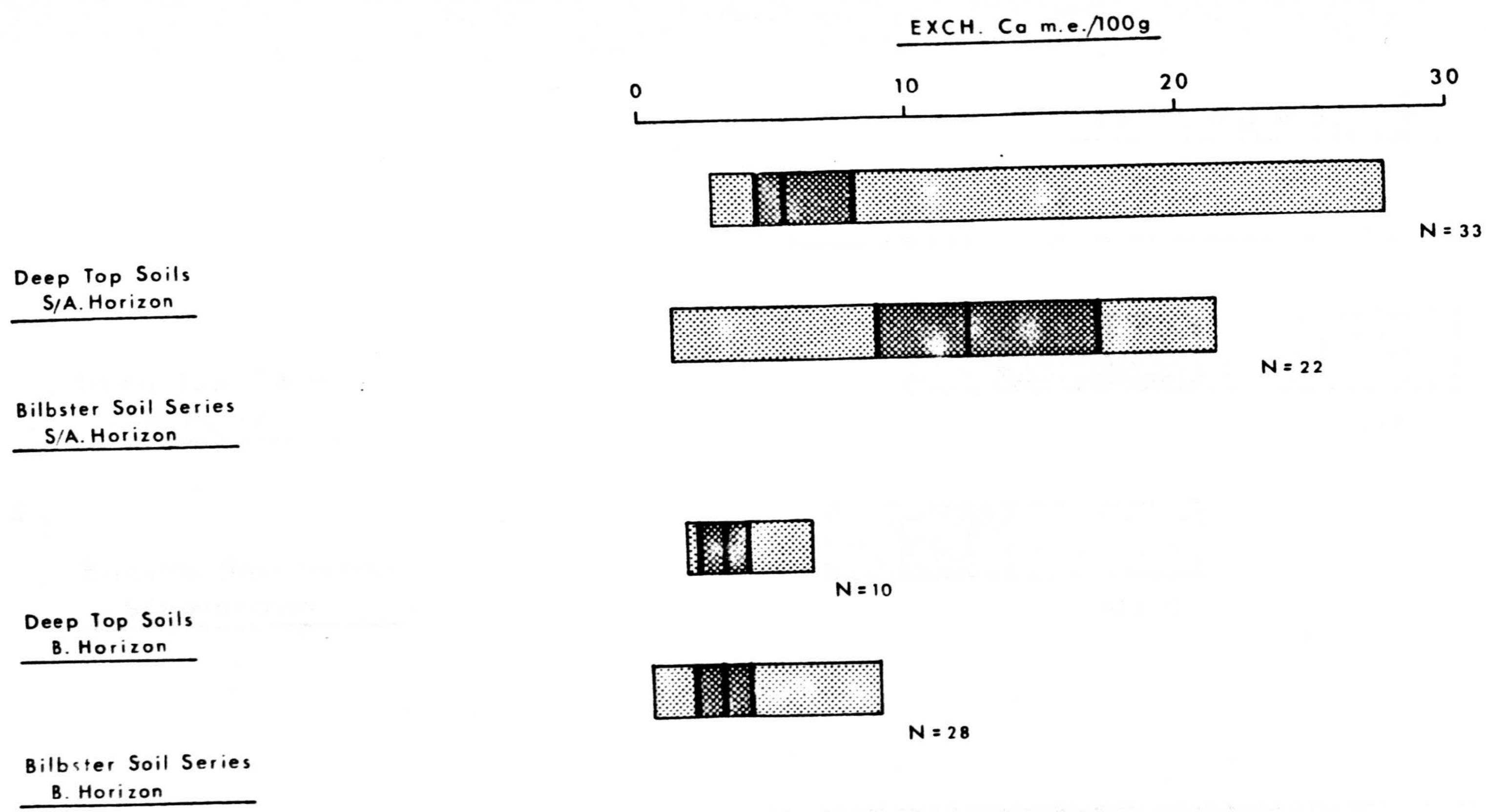


Figure 3:9 The exchangeable calcium value range from deep top soils and the Bilbster Soil Series. Also shown are the median (central black bar), the upper quartile (black bar on right) and the lower quartile (black bar on left).

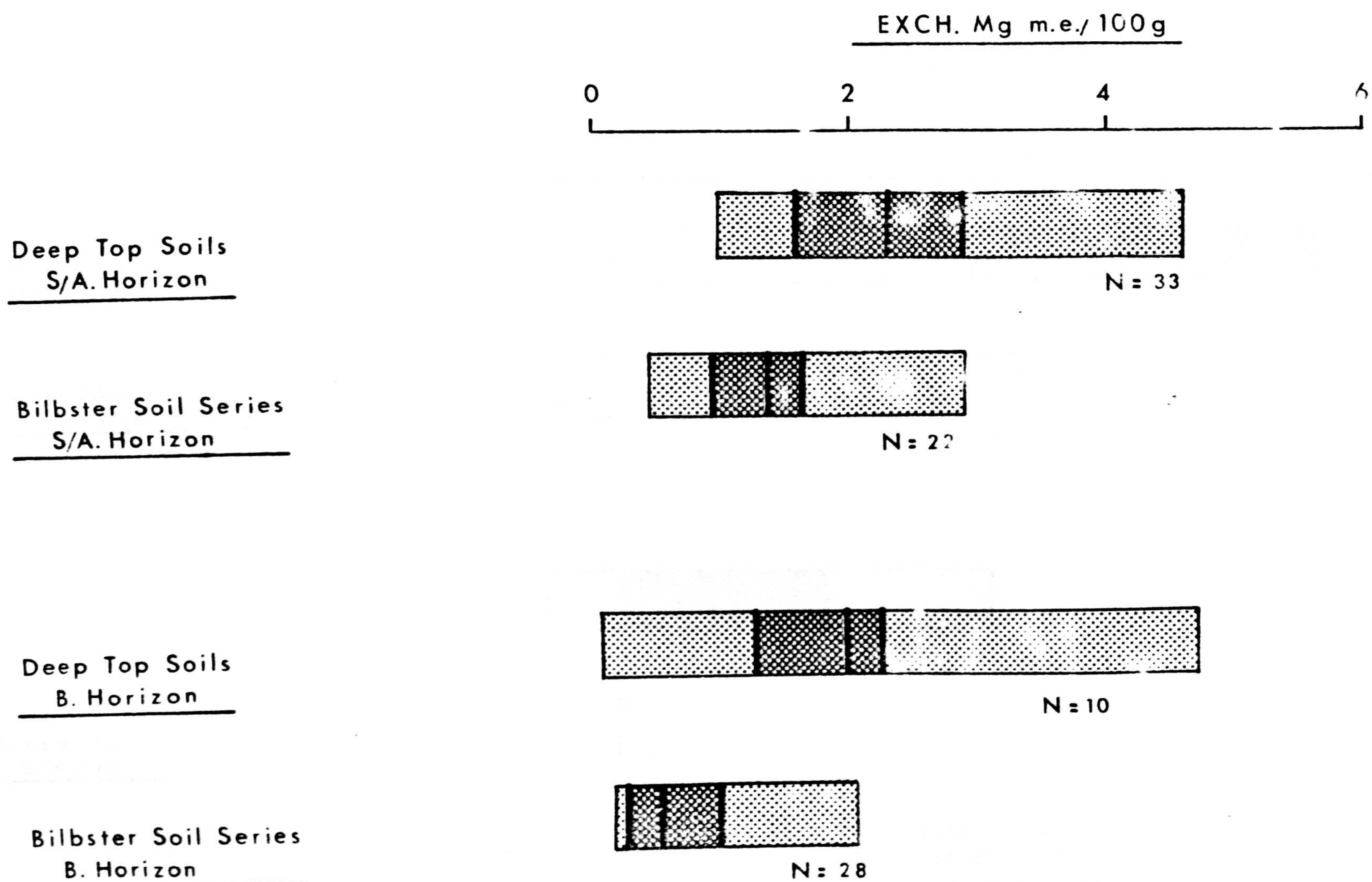
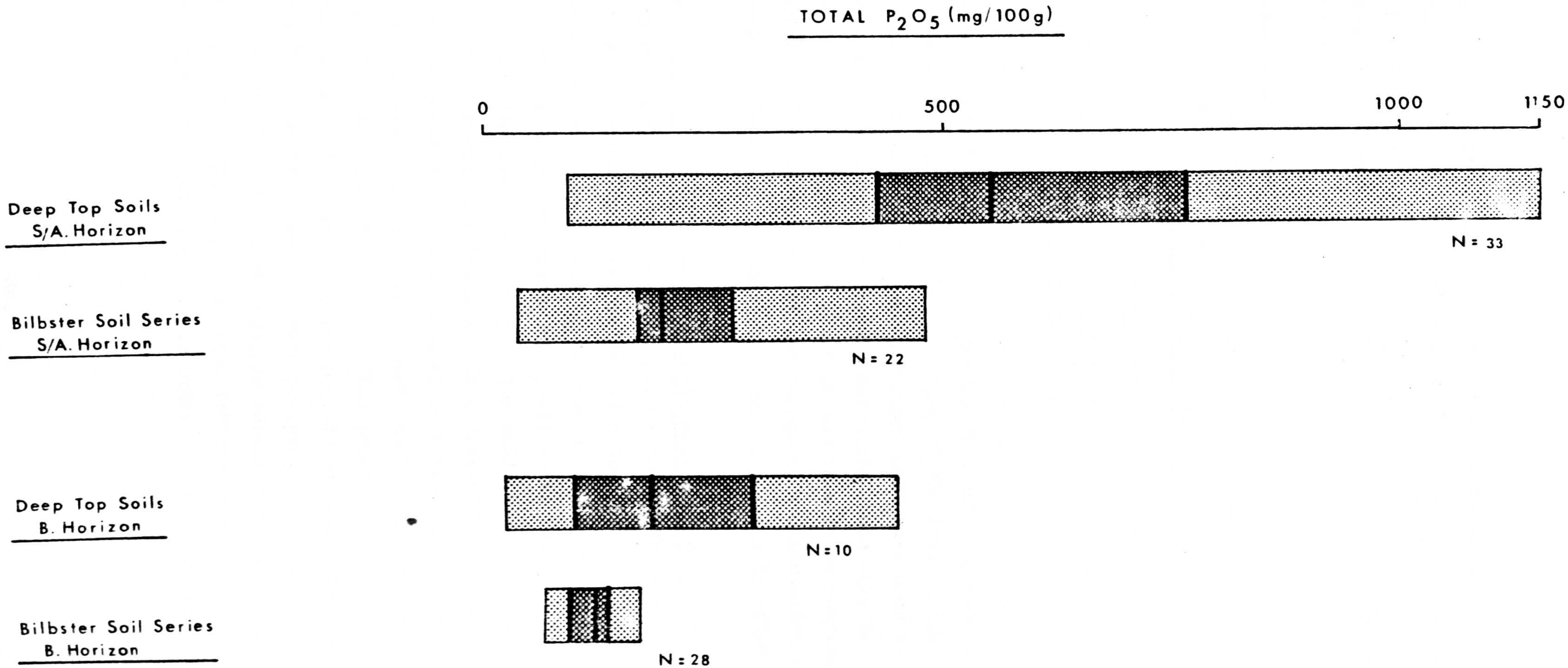


Figure 3:10 The exchangeable magnesium value range from deep top soils and the Bilbster Soil Series. Also shown are the median (central black bar), the upper quartile (black bar on right) and the lower quartile (black bar on left).



<u>Figure 3:11</u> The total phosphate value range from deep top soils and the Bilbster Soil Series. Also shown are the median (central black bar), the upper quartile (black bar on right) and the lower quartile (black bar on left).

soils and soils of the Bilbster Series, both in the S/A horizons and the B horizons (Table 3:11). These differences represent a greater level of P_2O_5 within the deep top soil profiles. Values of P_2O_5 in the deep top soils are in Orkney unique.

Table 3:11

Probability Values for the Mann-Whitney U Test Comparing Deep Top Soils with Bilbster Series Soils in Orkney

	S/A Horizon	B Horizon
Total P_2O_5	0.000 *	0.003 *

* = Significant to 0.05 level (Two tailed test).

The conclusion is therefore that substantial amounts of organic materials have been incorporated into the material forming the deep top soils. In view of the loss on ignition results the bulk of this organic input must have been mineralised. Such a concentration of organic materials could only be achieved by anthropogenic activity and this forms convincing evidence for the process of anthropogenic sedimentation being responsible for the formation of deep top soils in Orkney.

3:2:5 Conclusions : The Anthropogenic Nature of Deep Top Soils

Having outlined some of the basic properties of the deep top soils and compared these properties with the "parent" Bilbster Series, what conclusions can be made about the anthropogenic nature of the deep top soils? The distinctive field property, S/A horizon thickness of the deep top soils,has been demonstrated to increase around farmsteads and is a characteristic that can only be attributed to the process of anthropogenic sedimentation. In certain locations wind-blown sands have contributed to the formation of the deep top soils. This process has contributed a small amount of material to the profile at Skail, but at Keirfiold is probably the dominant process. Laboratory derived data also confirms the anthropogenic sedimentary status of the deep top soils. The loam/clay loam texture is of a type apparently not found elsewhere in Orkney. This suggests that inorganic materials have been subject to some anthropogenic process, perhaps trampling of turf material in cattle-byres, prior to being deposited on the land to form the deep top soil. The sediments that went to make up the deep top soil also seemed to have contained significant quantities of organic material. This is evident from the exchangeable magnesium and total phosphorus levels which are considerably greater than those found in the "parent" Bilbster Series. Thus texture, total phosphates and exchangeable magnesium values support the hypothesis that anthropogenic sedimentary processes were responsible for deep top soil formation.

Other laboratory derived properties, those that are sensitive to environmental changes, indicate the comparatively intensive arable use to which the deep top soils were put as they evolved. Within the S/A horizon exchangeable calcium and loss on ignition values relative to the Bilbster Series are depleted. Exchangeable magnesium and total phosphate values suggest that the deep top soil sediments originally consisted of much organic material. This might normally be reflected in higher exchangeable calcium and loss on ignition values. That this is not the case must be attributed to the removal of calcium and organic material by intensive cropping and by tillage and perhaps accelerated leaching.

Exchangeable potassium, exchangeable sodium and pH values are similar in the deep top soils and Bilbster Series. Either the processes involved in the formation of deep top soils did not influence these properties or else, having been altered, they returned to some equilibrium level. Similar reasons may be advanced for the lack of distinguishing field characteristics.

With the exception of the Keirfiold profile,the deep top soils exhibit a clear anthropogenic nature. Two types of human activities can be demonstrated from the deep top soil properties. One, the process of anthropogenic sedimentation can be detected and is considered to be the major process of formation for the deep top soils. Secondly, as deep top soils evolved, there is evidence to suggest that an arable practice of greater intensity than that associated with the Bilbster Series was practised. These two activities thus combined to give the distinctive anthropogenic nature of the deep top soils in Orkney.

3:3 The Anthropogenic Nature of Farm Mounds

The historical evidence that was cited in Chapter 1 would seem to leave little doubt as to the anthropogenic nature of the farm mounds. This section seeks to describe the mounds both in terms of their slope morphology and their stratigraphy thus confirming the anthropogenic nature of the farm mounds.

3:3:1 Slope Profile Analysis

The farm mounds vary widely in their size and form. Of the fifteen known farm mounds on Sanday, the mound diameter for the longest observable length of each mound varies from 50 to 205m. On North Ronaldsay the mound diameter range is between 35 to 160m. Slope profile analysis of the twenty-five farm mounds was carried out to provide a description of slope form, to permit their general classification and comparison, and to infer something of their formation processes. Slope profiles of three of the glacial moraines near Finstown were also analysed thus allowing comparison between the farm mounds and the only other similar features identified in Orkney.

Slope profile data was obtained by direct measurement in the field. The profile sampling line across the mound was the subjectively observed maximum diameter of the mound. Measurement of slope angles were taken using an Abney level over 5m length of slope, the lengths being measured by a tape and marked with ranging rods (Young, et al, 1974).

Initially standard distance/height slope profiles were plotted and examined visually (Fig 3:12 and 3:13). By this method it was possible to classify the farm mounds into the four categories tabulated below (Table 3:12). The first class of mound was characterised by being dissected to a greater or lesser extent by the sea. This is made evident by the anthropogenic sediments in the dune or cliff stratigraphy where the mound has been cut

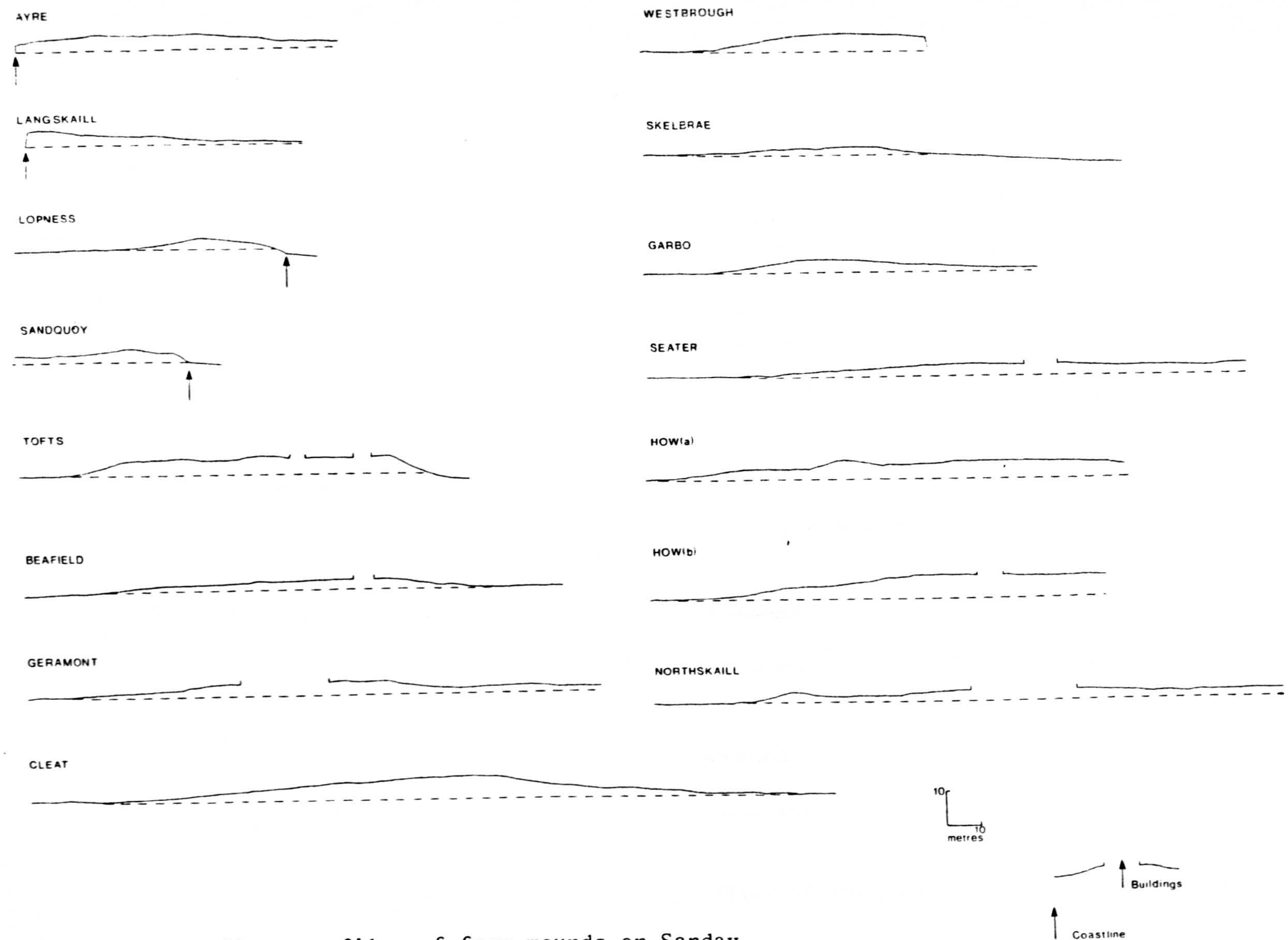


Figure 3:12 Slope profiles of farm mounds on Sanday.

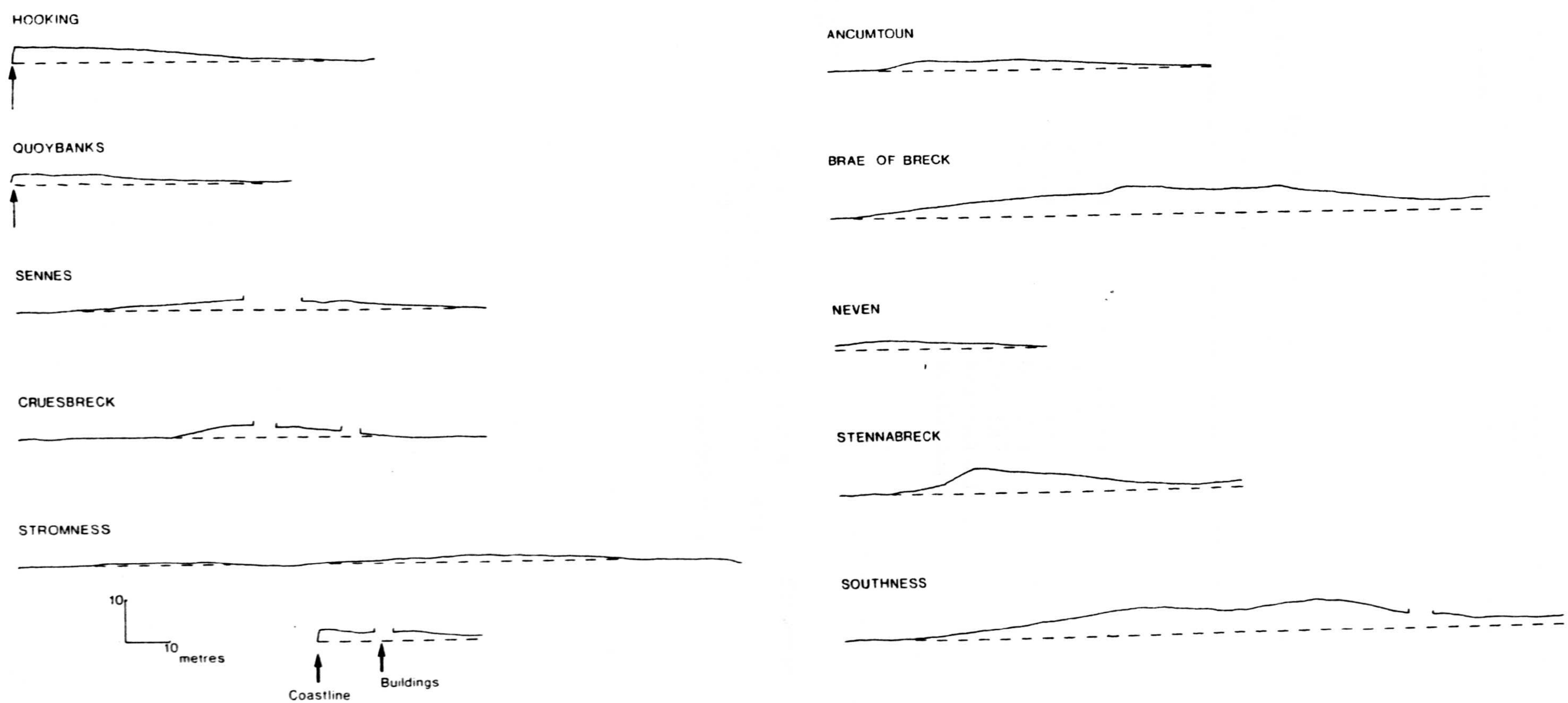


Figure 3:13 Slope profiles of farm mounds on North Ronaldsay.

TABLE 3:12

THE CLASSIFICATION OF FARM MOUNDS ON SANDAY AND NORTH RONALDSAY, BASED ON SLOPE PROFILE FORM

Mounds Dissected by Coastline	Approximately Symetrical Mounds	Approximately Assymetrical Mounds	Double Mounds
SANDAY			
Sandquoy	Cleat	Skelbrae	
Lopness	Geramont	Garbo	
Langskail	Beafield	Seater	
Ayre	Tofts	How (A)	
		How (B)	
		Northskail	
		Westbrough	
NORTH RONALDSAY			
Hooking	Sennes	Ancumtoun	Strømness
Quoybanks	Cruesbreck	Brae of Breck	
	Southness	Neven	
		Stennabreck	

(see Section 3:3:2). Thus the major factor controlling their form is coastal erosion. On Sanday, Langskail appears to have had approximately half the mound eroded away, Sandquoy approximately one quarter, while Lopness and Ayre have lost only the edges of one slope. Hooking and Quoybanks on North Ronaldsay have lost approximately half the mound to coastal erosion. It is likely that all these mounds would have fallen into the approximately symmetrical category had it not been for coastal erosion. All of these mounds, with the exception of Hooking, consist of layers of sediment clearly out of place in the dune or cliff stratigraphy. The cut edge of the Hooking mound appears to consist mainly of dune sand. Thick deposits of stone wall are evident in the mound but midden material consists only of a thin band some 45cm thick sandwiched in the dune sand material. The indications are therefore are that this mound has built up for different reasons than the others, wind-blown sand being the dominant material.

The second class of mound, approximately symmetrical, appears to have been constructed on a relatively level segment of land. One can envisage here the mounds growing by outward extension from the summit area with all sides of the mound having equal deposition of material. The Southness mound is a slight anomaly in that a small saddle is observable in the middle of the slope profile. This feature can perhaps be attributed to the fact that two farms occupy the summit area of this mound potentially giving a double nucleus for the formation of the mound. It is likely that the waste material generated by these two farms would each produce their separate zones of deposition as the mound evolved.

Thirdly, the asymmetrical mounds are characterised by at least one of two features. Some of these mounds particularly those on Sanday are characterised by having one end of the mound terminating at a higher level than the other end. The slope profile population of the slope terminating at the higher level is generally less steep than at the lower level. This implies that deposition has infilled a slight slope hollow in the landscape. The asymmetrical mounds at Ancumtoun and Stennabreck on North Ronaldsay indicate that there has been a greater build-up of material at one edge of the mound relative to the other end. If man is responsible for the formation of the farm mounds then selective deposition appears to have been practised with material being deposited either in slight landscape depression zones or at particular parts of the evolving mound.

A fourth category of farm mound is exemplified by Strømness on North Ronaldsay. This mound demonstrates a double peak and is more correctly described as two mounds. Their proximity perhaps indicates two close but separate farmsteads which generated waste materials. Insufficient material was generated to link the two mounds.

To conclude this introductory section of slope profile analysis, it is possible to state that there are apparently three major constraints on the general slope form of the Sanday and North Ronaldsay farm mounds. The microtopography of the landscape has controlled how the farm mound evolved. Uniform outward extension from the summit area is postulated for those mounds constructed on a relatively level segment of land while deliberate infilling of slope hollows may have been practised in areas of rougher microtopography. Where two farmstead communities co-exist together a double peak may be observed separated by a saddle. This represents two nuclei of mound formation. The final constraining factor, coastal erosion, has in all probability, occurred after anthropogenic deposition had ceased and thus is a more recent factor controlling mound form.

In an effort to obtain a more detailed quantitative analysis of the slope profiles various methods were considered. Despite its shortcomings (Cox, 1981; 1978), Young's (1971) method of analysing slope profiles was adopted. "Best Unit Analysis" provides a sequence of rectilinear (segments) and curved (elements) slope units which can be compared between profiles as the results are numerical. The nature of the mound slope profile data was also a consideration when selecting the method of analysis. Two quite distinct slope profile populations are frequently demonstrated for individual mounds. Best Unit Analysis partitions the profile into homogenous units and hence can incorporate two slope populations into the same sequence.

Segments and elements can be identified by graphical inspection. Graphs of angle against distance and curvature against distance were plotted. Angle and distance values were obtained from field measurements, while the best estimate of curvature (C) for a particular measured length (q) are given as Formula 3:1.

$$Cq = 100 \frac{\theta p - \theta r}{0.5p + q + 0.5r} \text{ degrees per 100m}$$

Formula 3:1

where

p, q & r = successive measured lengths

θp & θr = the angle of the measured lengths

Provisional segments and elements were selected by inspection and the coefficient of variation for both segments (Va) and elements (Vc) is calculated for each of these units by Formula 3:2 and Formula 3:3

Formula 3:2

$$\bar{\theta} = \frac{\Sigma li \theta i}{\Sigma li}$$

$$Va \text{ (or } Vc) = \frac{100 \sqrt{\frac{\Sigma li \theta^2 i}{\Sigma li} - \bar{\theta}^2}}{\bar{\theta}}$$

Formula 3:3

where

li and θi = length (meters) and angle (degrees) of a succession of measured length.

$\bar{\theta}$ = the mean angle.

These equations are given in Young (1971).

Two factors influence the results obtained by this method, the measured length used to survey the slope and the amount of the angular variation permissible within segments and elements (Gerrard, 1978). The measured length used by this survey was 5 metres. Maximum coefficients of variation were set at

Va maximum = 25%

Vc maximum = 50%

If a coefficient of variation value for a unit under consideration exceeded these values then the unit was shortened and the coefficient of variation recalculated for that shortened unit. If the coefficient was substantially below the maximum,additional measured lengths were included in the recalculation. Maximum coefficient of variation values were set at the level which, according to Young (1971), gives a schematic representation of slope form by partitioning the profiles into relatively few units. The calculated results are given in Tables 3:13 and 3.14 and are discussed below on the basis of the general classification system already given.

1. Mounds Dissected by the Coastline

For the remaining slope profile, Langskail and Ayre are dominated by rectilinear slope units of between 5 and 20m in length, ranging between 0^{o} and 8^{o} in steepness. The mounds of Sandquoy, Lopness, Quoybanks and Hooking on the other hand are characterised by a highly curved component in their slope profile. Sandquoy follows the classic slope profile form with a concave unit at the base leading into a convex unit towards the summit. Rates of curvature and range of angle are similar throughout this class of mound. Length of slope unit varies between 5 and 30m.

2. Approximately Symmetrical Mounds

Within this generalized class there is again a wide range of slope units. Of the Sanday mounds in this class Tofts is the most prominent with one slope population containing an angle of 10.5^{o} and the other an angle of 21.5^{o} over 10 and 15m respectively. These slopes lead onto an undulating summit

TABLE 3:13

RESULTS OF BEST UNIT ANALYSIS OF SANDAY FARM MOUND SLOPE PROFILES

AYRE

UNIT	LENGTH (m)	ANGLE (o)	CURVA-:TURE (o/100m)	MOUND END POINT (←X)	SLOPE POPUL-:ATION
1	5	+14			
				←X	
2	5	+2.5		(coastline)	
3	5	+5.0			1
4	5	+1.0			
5	10		+40		
6	15	+0.83			
7	10	-0.75			
8	20	-4.25			2
				←X	
10	15	-1.16			
mound =75					

LANGSKAIL

UNIT	LENGTH (m)	ANGLE (o)	CURVA-:TURE (o/100m)	MOUND END POINT (←X)	SLOPE POPUL-:ATION
1	5	+1.5			
2	10	-7.25			
3	5	-4.0			
4	20	-2.38			1
5	-5.5				
6	15	-2.5			
				←X	
7	20	-1.23			
mound =60					

LOPNESS

UNIT	LENGTH (m)	ANGLE (o)	CURVA-:TURE (o/100m)	MOUND END POINT (←X)	SLOPE POPUL-:ATION
1	25	+0.8			
2	5	+0.5			
				←X	
3	10		-52.5		1
4	10	+8.25			
5	10		+147.5		
6	10		+20		
7	5	-11.5			
				←X	2
8	5	-22		(coastline)	
9	10	-6.5			
mound =45					

SANDQUOY

UNIT	LENGTH (m)	ANGLE (o)	CURVA-:TURE (o/100m)	MOUND END POINT (←X)	SLOPE POPUL-:ATION
				←X	1
1	25		-43.75		
2	10		+125		
3	5	-8.0			
4	10		+285		2
				←X (coastline)	
5	5	-40			
6	10	-4			
mound =50					

TAFTS

UNIT	LENGTH (m)	ANGLE (o)	CURVA-:TURE (o/100m)	MOUND END POINT (←X)	SLOPE POPUL-:ATION
1	15	+1.33			
				←X	
2	10	+10.5+110			
3	15		+110		1
4	5	-1.0			
5	10		+50		
6	10		-95		
7	5	-7.0			
Buildings	23.82				
8	5	-4.0			2
9	15	-21.5			
				←X	
10	5	-7.0			
11	5	-4.0			
mound =98.82					

BEAFIELD

UNIT	LENGTH (m)	ANGLE (o)	CURVA-:TURE (o/100m)	MOUND END POINT (←X)	SLOPE POPUL-:ATION
1	15	+1.33			
				←X	
2	5	+0.5			
3	5	+2.0			
4	15	+4.83			
silage court	10				1
5	10	+3.25			
6	5	+1.5			
buildings & yard	37.5				
7	5	+3.0			
8	10	-7.0			
9	30		-23.33	←X	2
10	15	+0.17			
mound =32.5					

RESULTS OF BEST UNIT ANALYSIS OF SANDAY FARM MOUND SLOPE PROFILES

Cont'd 2.

UNIT	LENGTH (m)	ANGLE (o)	CURVA-:TURE (o/100m)	MOUND END POINT (←X)	SLOPE POPUL-:ATION
GERAMONT					
1	10		-27.5	←X	1
2	5	+5.0			
3	5	+1.0			
4	15		-40		
5	10	+6.75			
6	5	+1.0			
Building	27.57				
7	10	-1.5			2
8	20		-31.25		
9	5	+0.5			
10	5	-2.0			
11	15	-1.3			
12	5	-0.5		←X	
13	15	-1.67			
mound	=107.57				
CLEAT					
1	5	0			1
2	10	-1.5			
3	5	-5		←X	
4	30	+2.83			
5	10		+17.5		
6	5	+2.5			
7	5	+6.0			
8	5	+2.5			
9	15	+4.33			
10	10		+52.5		
11	10	+3.25			
12	10	+1.25			
13	15		+38.33		2
14	20	-7.63			
15	40	-4.25			
16	30	-1.92			
17	10	0		←X	
mound	=205				
WESTBROUGH					
1	15	0		←X	1
2	5	+3.5			
3	20	+8.25			
4	10	+5.25			
5	10	+1.5			
6	20		+33.75		
7	5	-8.0			
mound	=70				
SKELBRAE					
1	10	+0.5		←X	1
2	30	+1.83			
3	10		-12.5		
4	20		+52.5		
5	10	-7.75			2
6	15	-3.16			
7	5	-5.0			
8	15	-3.5		←X	
9	20	-1.7			
mound	=105				
GARBO					
1	5	+0.5		←X	1
2	20		-31.25		
3	20	+8.0			
4	15		+28.3		
5	5	-2.0			2
6	15		+18.3		
7	15	-3.0		←X	
8	20	-0.75			
mound	= 90				
SEATER					
1	25	+0.3		←X	1.
2	15	+1.67			
3	40	+2.87			
4	30	+0.67			
Building	11.1				
5	5	-3.0			2
6	5	+1.0			
7	5	-2.0		←X	
8	25	+0.6			
9	15	+1.33			
mound	=111.1				

RESULTS OF BEST UNIT ANALYSIS OF SANDAY FARM MOUND SLOPE PROFILES

UNIT	LENGTH (m)	ANGLE (o)	CURVA-:TURE (o/100m)	MOUND END POINT (←X)	SLOPE POPUL-:ATION
HOW (HY6606					
1	30	+5.33			
road	7.6				
2	10		-140		
3	10	14.5			
4	5	-4.5			
5	5	-11.0			
6	5	-1.5			
7	5	-0.5			
8	5	0			
9	10		+62.5		
10	10	+1.25			
silage court	12.2				
11	5	-3.0			
12	5	+1.0			
13	10		52.5		
14	5	-6.5			
15	5	-3.0			
HOW (HY7483					
1	30		-26.67		
2	10		+60.0		
3	10	+1.75			
4	15	+7.0			1
5	20		+36.25		
6	5	0			
Building	9.4				
7	5	0			
8	5	-1.0			2
9	5	-3.0		←X	
10	15	+0.167			
mound +114.5					
NORTHSKAIL					
1	10	+0.75			
2	5	-1.5			
3	5	+0.5			
4	15		-90.0	←X	
5	10		+200.0		
6	5	-12.0			1
7	5	-4.5			
8	5	+2.5			
9	5	0			
10	15		-15.0		
11	10		+18.0		
Building	34.55				
12	10	-2.5			
13	15	-1.17		←X	2
14	25	-0.5			
15	5	-2.0			
mound =125.55					

TABLE 3:14

RESULTS OF BEST UNIT ANALYSIS OF NORTH RONALDSAY FARM MOUND SLOPE PROFILES

UNIT	LENGTH (m)	ANGLE (o)	CURVA-:TURE (o/100m)	MOUND END POINT (←X)	SLOPE POPUL-:ATION
SOUTHNESS					
				←X (?)	↑
1	20	-	-15		
2	5	+3.5	-		
3	30	+6.17	-		
4	25	-	+68		
5	15	-5	-		
6	20	-	+63.75		↓
7	5	-2.5	-		↑
8	10	-10.5	-		
9	5	-15	-		
10	5	-7	-		
11	20	-	-21.25		
				←X	
12	10	-0.5	-		↓
BRAE OF BRECK					
1	10	+1.75	-		
				←X	
2	20	+5.75	-		
3	5	+4.00	-		
4	15	-	+2333		
5	19	+3	-		
6	5	+5			
7	10		+105		
8	5	+0.5			
9	5	-1.5			
10	10	-	+65		
11	40	4.44	-		
12	5	-1.0	-		
13	5	+3.0	-		
				←X	
14	5	0	-		
15	5	-0.5	-		
SENNES					
1	15	+1.0	-		
2	5	+2.0	-		
3	10	+4.25	-		
4	15	-	28.33		
5	10	+6.25	-		
Building					
6	5	-10.0			
7	15	-5.17	-		
8	15	-2.67	-		
9	5	0	-		
10	5	-2.0	-		

UNIT	LENGTH (m)	ANGLE (o)	CURVA-:TURE (o/100m)	MOUND END POINT (←X)	SLOPE POPUL-:ATION
STRØMNESS					
1	5	-1.5	-		
2	5	+2.5	-		
3	5	+0.5	-		
4	5	+1.5	-		
5	15	-	+21.67		
6	5	-0.5	-		
7	5	-2.0	-		
8	5	-1.0			
9	20	-	-16.25		
10	10	+2.0			
11	20	+1.37	-		
12	5	+4.0	-		
13	15	0	-		
14	10	-1.25	-		
15	5	-0.5	-		
16	10	-4.25	-		
17	5	+3.0			
18	5	0			
19	10	-	+70		
20	5	-5.0	-		
21					
5	-11.0	-			
ANCUMTOUN					
1	20	-	-71.25		
2	5	+13.0	-		
3	5	+4.5	-		
4	5	-4.5	-		
5	10	+0.5	-		
6	5	+2.0	-		
7	5	-1.0	-		
8	15	3.17	-		
9	10	-	17.5		
10	9	-0.5	-		
11	5	+0.5	-		

RESULTS OF BEST UNIT ANALYSIS OF NORTH RONALDSAY FARM MOUND SLOPE PROFILES

Cont'd 2.

STENNABRECK

UNIT	LENGTH (m)	ANGLE (o)	CURVA-:TURE (o/100m)	MOUND END POINT (←X)	SLOPE POPUL-:ATION
1	10	-	-35		
2	15	+4.667	-		
3	15	+9.667	-		
4	5	-11.0	-		
5	15	-3.167	-		
6	15	-7.667	-		
7	15	-	-25		
8	5	+0.5	-		
9	5	+1.5	-		

HOOKING

UNIT	LENGTH (m)	ANGLE (o)	CURVA-:TURE (o/100m)	MOUND END POINT (←X)	SLOPE POPUL-:ATION
1	5	+3.0		←X	
2	30	-	+15.83		
3	20	+4.5	-		
4	10	-1.5	-	←X	
5	5	-0.5	-		
6	15	0	-		

QUOYBANKS

UNIT	LENGTH (m)	ANGLE (o)	CURVA-:TURE (o/100m)	MOUND END POINT (←X)	SLOPE POPUL-:ATION
1	5	+2.0	-		
2	10	-	47.5		
3	10	-	97.5		
4	10	7.5	-		
5	5	-0.5	-		
6	5	-3.0	-		
7	5	-0.5	-		
8	10	1.25	-		
9	5	0	-		
10	5	+0.5	-		

CRUESBRECK

UNIT	LENGTH (m)	ANGLE (o)	CURVA-:TURE (o/100m)	MOUND END POINT (←X)	SLOPE POPUL-:ATION
1	5	-1.5	-		
2	10	-	+7.5		
3	10	-	-2.5		
4	15	+2.167	-		
5	10	+10			
6	5	6.5	-		
7	5	+0.5	-		
building					
8	5	-25	-		
9	10	-5	-		
10	10	-3.75	-		
11	20	-1.125	-		

NEVEN

UNIT	LENGTH (m)	ANGLE (o)	CURVA-:TURE (o/100m)	MOUND END POINT (←X)	SLOPE POPUL-:ATION
1	5	+2.0	-		
				←X	
2	10	-	+72.5		
3	10	-	+20		
4	15	-3.5	-		
5	10	-2.00	-	←X	
6	5	-3.5			

zone on which are buildings, still functioning, and the farm yards. The remaining three mounds on Sanday in this category are less steep. Cleat has an angle range of 0° to 7.6°, Geramont 0.5° to 6.75° and Beafield 0.5° to 7°, all within a unit length range of 5 to 30m. Variance in slope profile characteristics is also demonstrated by the curvature values. Geramont's longest slope units are concave in both slope populations, while Cleat has shorter convex slope units. The symmetrical mounds of North Ronaldsay are diverse in their slope profile characteristics. No definite pattern emerges in terms of slope angles and positions of angles or positions and degrees of curvature.

3. Approximately Asymmetrical Mounds

Upon examining mounds of this class it quickly becomes apparent that they too are devoid of any comparable pattern. However a clue as to the cause of the wide variation in slope characteristics in the mounds is given by the mound at How (HY6606 3927). It is clearly seen in the field that this mound has been severely disturbed. Very short slope units predominate with an angle range of between 0° and 14.5°. Both convex and concave elements are evident in the slope profile. Northskail mound contains two slope populations within its generalized slope population 1 suggesting differential deposition of material. The exception in this class of mound is Westbrough which has been dissected by the building of a new cattle court.

4. Double Mounds

The one example of this mound type, Strømness on North Ronaldsay is characterised by short rectilinear segments. Slope angles are of a gentle gradient and the mound itself is of no great height. It is possible that this is a mound terminated at the early stages of its formation.

On reviewing all the results obtained, the outstanding feature is the diversity of the slope units in terms of number and type, ie of slope angle, curvature and length. A number of factors may contribute to this diversity. Slight variation in rates of deposition at different parts of the mounds and the deposition of different materials would contribute to the diverse slope characteristics observed. Post depositional anthropogenic activity, for example, digging into the mound to permit construction or to remove material for the arable land, are processes which would be expected within the immediate vicinity of a farmstead. The slope profile characteristics of the farm mounds are therefore consistent with anthropogenic activity at least, if not anthropogenic sedimentation.

To support this conclusion, slope profile analysis of three randomly selected glacial moraines was undertaken so that comparison could be made between them and the farm mounds. These glacial moraines are perhaps the closest morphologically comparable features in Orkney to the farm mounds (Fig 3:14). What emerged from this analysis was a tendency to asymmetry in the moraines (Table 3:15). Furthermore the moraines consist of a greater number of curved components while all slope components are, with one exception, greater than 15m. This contrasts with the farm mounds which are found in a number of microtopographic situations and exhibit several different slope profile shapes. A wide range of slope component lengths are also found in the farm mounds and frequently these component lengths are less than 15m.

Anthropogenic deposition and disturbances are concluded to be the cause of slope profile morphology of the farm mounds. The major basis for such a conclusion is the wide diversity of slope component types found on the farm mounds. This suggests microdeposition processes over the mound and/or fairly severe post depositional disturbances resulting in the high degree of surface roughness. Man is considered to be responsible for this as the natural sedimentary processes resulting in comparable features do not produce these small scale effects. Piece-meal deposition is more likely to be caused by anthropogenic deposition. Anthropogenic activity is also most likely responsible for small scale localised disturbances on the mounds.

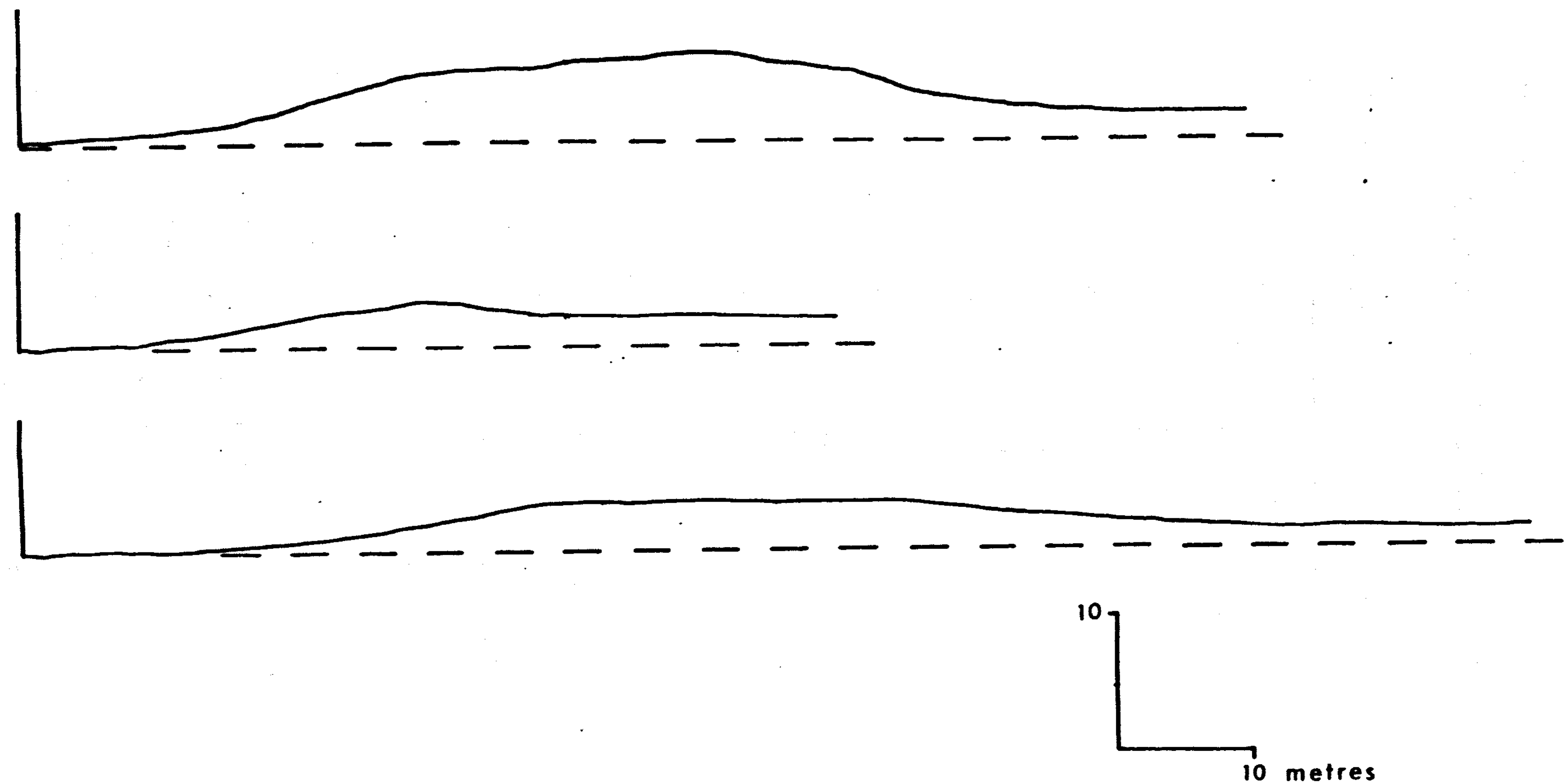


Figure 3:14 Slope profiles of glacial moraines, near Finstown, Mainland Orkney.

TABLE 3:15

RESULTS OF BEST UNIT ANALYSIS OF GLACIAL MORAINES

MORAINE NO	UNIT	LENGTH (m)	ANGLE (o)	CURVATURE (o/100m)	MOUNDED POINT
1.	1	15	-	-80	
	2	15	+15	-	
	3	15	+3.833	-	
	4	15	-	+112.5	
	5	10	13.75	-	
	6	15	-	+48.333	←X
	7	10	0	-	
2.	1	15	-	-53.33	
	2	15	-	+100	
	3	10	-5	-	←X
	4	20	0	-	
3.	1	25	-	-40	
	2	15	-	+58.33	
	3	20	-	+23.75	
	4	30	-3.5	-	
	5	20	-	12.5	←X

KEY:

Angles + = Upslope
- = Downslope

Curvatures - = concave
+ = convex

Va max = 25%
Vc max = 50%

Sampling Interval = 5 metres

←X = Mound End Point

3:3:2 Farm Mound Stratigraphy

D A Davidson was the first to examine in detail the stratigraphy of selected farm mounds in Orkney and to present analytical data from stratigraphic sequences. Davidson examined three farm mounds on Sanday, the mounds at Westbrough, Skelbrae and Langskail. This work, which is presented in full in Davidson et al (in press), confirms the anthropogenic sedimentary nature of the farm mounds and is summarised below. The author described and analysed the farm mound of Southness on North Ronaldsay in a similar manner to those examined on Sanday by Davidson. This work also indicated the anthropogenic nature of the farm mounds.

1. Westbrough (HY 663 424) (after D A Davidson). Lying some 300m from the coastline this farm mound is the site of an active farm with most of the buildings on the southern part of the mound. To the north of the farm buildings approximately two-thirds of the farm mound is evident (Fig 3:15). The mound is virtually flat-topped with minor undulations on its summit area. Steep sides, particularly to the north-east, drop down from the summit area of the mound to a relatively flat plain. A shingle ridge impedes drainage to the coast from the north-west and consequently immediately to the north of the mound is an area of poorly drained saltings. Surrounding the rest of this farm mound are soils of the Bilbster Series, a freely or imperfectly drained podzol.

   For the construction of a new cattle court the farmer excavated into the mound The results of this is that up to 1m of the upper part of the mound is exposed along the north side of the cattle court. More of the stratigraphy was revealed by digging below the exposed face, giving a total profile length of 2.28m. A further 0.48m was investigated by auger (Fig 3:16). Davidson gave the following general description of the profile stratigraphy.

0.00-0.54m	Material recently added by farmer during construction of byre.
0.54-1.35m	Well stratified sediments dominantly of mineral composition and resembling midden deposits.

Figure 3:15 The morphology of the Westbrough farm mound.

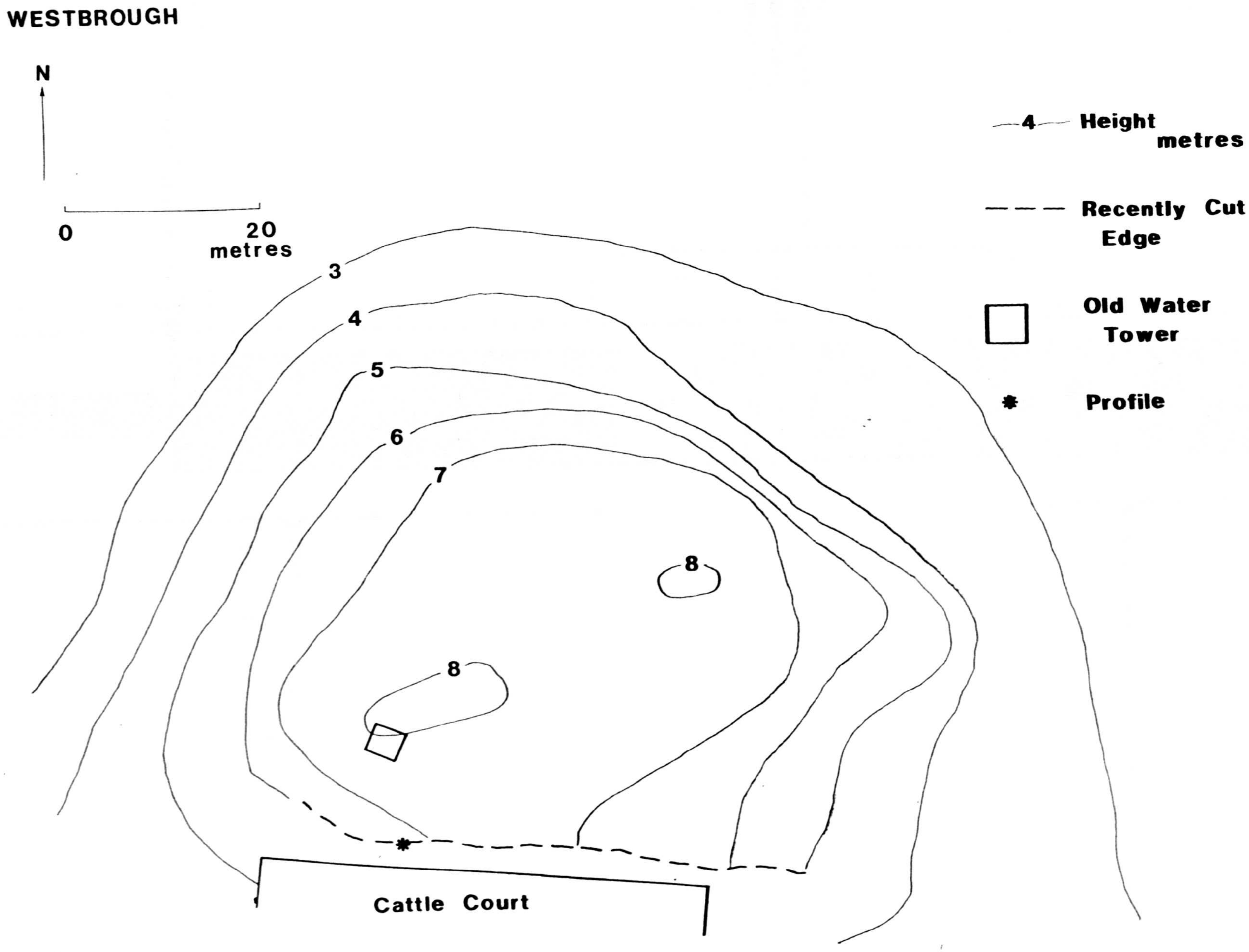
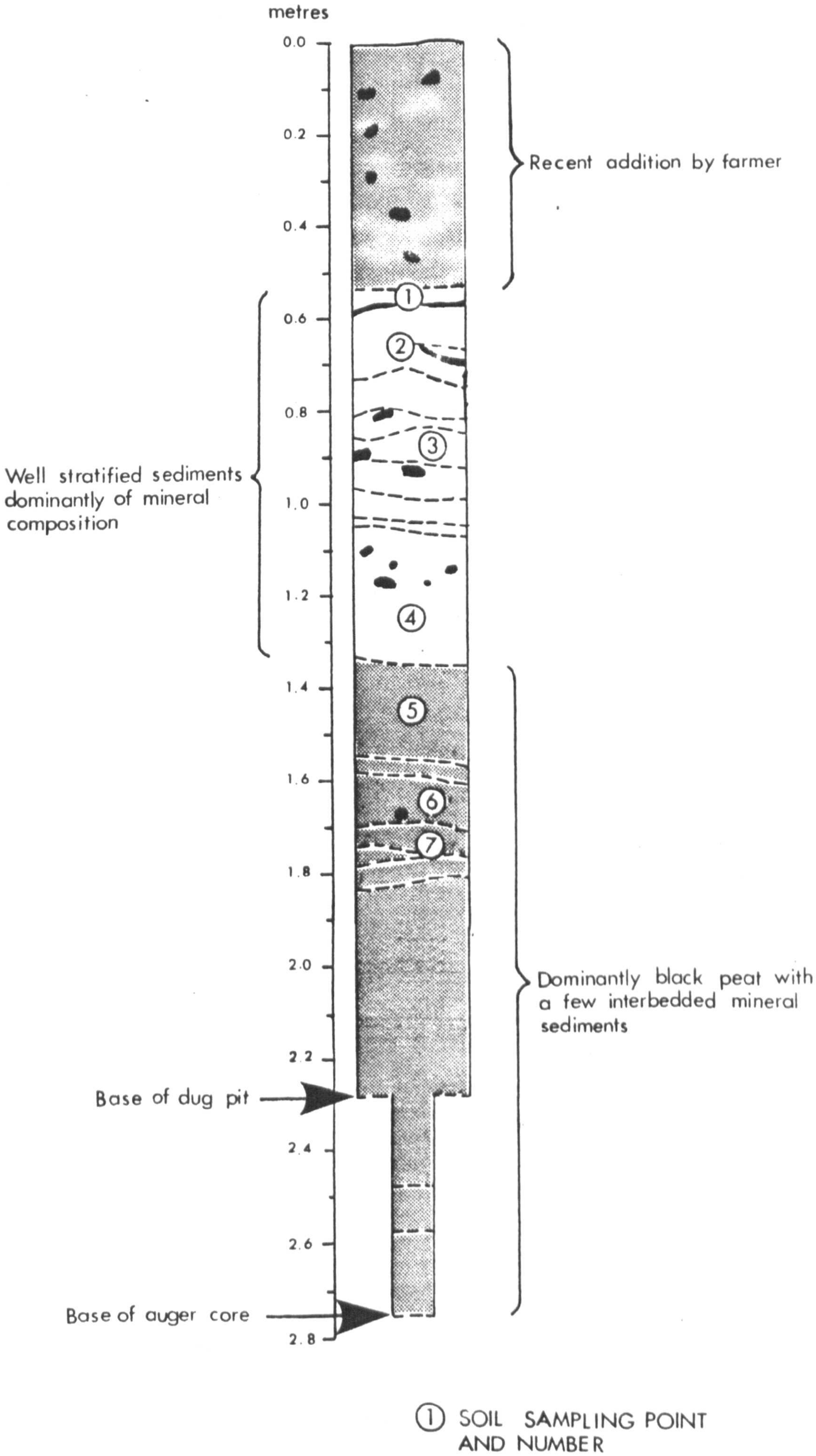


Figure 3:16 Profile stratigraphy from the Westbrough farm mound. (after D. A. Davidson).



1.35-2.76m	Dominantly black peat containing Calluna and Sphagnum remnants with a few interbedded mineral sediments containing charcoal remnants and shells.
2.76m	Presumed original land surface.

No building structures were evident.

Analytical data (Table 3:16) indicates a high silt content throughout the profile with a fluctuating clay content. Percentage loss on ignition values confirm the contrast in organic content in the upper and lower parts of the mound. Available bases are at their maximum at sampling point 1, declining with depth but increasing again in the lower part of the profile. Calcium and magnesium are the dominant available bases. Total phosphate values are high throughout except at the lowest sampling position. These high total phosphate values confirm the anthropogenic origin or the farm mound material. Pollen analysis of the peaty material in the lower parts of the stratigraphy revealed the dominance of Ericacea with secondary species types of Graminae, Cyperacea and Sphagnum, species which are indicative of a wet heathland community. Micromorphological examination of the peat from 1.75-185m reveal a clear laminer microstructure of mineral and organic materials, indicative of deposition in fine bandings.

This first description of the stratigraphy of the Westbrough farm mound was of particular interest because of the two quite distinctive sets of materials identified. The well stratified sediments in the upper portion of the mound would appear to have been deposited by human agencies and this is confirmed by the high total phosphate levels. In the lower part of the mound the peaty material is quite distinct. Augering by D A Davidson revealed that the peaty material underlies a substantial part of the mound in contrast to the stratified, small deposition zones of other sedimentary material in the mound. The question arises therefore as to whether this peaty material has formed in situ or is the result of deposition by anthropogenic processes. The dark grey mineral

TABLE 3:16

ANALYTICAL DATA FOR THE WESTBROUGH SECTION

Sample Number	Colour	Particle Size* (%)						% Loss-on-Ignition	Exchangeable Bases (meq/100g)				Total P_2O_5 (mg/100g)
		Clay	Fine Silt	Coarse Silt	Fine Sand	Medium Sand	Coarse Sand		Na	K	Ca	Mg	
1	5YR5/6	11.1	29.0	37.8	14.4	1.8	4.0	2.8	0.34	0.45	2.08	2.73	495.1
2	7.5YR3/2	20.4	31.5	32.0	12.3	2.0	1.8	5.5	0.42	0.52	2.27	2.06	864.9
3	10YR4/2	17.5	50.6	17.6	10.6	2.2	1.5	3.6	0.41	0.69	2.08	1.82	608.9
4	10YR4/2	13.3	25.1	30 5	12.5	6.0	12.6	2.4	0.28	0.64	2.43	1.66	562.0
5	7.5YR3/2	31.3	34.0	22.9	8.7	1.6	1.5	33.3	0.30	0.22	3.16	1.74	469.5
6	7.5YR3/2	26.6	32.7	26.3	8.9	2.5	3.0	23.8	0.29	0.27	2.74	2.33	453.2
7	7.5YR2.5/0	-	-	-	-	-	-	51.6	0.24	0.12	2.42	3.43	138.5

* Clay: less than 2 microns
Fine Silt: 16-2 microns
Coarse Silt: 63-16 microns
Fine Sand: 250-63 microns
Medium Sand: 500-250 microns
Coarse Sand: 2000-500 microns

Source: D A Davidson

TABLE 3:16

lenses and straw material within the peaty material would tend to support the anthropogenic hypothesis. Also, the peat appears to have accumulated above the level of the local peat deposit further suggesting anthropogenic deposition processes. Whether this material was used as cattle bedding and then dumped as waste material or whether the peaty material was used in purposively constructing the base of the mound is not clear. In any event, for whatever reason, it seems clear that the farm mound at Westbrough arose as a result of anthropogenic sedimentary processes.

2. Skelbrae (HY 676 437) (after D A Davidson). This farm mound is located on the Burness peninsula some 150m from the Lamaness Firth. The farm at Skelbrae is still occupied although the farmer has retired. Figure 3:17gives an outline of mound form. It is steeper to the south and south-west and there is a small, secondary, peak behind the byre. Foundations of older buildings are evident on the small main summit area of the mound. Foundations for the buildings in use today have apparently been dug into the north-western side of the mound. This farm mound is located within an area of soils mapped as the Bilbster Series, a freely or imperfectly drained podzol.

Davidson exposed a profile at the top of the mound. In the field this profile appears homogenous (Fig 3:18). Only the upper c20cm are slightly different due to the presence of calcareous sand. Analytical data including micromorphological analysis from this profile (Table 3:17) reflects the homogeneity seen in the field with the exception of the total phosphate values. The application of shelly sand has resulted in higher levels of magnesium and calcium in the upper portion of the profile. Slightly higher sodium values are evident in the middle and lower part of the section. By contrast total phosphate values show three distinct zones. Between samples 1 and 6 form one zone, samples 7 and 8 a second zone and the third zone is represented by samples from the lower auger core which yielded results ranging from 800mg/100g to 1050mg/100g. These results clearly indicate the anthropogenic nature of the farm mound at Skelbrae as well as demonstrating that several intensities

Figure 3:17 Morphology of the Skelbrae farm mound.

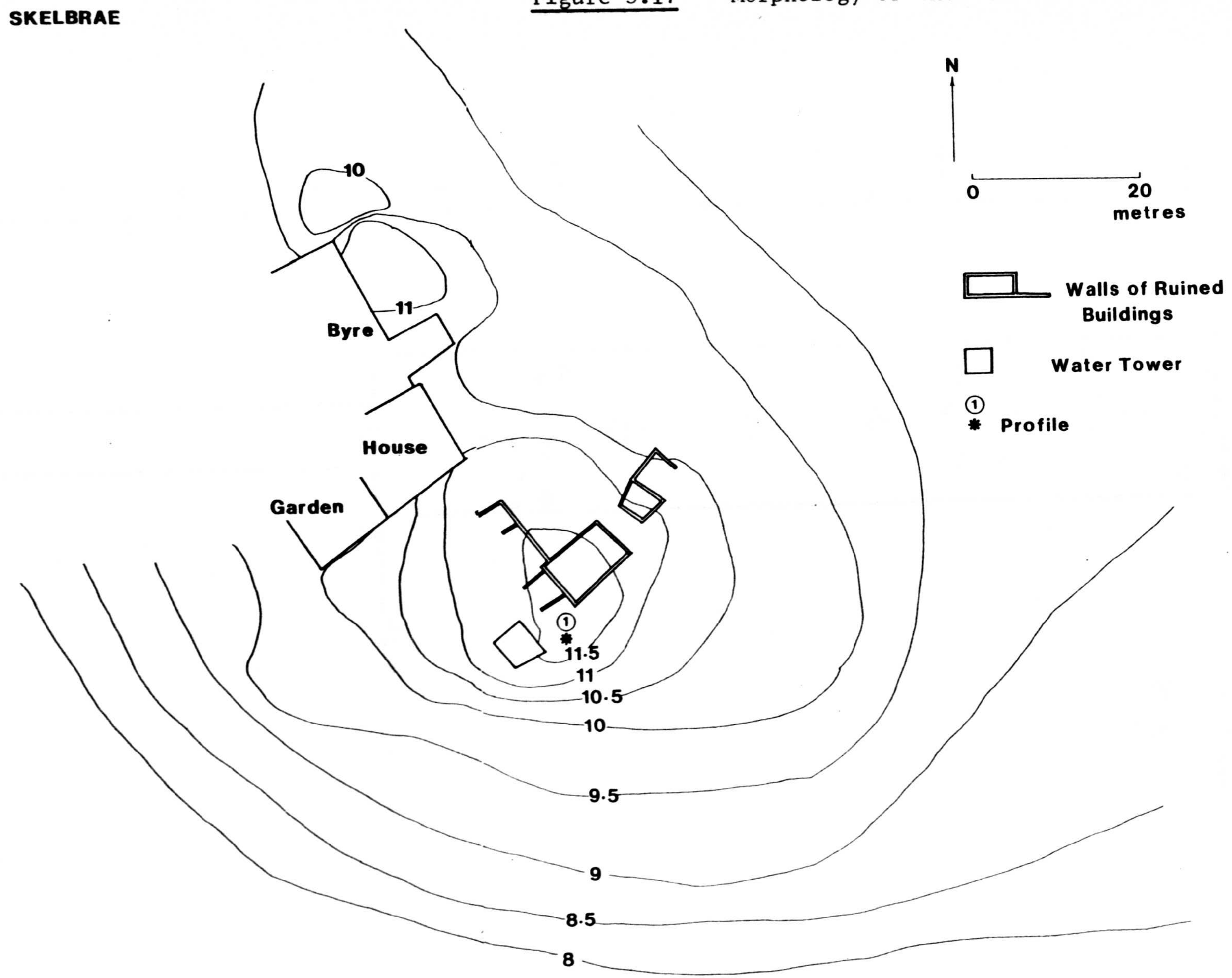


Figure 3:18 Profile stratigraphy of the Skelbrae farm mound. (after D.A. Davidson).

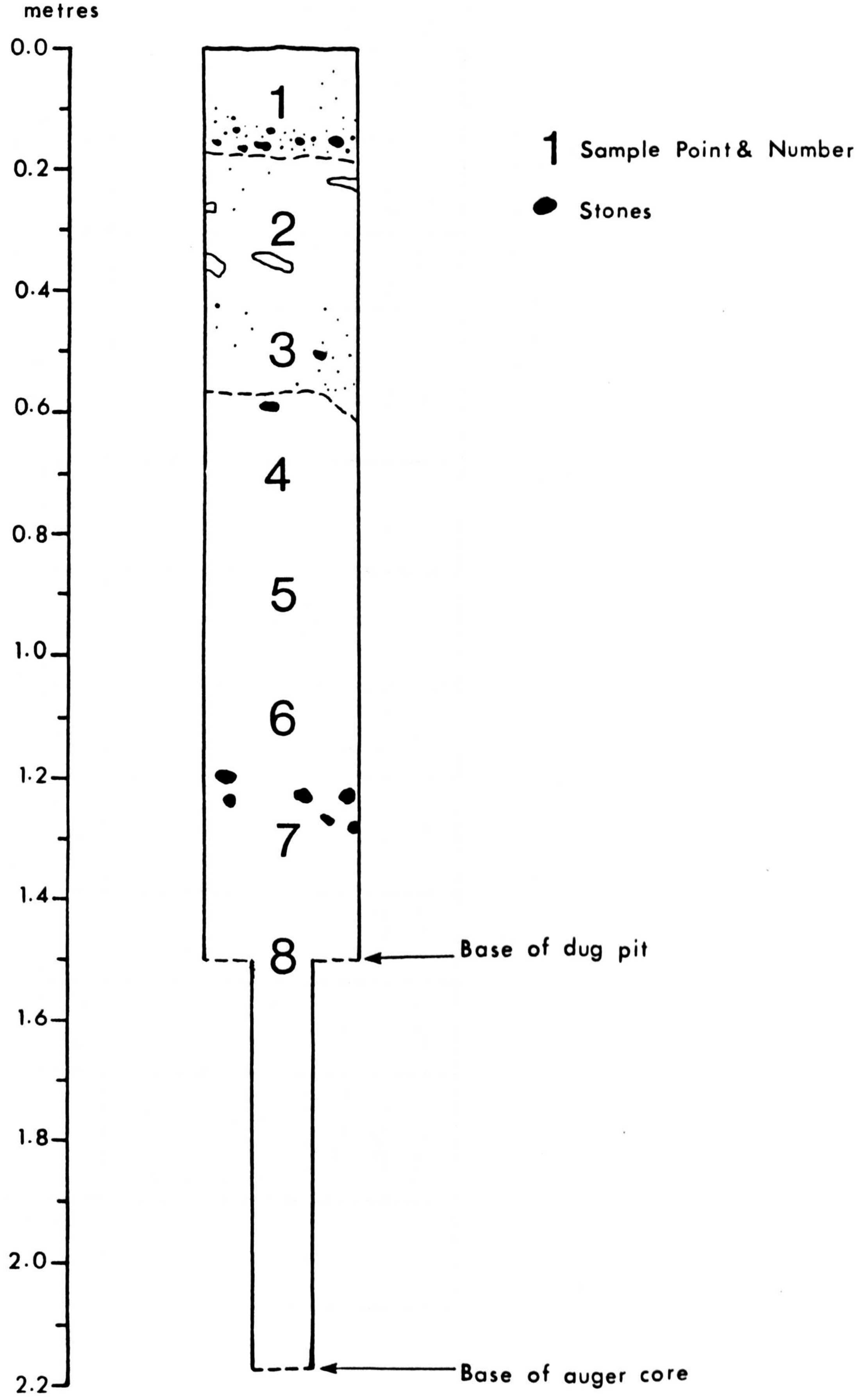


TABLE 3: 17

ANALYTICAL DATA FOR THE SKELBRAE SECTION

Sample Number	Colour	Particle Size* (%)						% Loss-on-Ignition	Exchangeable Bases (meq/100g)				Total P_2O_5 (mg/100g)
		Clay	Fine Silt	Coarse Silt	Fine Sand	Medium Sand	Coarse Sand		Na	K	Ca	Mg	
1	10YR4/2	23.6	23.4	21.8	17.2	7.2	6.8	8.8	0.74	0.41	19.00	4.54	678.1
2	10YR4/3	24.1	26.4	29.5	14.2	3.0	2.8	5.9	0.35	0.33	9.53	3.57	491.2
3	10YR4/3	23.3	25.2	30.7	15.3	3.0	2.5	5.9	0.26	0.52	8.19	3.53	447.0
4	7.5YR3/2	21.8	27.7	30.9	14.8	2.8	2.0	5.0	0.48	0.83	7.76	4.04	516.6
5	7.5YR3/2	21.2	25.9	31.2	16.3	3.1	2.3	4.8	0.63	0.87	7.52	3.86	651.3
6	7.5YR3/2	21.1	26.2	30.9	16.2	3.1	2.5	6.1	0.73	0.85	8.79	4.02	627.9
7	7.5YR3/2	23.2	25.1	28.8	18.2	3.1	1.6	7.7	0.68	0.66	11.56	4.11	256.9
8	5YR3/1	21.8	27.5	29.2	16.0	2.9	2.7	6.2	0.65	0.63	7.78	3.26	116.1

* Clay: less than 2 microns
Fine Silt: 16-2 microns
Coarse Silt: 63-16 microns
Fine Sand: 250-63 microns
Medium Sand: 500-250 microns
Coarse Sand: 2000-500 microns

Source: D A Davidson

of occupation have taken place during the evolution of this mound.

3. Langskail (HY 684 444) (after D A Davidson). This farm mound is incorporated into the narrow sand dune system found on the eastern side of the Burness peninsula. Coastal erosion has removed approximately half the mound (Fig 3:19) exposing a face which is complex in its stratigraphy. A section of this face is illustrated in Figure 3:20and the nature of the 4.3m stratigraphy is summarised by Davidson as follows:

0.00-0.54m	Dominantly recently blown sands.
0.54-2.30m	Intricate sequence of mineral sediments with many lenses and shells.
2.30-3.90m	Sequence of thicker more homogenous mineral sediments but with many shells and some stone lines.
3.90-4.18m	Distinct layer of cockle shells (Cardium) with a sandy matrix.
4.18-4.28m	Basal occupation layers.
4.28-4.70m +	Sterile sands.

Particle size analysis of the sediments from this section (Table 3:18) differentiates the natural wind blown sand deposits, dominant at the base of the mound and in its uppermost portion, from what is anthropogenic material by its high percentage of fine sand and smaller amount of medium sand. Fluctuation in sand content throughout the mound can probably be attributed to a wind blown sand input. Within this farm mound silt is dominant while the clay content is reasonably uniform, a characteristic shared with the loss on ignition values. No discernable exchangeable base pattern is evident although calcium is dominant throughout because of the calcareous sand input. Except for the basal sands total phosphate values are high throughout the section indicating the anthropogenic nature of the deposits. These values fluctuate throughout the section reflecting the interacting factors of site occupation intensity, rate of sediment accumulation, input of blown sands and pedogenic movement of phosphate.

Two thin sections were described from the exposed mound face.

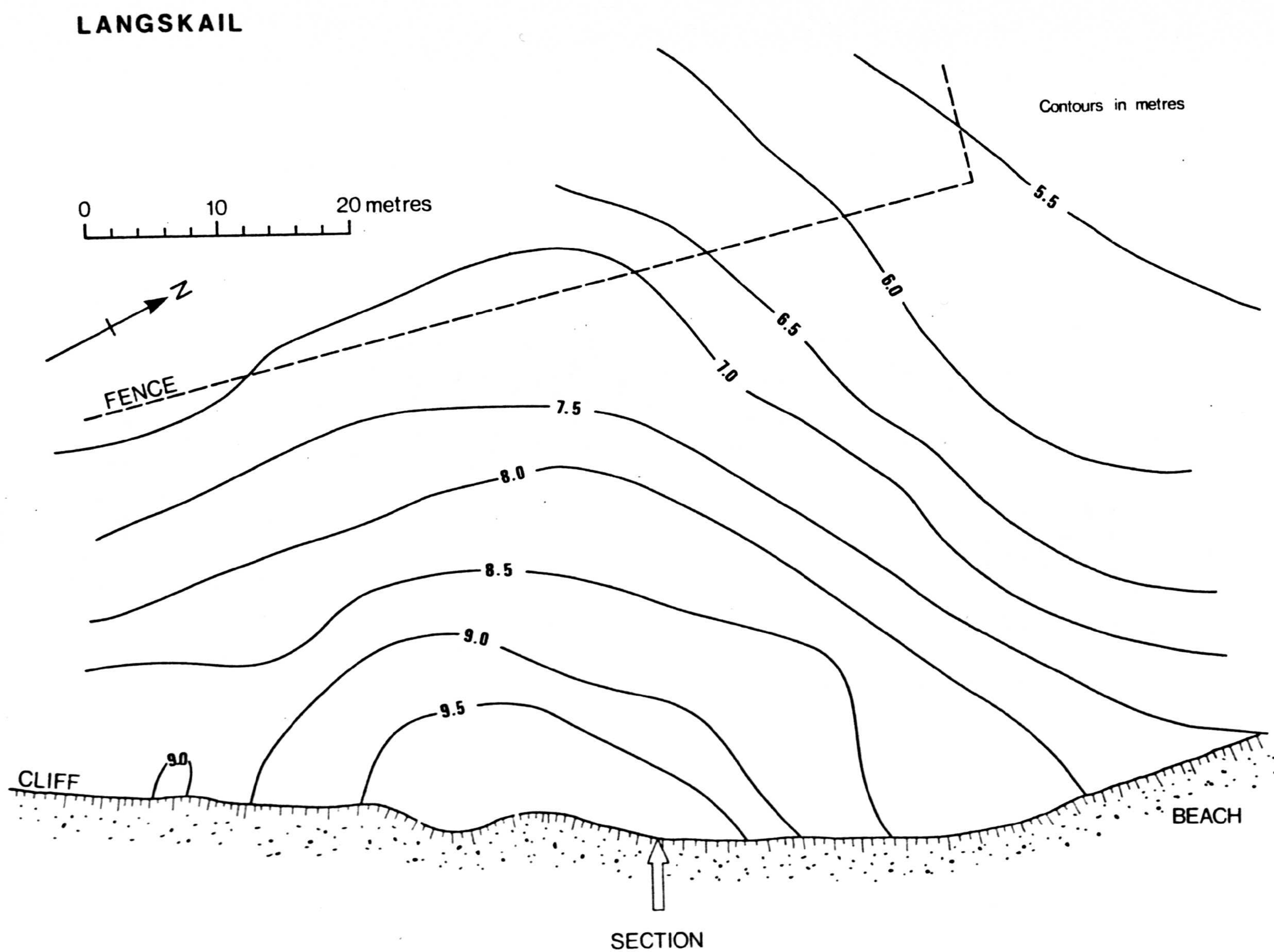


Figure 3:19 Morphology of the Langskail farm mound. (after D.A. Davidson).

Figure 3:20 Profile stratigraphy of the Langskail farm mound. (after D.A. Davidson).

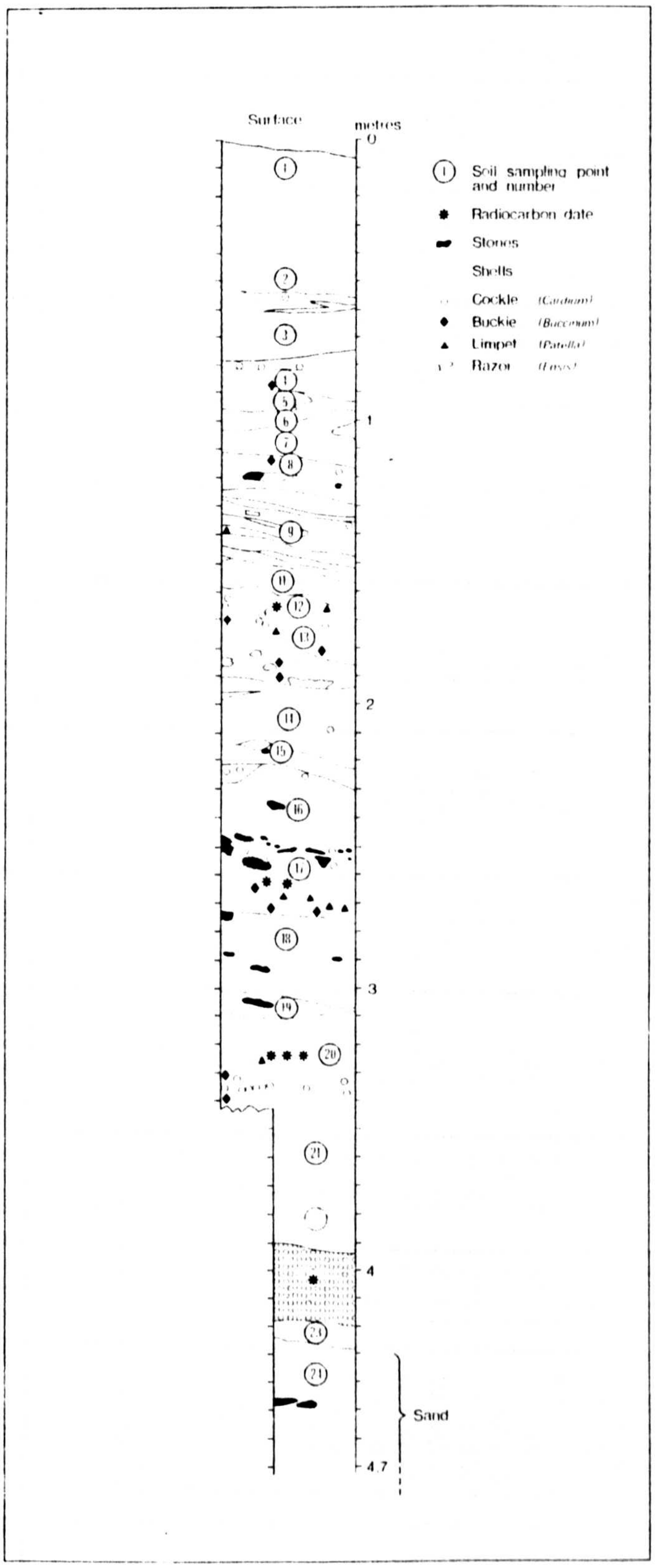


TABLE 3:18

ANALYTICAL DATA FOR THE LANGSKAIL SECTION

Sample Number	Colour	Particle Size*(%)						% Loss-on-Ignition	Exchangeable Bases (meq/100g)				Total P_2O_5 (mg/100g)
		Clay	Fine Silt	Coarse Silt	Fine Sand	Medium Sand	Coarse Sand		Na	K	Ca	Mg	
1	10YR5/1	9.9	7.5	8.2	45.3	26.8	2.3	4.8	1.07	0.46	14.45	5.19	318.1
2	10YR3/2	14.7	13.4	17.1	35.5	17.2	2.1	4.4	0.76	0.62	10.33	4.48	434.9
3	10YR5/2	16.4	30.2	31.9	14.3	3.5	3.7	3.1	0.79	0.73	11.41	3.59	284.4
4	10YR5/2	17.2	29.3	31.3	16.7	3.8	1.7	3.7	1.02	0.71	9.78	3.91	348.1
5	10YR4/4	8.4	33.7	30.3	31.7	4.5	1.4	2.6	1.20	0.85	9.95	3.90	423.2
6	10YR3/3	17.5	25.8	28.3	21.5	5.7	1.2	4.4	1.89	0.98	16.56	4.73	594.0
7	10YR4/4	14.5	27.6	31.2	19.0	5.0	2.8	3.8	1.27	0.71	12.19	3.92	284.6
8	10YR3/2	14.1	17.4	21.7	36.8	8.1	1.9	5.5	1.57	0.54	18.58	4.44	579.4
9	10YR4/2	17.2	28.8	31.2	16.8	4.3	1.7	4.4	1.40	0.62	15.41	4.68	301.4
10	7.5YR4/4	16.4	28.4	28.2	19.9	5.3	1.8	4.9	1.20	0.56	13.95	4.56	609.1
11	10YR3/2	17.4	24.6	26.4	23.8	6.3	1.5	4.8	1.86	0.60	17.38	4.68	476.1
12	7.5YR3/2	15.9	18.6	22.1	29.5	11.6	2.3	4.8	4.01	0.67	20.42	4.69	755.5
13	7.5YR3/2	15.2	24.6	28.7	24.8	5.0	1.7	3.7	2.44	0.55	14.49	4.97	621.0
14	10YR4/2	15.3	31.6	33.6	14.9	2.5	2.1	3.2	1.61	0.41	7.78	3.37	451.1
15	5YR4/4	12.1	22.4	23.2	34.2	6.8	1.3	2.5	1.48	0.49	11.76	3.94	600.7
16	7.5YR3/2	15.9	27.6	29.4	22.0	3.7	1.4	4.9	2.41	0.50	12.84	4.54	758.0
17	7.5YR3/2	17.2	25.3	25.9	24.3	5.6	1.7	5.1	1.81	0.28	17.03	4.64	554.9
18	7.5YR3/2	16.7	17.6	19.4	31.7	12.8	1.8	5.1	1.92	0.17	21.32	4.92	816.8
19	10YR4/3	12.7	24.9	26.5	20.0	19.9	2.8	3.7	2.81	0.54	16.89	5.67	895.4
20	10YR5/2	15.6	29.0	31.0	18.0	4.1	2.3	4.3	2.19	0.42	15.85	5.18	699.4
21	10YR3/2	15.2	29.9	29.9	15.6	6.1	3.3	5.3	2.32	0.44	12.96	4.86	469.7
22	7.5YR3/2	18.2	20.6	24.3	29.1	5.6	2.2	5.1	2.16	0.38	15.85	4.08	680.1
23	7.5YR3/2	16.4	11.8	12.6	46.8	10.8	1.6	11.3	2.37	0.35	19.24	5.91	352.0
24	-	7.9	2.6	3.4	66.7	18.5	0.9	2.2	0.81	0.08	15.66	2.78	241.4

* Clay: less than 2 microns
Fine Silt: 16-2 microns
Coarse Silt: 63-16 microns
Fine Sand: 250-63 microns
Medium Sand: 500-250 microns
Coarse Sand: 2000-500 microns

Source: D A Davidson

One thin section came from sampling point 15. This revealed a loosely packed, porous, homogenous structure. Cellular fragments filling pores were evident. All organic matter was decomposed and may have included faecal pellets. A second thin section from elsewhere in the cliff exposure revealed pores with horizontal orientation suggesting deposition of material as thin layers. Organic matter was structureless with no faecal pellets observed.

4. Southness, North Ronaldsay (HY 768 526) (after the Author). This, the largest farm mound on North Ronaldsay, is occupied by two independent farm steadings, now abandoned on its summit area (Fig 3:21). The mound is located just beyond the flat plain leading to the coast some 200m to the east. On its western side the mound runs into one of the Treb dykes which divide North Ronaldsay into three parts, (R.C.A.M.S.,1980). A track leads over this western portion of the mound and access to the farms was gained via this track. The contour map (Fig 3:21) gives some indication of the dimensions of the mound which posed real problems in obtaining a representative stratigraphy. Four profiles were exposed in this mound at different points, thus it was hoped that a representative stratigraphy would be obtained including details of the original land surface.

The farm mound straddles three different soil mapping units, the Tresdale Series, the Ocklester Series and the Fraserburgh Series. Much of the mound is surrounded by soils of the Tresdale Series, a poorly drained calcareous/non calcareous gley formed on drift derived from flagstones, sandstones, marls, mudstones and limestones of the Stromness and Rousay Flags and the Eday beds of the Middle Old Red Sandstone. A profile description of the Tresdale Series soil adjacent to the Southness farm mound is given below (Table 3:19).

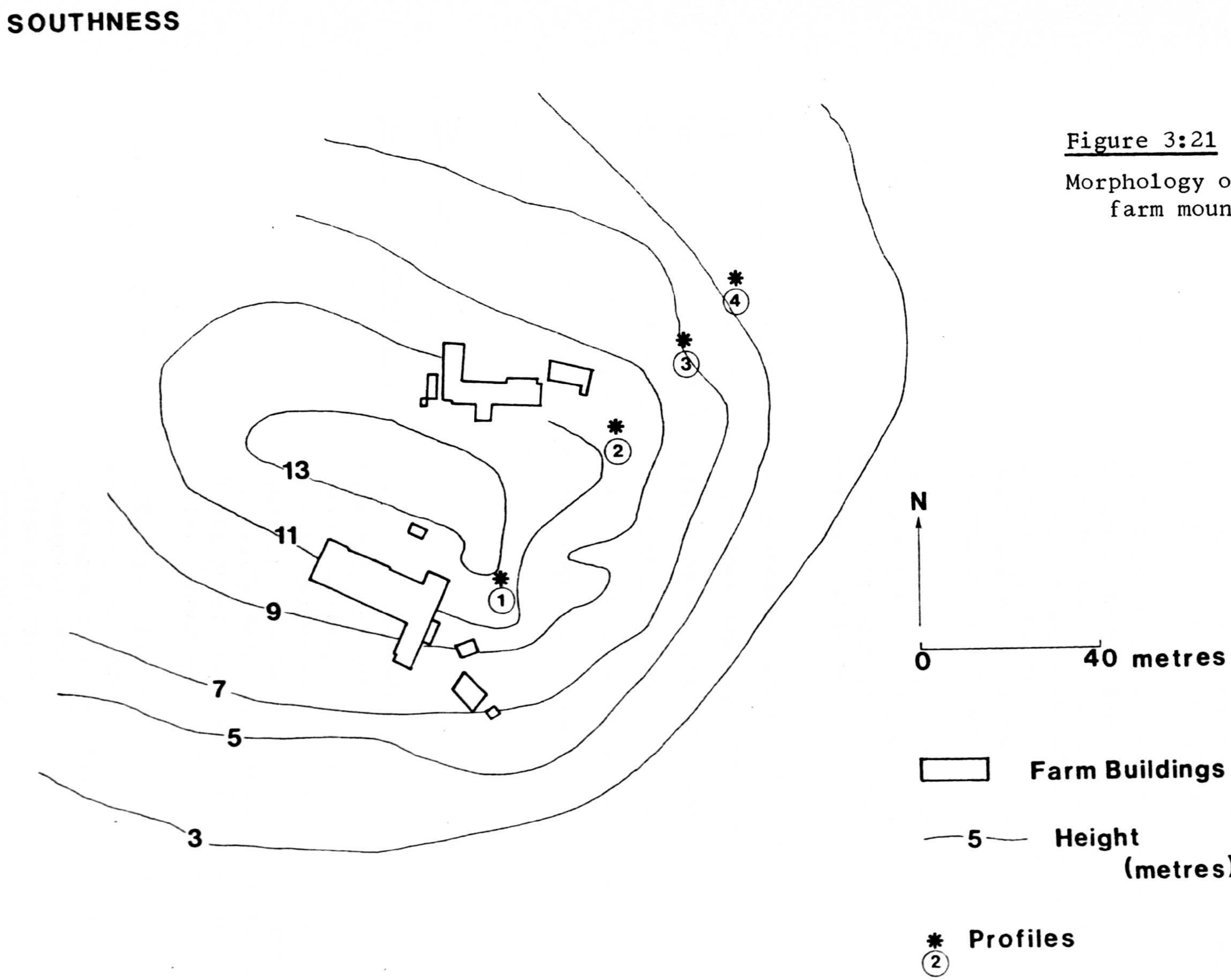


Figure 3:21

Morphology of the Southness farm mound.

Table 3:19

Horizon	Depth (cms)	Description
S	0-30	10YR 4/2; no mottles; low organic matter content, intimate; loam texture; moderately well developed medium subangular blocky peds; frequent small subangular stones; frequent fine fibrous roots; clear smooth change to
B_{2g}	30-74	2.5Y 4/6; many coarse 10YR 7/1 gley patches; many medium 10Y 5/6 mottles; loam to clay loam texture; no organic matter; moderately well developed medium subangular blocky peds; frequent small and medium stones; no roots; merging smooth change to
C_g	74-100+	2.5YR 4/6; few fine and medium 7.5YR 5/8 mottles; no organic matter; sandy clay loam; massive; frequent large stones; no roots.

The north-west corner of the Southness farm mound abuts soils of the Ocklester Series. This soil mapping unit is defined by the Soil Survey for Scotland as a freely or imperfectly drained podzol formed on the same parent material as those soils of the Tresdale Series. Description of an Ocklester Series profile adjacent to the farm mound under discussion is given below (Table 3:20).

Table 3:20

Horizon	Depth (cms)	Description
S	0-20	10YR 3/1; no mottles; moderate organic matter, intimate; sandy loam (due to influence of adjacent blown sands?); few small subangular stones; moderately developed medium subangular blocky peds; frequent fine fibrous roots; sharp smooth boundary to
$B_{2(g?)}$	20-40	2.5YR 5/4; few medium 7.5YR 5/8 mottles; no organic matter; sandy loam to sandy clay loam texture; few medium subangular stones; weakly developed medium subangular blocky peds; few fine fibrous roots; sharp smooth boundary to
B_2/C	40-90+	10YR 4/4; no mottles; no organic matter; sandy clay loam texture; massive; frequent to many medium subangular stones; no roots.

The north-east corner of this farm mound lies adjacent to soils of the Fraserburgh Series which are brown calcareous soils formed on shelly sand. Description of a Fraserburgh Series soil profile adjacent to the Southness farm mound is given below (Table 3:21).

Table 3:21

Horizon	Depth (cm)	Description
S	0-14	10YR 4/2; no mottles; moderate organic matter, intimate; loamy sand texture; few small subangular stones; moderately developed coarse subangular blocky peds; frequent fine fibrous roots; sharp clear boundary to
B_2	14-40	10YR 5/4; no mottles; no organic matter; sand texture; few small subangular stones; single grain; few fine fibrous roots; sharp clear boundary to
C/D	40	stone.

There is therefore some diversity in the soils surrounding this farm mound, chiefly because of differences in drainage conditions and in the parent material on which these soils have evolved. The pedogenic horizonation of these profiles stand in sharp contrast to the sedimentary horizonation which is evident in the mound profiles (Fig 3:22). Descriptions of the mound profiles are given in Table 3:22 and a general interpretation of the stratigraphy is now given.

The outstanding features of profile 1 are the large subrounded beach stones/boulders. These stones are apparently laid in an orderly manner and it is therefore assumed that they form part of some structure. This structure once its usefulness was over was overlain by a comparatively uniform dark coloured loam material containing numerous shell fragments and charcoal flecks. It is not unlike a Tresdale Series top soil although it is slightly darker, suggesting a greater organic matter content, and contains inclusions. The presence of beach stones in the mound stratigraphy is clearly indicative of material being transported and deposited by man, in this case for construction purposes. Being on the summit area of the mound

Figure 3:22 Profile stratigraphy of the Southness farm mound.

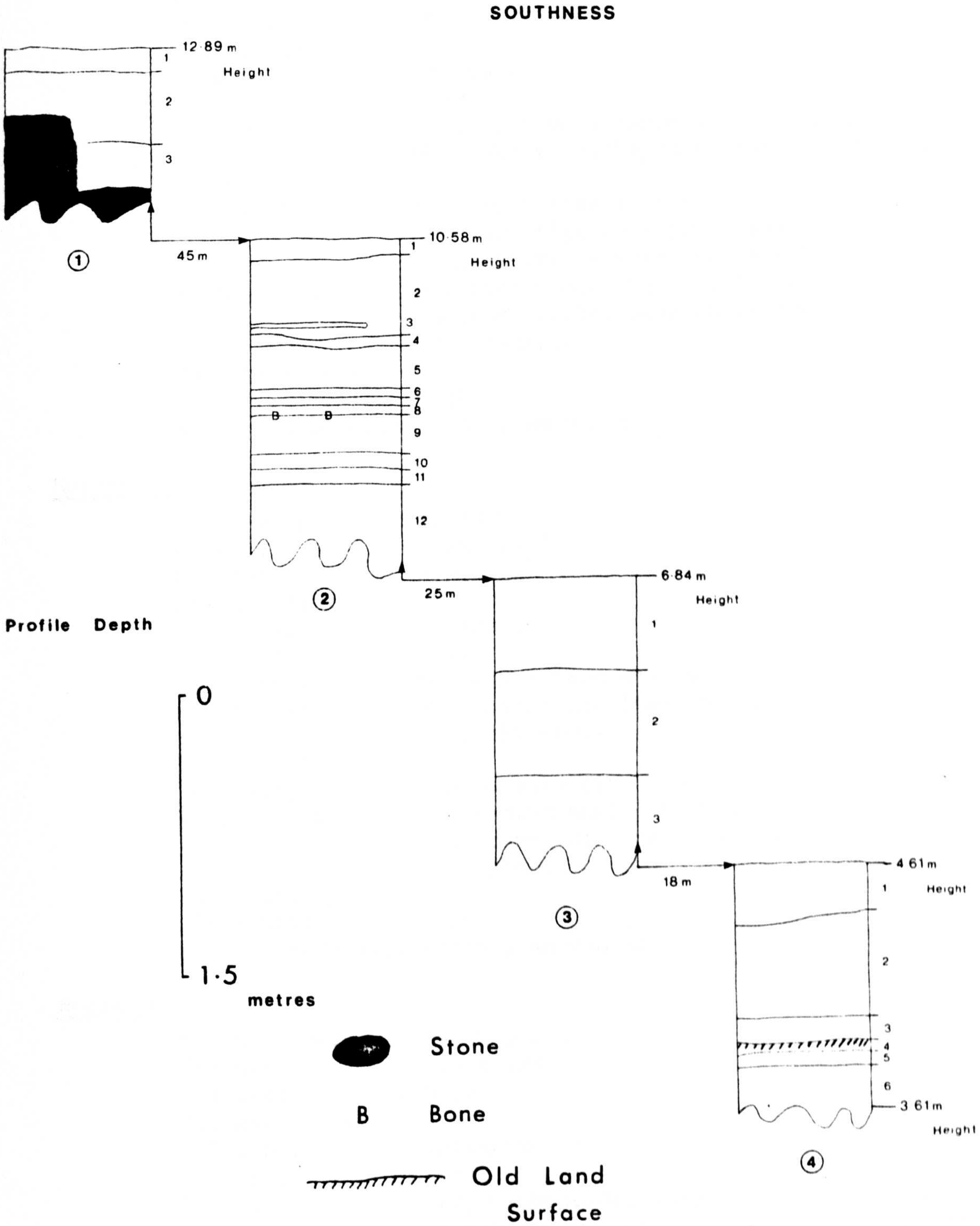


TABLE 3:22

PROFILE DESCRIPTIONS FROM THE SOUTHNESS FARM MOUND, NORTH RONALDSAY

SOUTHNESS PROFILE 1

Horizon 1

Depth Range:	0-12cm
Colour:	7.5YR 3/2
Mottles:	None
Organic Matter Status:	Intimate
Texture:	Loam
Stoniness:	Medium, common subrounded stones.
Structure:	Moderately developed medium granular peds.
Biological Activity:	Many very fine fibrous roots; evidence of very fine macropores within peds, suggestive of worm (nematode?) activity.
Inclusions:	Few fine black charcoal flecks; few medium shells, both whole and badly decomposed.
Phosphate Spot Test Status:	High
Horizon Boundary:	Abrupt, smooth to

Horizon 2

Depth Range:	12-49cm
Colour:	10YR 3/2
Mottles:	None
Organic Matter Status:	Intimate
Texture:	Loam
Stoniness:	Medium, common subrounded stones.
Structure:	Moderately developed medium subangular blocky peds.
Biological Activity:	Common very fine fibrous roots.
Inclusions:	Few medium shells both whole and badly decomposed; occasional small shell fragments.
Phosphate Spot Test Status:	High
Horizon Boundary:	Abrupt, smooth to

Horizon 3

Depth Range:	49-80cm +
Colour:	7.5YR 3/2
Mottles:	None
Organic Matter Status:	Intimate
Texture:	Loam
Stoniness	Large subrounded stones. The horizon is dominated by boulders (greater than 60cm) which are subrounded and have similar characteristics to the stones of nearby beach.

SOUTHNESS PROFILE 1 Cont'd

Structure:	Moderately developed coarse subangular blocky peds.
Biological Activity:	No evidence.
Inclusions:	Few medium shells, both whole and badly decomposed.
Phosphate Spot Test Status:	High

SOUTHNESS PROFILE 2

Horizon 1

Depth Range:	0-11cm
Colour:	10YR 3/2
Mottles:	None
Organic Matter Status:	Intimate
Texture:	Loam
Stoniness::	None
Structure:	Moderately developed granular peds.
Biological Activity:	Frequent fine fibrous roots, earthworms evident.
Inclusions:	Rare shell fragments, possibly blown sand material.
Phosphate Spot Test Status:	High
Horizon Boundary:	Abrupt, smooth to

Horizon 2

Depth Range:	11-52cm
Colour:	10YR 3/3
Mottles:	None
Organic Matter Status:	Intimate
Texture:	Loam
Stoniness:	None
Structure:	Moderately developed granular peds
Biological Activity:	Occasional fine fibrous roots; evidence of earthworms.
Inclusions:	Rare small black charcoal flecks; numerous very small bones (fish bones?).
Phosphate Spot Test Status:	High
Horizon Boundary:	Abrupt, smooth to Horizon 4

Horizon 3

A thin layer sandwiched in Horizon 2; 10YR 4/4 colour.

Horizon 4

Depth Range:	52-57cm
Colour:	10YR 4/4
Mottles:	None
Organic Matter Status:	Intimate
Texture:	Loam
Stoniness	None
Structure:	Moderately well developed granular peds.
Biological Activity:	Rare fine fibrous roots; macropores suggestive of earthworm activity.
Inclusions:	Rare small shell fragments; rare small bone fragments (fish bones?).
Phosphate Spot Test Status:	High
Horizon Boundary:	Abrupt, clear to

Horizon 5

Depth Range:	57-77cm
Colour:	10YR 4/3
Mottles:	None
Organic Matter Status:	Intimate
Texture:	Loam
Stoniness:	None
Structure:	Moderately well developed granular peds.
Biological Activity:	Rare fine fibrous roots; macropores suggestive of earthworm activity.
Inclusions:	Frequent small shell fragments, occasional badly decomposed shell; rare small bone fragments (fish bone?).
Phosphate Spot Test Status:	High
Horizon Boundary:	Abrupt, smooth to

Horizon 6

Depth Range:	77-82cm
Colour:	10YR 4/2
Mottles:	None
Organic Matter Status:	Intimate
Texture:	Loam
Stoniness:	None
Structure:	Moderately well developed granular peds.
Biological Activity:	Rare fine fibrous roots; no earthworm activity.
Inclusions:	Occasional decomposed shell, occasional small shell fragments; rare small charcoal flecks; rare small bone fragments (fish bone?).

Phosphate Spot
Test Status: High
Horizon Boundary: Sharp, smooth to

Horizon 7

Depth Range: 82-87cm
Colour: 10YR 4/4
Mottles: None
Organic Matter
Status: Intimate (if present?)
Texture: Loam
Stoniness: None
Structure: Moderately developed granular peds.
Biological
Activity: None
Inclusions: Occasional small shell fragments; occasional small bones (fish bones?); "ashy" smell is evident from this material.
Phosphate Spot
Test Status: High
Horizon Boundary: Sharp, smooth to

Horizon 8

Depth Range: 87-91cm
Colour: 10YR 4/3
Mottles: None
Organic Matter
Status: Intimate (if present?)
Texture: Sandy clay loam
Stoniness: None
Structure: Moderately well developed granular peds
Biological
Activity: None
Inclusions: Occasional small shell fragments; occasional small bones (fish bones?); "ashy" smell is evident from this material.
Phosphate Spot
Test Status: High
Horizon Boundary: Abrupt, smooth to

Horizon 9

Depth Range: 91-113cm
Colour: 7.5YR 4/2
Mottles: None
Organic Matter
Status: Intimate
Texture: Loam
Stoniness: None
Structure: Moderately well developed granular peds
Biological
Activity: None
Inclusions: Occasional small shell fragments: occasional small bones (fish bones?); "ashy"smell is evident from this material.

Phosphate Spot
Test Status: High
Horizon Boundary: Abrupt, smooth to

Horizon 10

Depth Range: 112-120cm
Colour: 10YR 3/3
Mottles: None
Organic Matter
Status: Intimate
Texture: Loam
Stoniness: None
Structure: Moderately well developed granular peds.
Biological
Activity: None
Inclusions: Occasional small charcoal flecks.
Phosphate Spot
Test Status: High
Horizon Boundary: Abrupt, smooth to

Horizon 11

Depth Range: 120-128cm
Colour: 10YR 4/4
Mottles: None
Organic Matter
Status: Intimate
Texture: Loam
Stoniness: None
Structure: Moderately well developed granular peds.
Biological
Activity: None
Inclusions: Abundant small charcoal flecks; "ashy" smell is evident from this material.
Phosphate Spot
Test Status: High
Horizon Boundary: Abrupt, smooth to

Horizon 12

Depth Range: 128-171cm
Colour: 10YR 4/2
Mottles: None
Organic Matter
Status: Intimate
Texture: Loam
Stoniness: None
Structure: Moderately well developed granular peds.
Biological
Activity: None
Inclusions: Abundant small charcoal flecks; rare small shell fragments.
Phosphate Spot
Test Status: High

SOUTHNESS PROFILE 3

Horizon 1

Depth Range: 0-49cm
Colour: 5YR 2.5/2
Mottles: None
Organic Matter Status: Intimate
Texture: Sandy clay loam (includes some blown shelly sand).
Stoniness: None
Structure: Moderately well developed medium sub-angular blocky peds.
Biological Activity: Frequent very fine fibrous roots, evidence of earthworm activity.
Inclusions: Occasional whole shells.
Phosphate Spot Test Status: High
Horizon Boundary: Abrupt, smooth to

Horizon 2

Depth Range: 49-104cm
Colour: 7.5YR 3/2
Mottles: None
Organic Matter Status: Intimate
Texture: Loam (includes some blown shelly sand)
Stoniness: None
Structure: Moderately well developed medium sub-angular blocky peds.
Biological Activity: Frequent very fine fibrous roots, evidence of earthworm activity.
Inclusions: Occasional whole shells.
Phosphate Spot Test Status: High
Horizon Boundary: Abrupt, smooth to

Horizon 3

Depth Range: 104-155cm
Colour: 10YR 3/2
Mottles: None
Organic Matter Status: Intimate
Texture: Loam (includes some blown shelly sand)
Stoniness: None
Structure: Moderately well developed granular peds.
Biological Activity: Evidence of earthworm activity.
Inclusions: Occasional whole shells.
Phosphate Spot Test Status: High

SOUTHNESS PROFILE 4

Horizon 1

Depth Range:	0-32cm
Colour:	10YR 3/2
Mottles:	None
Organic Matter Status:	Intimate
Texture:	Loam
Stoniness:	Few small subangular stones.
Structure:	Moderately developed granular peds.
Biological Activity:	Rare fine fibrous roots; no earthworm activity.
Inclusions:	The horizon consists of approximately 30% fine shell fragments considered as blown sand from the beach.
Phsophate Spot Test Status:	High
Horizon Boundary:	Abrupt, smooth to

Horizon 2

Depth Range:	32-81cm
Colour:	10YR 4/3
Mottles:	None
Organic Matter Status:	Intimate
Texture:	Loam
Stoniness:	Few small subangular stones.
Structure:	Moderately developed granular peds.
Biological Activity:	Rare fine fibrous roots; no earthworm activity.
Inclusions:	The horizon consists of approximately 20% fine shell fragments considered as blown sand from the beach.
Phosphate Spot Test Status:	High
Horizon Boundary:	Abrupt, smooth to

Horizon 3

Depth Range:	81-94cm
Colour:	10YR 3/3
Mottles:	None
Organic Matter Status:	None
Texture:	Loam
Stoniness:	Few small subangular stones.
Structure:	Moderately developed granular peds.
Biological Activity:	None
Inclusions:	None
Phosphate Spot Test Status:	High
Horizon Boundary:	Abrupt, smooth to

Horizon 4 - A pedogenic A horizon, the old surface horizon.

Depth Range: 94-100cm
Colour: 10YR 4/3
Mottles: Few fine distinct mottles, 7.5YR 6/8
Organic Matter Status: Intimate
Texture: Loam
Stoniness: Rare small subangular stones.
Structure: Moderately developed medium subangular blocky peds.
Biological Activity: Few fine fibrous roots.
Inclusions: None
Phosphate Spot Test Status: High
Horizon Boundary: Clear, smooth to

Horizon 5 - A pedogenic B_2 horizon.

Depth Range: 100-106cm
Colour: 5YR 4/4
Mottles: Frequent fine distinct mottles, 7.5YR 6/8
Organic Matter Status: Intimate
Texture: Sandy clay loam
Stoniness: Frequent small subangular stones
Structure: Moderately developed medium subangular blocky peds.
Biological Activity: None
Inclusions: None
Phosphate Spot Test Status: High
Horizon Boundary: Clear, irregular to

Horizon 6 - A pedogenic B_2/C horizon

Depth range: 106-129cm
Colour: 5YR 4/6
Mottles: None
Organic Matter Status: None
Texture: Sandy clay loam
Stoniness: Frequent small to large subangular stones.
Structure: Massive.
Biological Activity: None
Inclusions: None
Phosphate Spot Test Status: High

the overlying sedimentary material could not possibly be transported and deposited by any other agent other than man, confirmed by the "high" phosphate spot test status. Textural assessment is suggestive of a Tresdale Series origin for this material which was subject to organic additions together with shell and charcoal inclusions. The material may therefore have had several stages in its transportational history before deposition probably as one mass.

Profile 2, also on the summit area of the mound, is a profile of clear stratified deposits of varying thickness. The fluctuation in colour down the profile, the inclusions of charcoal, fish(?) bone and decomposing shell together with the consistently "high" phosphate spot test status confirm the anthropogenic sedimentary nature of the sediments in this profile. Field texture is consistently loam down the profile with the exception of horizon 8 which is sandy clay loam. This again is suggestive of Tresdale Series soil material being predominant in the construction of the mound. Differences in colour range suggest variation in type or amount of organic additions; lighter coloured material is, given its odour, almost certainly ash material and is dominant in horizons 7, 8 and 9. As there is no evidence of any great degree of mixing it can be suggested that deposition proceeded at a relatively rapid rate. Deposition of the upper part of the profile, from horizon 6 upwards, probably proceeded at a slower rate than those horizons beneath. Such an accretion is based on the presence of in situ roots in the upper part of the profile, which are absent beneath. It is likely that a slower deposition rate allowed vegetation cover to be established before being subsequently buried by additional material. The rate of deposition in the lower part of the mound was such that there was insufficient time for a vegetation cover to be established before the next horizon was deposited.

Laboratory derived data (Table 3:23) demonstrate the dominance of sand in the particle size fraction reflecting the input of calcareous wind blown sand. This input is also reflected in

TABLE 3:23

ANALYTICAL DATA FROM SOUTHNESS PROFILE 2

Sample Number	Depth(cm)	Particle Size (International Standard)			Loss-on-Ignition(%)	pH	ExchangeableBases (meq 100g)				Total P_2O_5 (mg/100g)
		Clay(%)	Silt(%)	Sand(%)			Na	K	Ca	Mg	
1	5	19.0	15.7	65.3	11.227	5.7	0.96	0.15	9.82	5.58	653
2	30	21.4	17.3	61.3	4.389	6.1	0.73	0.11	8.60	3.15	803
3	49	16.8	22.4	60.8	3.660	6.7	0.74	0.18	8.73	2.95	441
4	58	15.6	24.4	60.0	3.361	7.0	0.79	0.17	13.64	2.01	685
5	75	19.5	20.5	60.0	3.617	7.4	0.82	0.24	14.88	1.88	722
6	85	16.3	20.7	63.0	2.329	7.4	0.83	0.21	12.47	1.73	531
7	89	12.4	23.8	63.8	3.172	7.4	1.40	0.30	43.77	4.25	801
8	95	17.4	23.5	59.1	3.142	7.4	0.87	0.31	24.07	2.97	708
9	110	17.8	20.3	62.6	3.572	7.4	0.82	0.29	17.42	1.86	886
10	125	15.6	18.9	65.5	2.525	7.0	0.81	0.37	9.29	1.69	520
11	130	14.0	23.7	62.3	1.637	7.3	0.81	0.41	8.36	1.84	599
12	140	15.0	18.7	66.3	2.947	7.3	0.84	0.41	10.56	1.90	497
13	150	14.9	21.5	63.6	2.616	7.2	0.83	0.43	11.48	1.81	557

Source: Author

the basic pH levels found in all but the uppermost part of the mound and in the abnormally high available calcium levels. High sodium levels can be attributed to the coastal proximity of the mounds and reflect salt spray input. High total phosphate values confirm the anthropogenic status of this profile and suggest that the sediments forming this part of the mound were derived from human activities. Fluctuations in these laboratory derived properties down the profile indicate the variation in materials that form the mound together with the intensity of the deposition process.

Profile 3 was positioned on the side of the mound. The stratigraphy of this profile was not as complex as the other three. Blown shelly sand has made a significant contribution to the stratigraphy of this profile. Consequently the "high" phosphate spot test status means little in terms of anthropogenic sedimentary processes. The occasional whole shell inclusions and the general similarity of the horizons of this profile to the profiles just described above indicate the anthropogenic nature of profile 3 but with comparatively uniform material involved in its formation.

Horizons 1, 2 and 3 of profile 4 are considered to be part of the anthropogenic farm mound while horizons 4 to 6 are pedogenetic horizons of striking similarity to the Ocklester Series profile outlined earlier (Table 3:20). Wind blown calcareous sand accounts for a major component of these upper horizons. Otherwise the materials of these upper sediments and their general mode of formation is as already discussed for the other profiles of this farm mound in terms of both field and laboratory derived properties (Table 3:24). The characteristics of the underlying pedogenic horizons in terms of texture and mottling are consistant with those of the described Ocklester Series profile. Rootlets indicate the old land surface which has no evidence of cultivation having taken place prior to the deposition of mound material.

The stratigraphic characteristics of the Southness farm mound are entirely consistent with the hypothesis of anthropogenic

TABLE 3: 24

ANALYTICAL DATA FROM SOUTHNESS PROFILE 4

Sample Number	Depth(cm)	Particle Size (International Standard)			Loss-on-Ignition(%)	pH	Exchangeable Bases (meq/100g)				Total P_2O_5 (mg/100g)
		Clay(%)	Silt(%)	Sand(%)			Na	K	Ca	Mg	
1	20	15.4	10.4	74.2	5.343	7.3	79.7	0.24	293.47	14.98	709
2	40	15.0	9.8	75.2	3.394	7.4	82.57	0.29	315.77	16.06	532
3	60	17.1	13.5	69.4	3.442	7.4	63.97	0.41	224.55	9.41	683
4	80	18.0	20.3	61.7	3.968	7.2	15.05	0.67	11.38	3.00	1029
5	100	13.0	28.8	58.2	3.255	7.3	11.98	0.64	8.47	2.05	535
6	120	20.4	21.4	58.2	2.053	7.3	10.89	0.62	4.94	1.79	533
7	140	19.1	19.1	61.8	0.678	7.3	11.90	0.25	2.97	1.63	104

Source: Author

sedimentary origin when considered in relation to the surrounding soil types. The horizons of the mound are sedimentary in origin, not pedogenic. Texturally there is evidence for a significant calcareous blown sand input. However the bulk of materials forming the mound are most likely to have come from the surrounding Trestdale Soil Series, with some ash, and modified with organic materials before deposition. Rates of deposition are in general considered to be relatively rapid given the frequently clear stratigraphic layers, indicative of little post-depositional disturbance which is only possible with rapid deposition. Present of rootlets in some horizons may indicate periods when there was no deposition in certain parts of the mound. These characteristics are entirely consistent with a hypothesis of anthropogenic sedimentation, a statement confirmed by the inclusions evident in some horizons and the high total phosphate levels.

3:3:3 Conclusions : The Anthropogenic Nature of Farm Mounds

Little more needs to be added to the discussion above. All evidence points to the vast majority of farm mounds in Orkney being the result of anthropogenic sedimentary processes. The farm mounds are the result of man transporting material from various areas of the landscape to specific points. The observations of this chapter thus confirm the observations of earlier workers outlined in Chapter 1.

The other conclusion of significance is the considerable diversity of form and stratigraphy that exists between and within the farm mounds. Slope morphology of farm mounds indicates a considerable variety of depositional and post-depositional influences upon them. Farm mound stratigraphy demonstrates the wide range of materials and depositional characteristics involved in mound formation.

With the anthropogenic sedimentary nature of the farm mounds confirmed, it is now possible to further develop the theory of anthropogenic sedimentation to explain the formation of these significant and complex landscape features on the north isles of Orkney.

CHAPTER 4

CONCEPTUAL MODELLING OF ANTHROPOGENIC SEDIMENTATION

4:1 Introduction

It is clear from the previous chapter that man was responsible for the formation of deep top soils and farm mounds by transporting sedimentary material from one part of the landscape to another. The hypotheses of earlier workers outlined in Chapter 1 are thus confirmed. Deep top soils and farm mounds are two quite distinct manifestations of what maybe termed anthropogenic sedimentation. Furthermore it can be stated that one sediment type, the deep top soils, are the result of arable activity; farm mounds are the result of habitation activity. The remainder of this thesis concerns itself with elucidating the formation of these two anthropogenic sedimentary features.

To give direction and order in the task of elucidating deep top soils and farm mound formation,a generalised conceptual model of anthropogenic sedimentation is presented in this chapter. The model is derived from previous studies of sediments formed as a result of anthropogenic sedimentation during arable and settlement activities prior to the invention and/or availability of power machinery. A review of selected studies is now given before attention is drawn to the key elements of the anthropogenic sedimentary system that these studies identify.

4:2 Anthropogenic Sedimentation During Arable Activity

Soils deliberately raised by man's own efforts were generally attempts to overcome some set of environmental constraints which impinged upon arable activity. According to Conry (1974), four major objectives were in mind when the cultivator applied material to his arable land. Normally the most important was to compensate for loss of nutrients as a result of prolonged arable cropping. Application of fertility sustaining material to the land enabled it to be maintained in regular and continual tillage. Improvement of the physical properties of certain soils was a second objective, achieved by adding lighter material to heavy soil thus making it easier to work. The remaining two objectives, to level uneven soil surfaces and to raise the soil surface above the groundwater level, were important locally.

Raised fields, created by transferring earth to elevate an area above the natural terrain, is found to have been extensive in the tropical regions of the New World (Denevan, 1970) and the Old World (Denevan and Turner, 1974; Harris and Laba, 1982). As population pressure on agricultural resources increased, agricultural intensification was achieved by the utilisation of new ecological niches. Essentially these raised fields permitted cultivation in zones where drainage was poor and where there were the hazards of seasonal or permanent inundation or waterlogging. Other benefits did arise whether intentional or not. These included increased soil fertility, erosion control, facilitation of harvest, microclimate modification and moisture retention (Denevan and Turner, 1974). Such fields can range in length from two to several hundred metres and from fifteen to two hundred centimetres in height. In some areas their orientation may have had religious significance (Seimens, 1983).

In the swamp environments of the Yucatan peninsular region of northern Belize, the prehistoric Maya constructed a single level platform type raised field of various shapes. Whether construction evolved incrementaly or was implemented as a large scale project is not clear (Turner and Harrison, 1981). Construction was achieved by the removal of swamp depression soil and then cutting into the underlying decomposed limestone to produce canals. A decomposed limestone and subsoil mix was then laid between the canals and the swamp depression soil added on top to produce the planting surface. Fertility was sustained by mulches from various sources. Turner and Harrison (1981) suggest that 6,000 worker years were required for the 300ha field-canal network of their study area, the Pulltrouser Swamp, North Belize.

Reclamation in an entirely different environmental setting has been demonstrated by Macphail (1981). Excavations in London have identified a "dark earth" deposit in the stratigraphic sequence lying between Roman and Medieval levels. Phytolith and pollen analysis of the dark earth material indicated that plant material brought in from rural areas and refuse material had formed the deposit. Pedological evidence suggested that the dark earth had possibly served the function of a market garden. This represents a dramatic change in the land use from an urban existence to the cultivation of artificial soils. These soils bury the foundations of the previously built-up area of the Roman period.

Raised soils are found extensively throughout the temperate regions, generally the result of efforts to maintain soil fertility levels. The material used depended upon what was available in the particular environment. In coastal districts of Ireland large quantities of calcareous sea sand were applied to the soil either alone or in conjunction with seaweed. This has resulted in a man-made soil depth of between 27 and 85cm (Conry, 1971; 1972). The bulk of the material was applied from the latter part of the 18th century to the middle of the 19th century, a period of high population density in the coastal districts of Ireland. Deepest top soils are associated with the greatest population density. Similarly, in Cornwall, different types of sand have been composted with seaweed, animal and vegetable manures, and town refuse from Penzance and Marazion (Staines, 1979). This material was then applied to pre-existing brown earths, gley soils and brown podzolic soils. In the district of Hayles, the result has been a coarse loamy and fine loamy earthy man-made soil of high pH up to 1m deep. This degree of accumulation required the movement of 10,000 tonnes per hectare over the past 300 years. Today only one or two horticulturalists still collect seaweed and sand for compost as new forms of more convenient fertiliser are now available.

The build-up of manmade soil horizons has perhaps been best documented for the plaggen soils occurring in the sandy Pleistocene areas of Belgium, Germany and the Netherlands. (German:- plagge = sod; plaggen = to cut sods). Plaggen soils are confined to this, in terms of agricultural value, poorer parent material. These soils were gradually raised by the addition of mineral material as a result of a particular agricultural practice over the past 1,000 years (de Bakker, 1979). The broad distribution pattern is dictated by both natural and cultural factors. The northern boundary is formed by the Holocene marine and peat deposits, the southern boundary is either the loess area or the low hills in Germany. This coincides with the limits of the Pleistocene fluvioglacial sands. The eastern boundary cannot be explained by soil or geological conditions as the same landscape continues eastward with the dominant podzols developed on Pleistocene sands. According to de Bakker (1979; 1980), explanation of the eastern boundary may be found in the different agricultural practices of different cultures. The technique of plaggen manuring may have been restricted to the Saxons and, in part, the Franks and the Frisians. Scandinavians and Slavs did not use this practice.

Plaggen material came from a variety of sources. Heather or grass sods 25-30cm^2 by 3cm thick were cut from waste land and were used in the stables and byres as animal bedding. This dung impregnated bedding material was then applied to the arable land. It is estimated that 3-7ha of heathland was required to manure 1ha of arable land (van Bath, 1963). The sods were cut as thin as possible but inevitably some sand, often derived from the A_2 horizon of a podzol, was attached to the sod. It is this material that forms the mineral component of the man-made plaggen soil. Sods containing large amounts of clay were not used as bedding. Instead they were mixed outside with manure or were transported directly onto the arable land. Forest litter, peat litter and sand from borrow pits were the other types of litter used (Pape, 1970). The colour of the man-made horizon closely reflects the kind of litter used in the stables. Two other sources of material for anthropogenic soils in marine districts of the Netherlands were dune sand and mud dredged from ditches. The resulting soil was normally used as a horticultural soil. Crested and domed fields have been created by taking material from the margins of individual fields and bringing it in towards the centre (de Bakker, 1979). In more recent times the special needs of different crops were taken into account by this manuring system. Cow or sheep dung was mixed with grassy turf or earth from the wasteland and, with the addition of straw, was applied to meadows or rye fields. Pig dung mixed with turf from the heath was used as a fertiliser for buckwheat and potatoes (van Bath, 1963).

As well as being similar to the Orcadian deep top soils, the plaggen soils of north-west Europe closely resemble other soils in Scotland. Top soils of between 30 and 75cm have been identified in Aberdeenshire (Glentworth, 1944). Walton (1950) drew attention to the correlation of these deep top soil areas with concentrations of population recorded in the Poll Tax returns of 1696. Using historical documentation Walton argues the case for long-term improvement of the intensively cultivated innfield land during and since the Middle Ages. Romans (pers comm) points out that there are more concentrations of population than there are deep top soil areas in Aberdeenshire and so the deep top soil areas maybe older than the Middle Ages period. Romans attributes the occurrence of deep top soils to monastic improvements which were then taken over by the lay world. This is supported by Barber (1981) who identified top soils with surface horizons of 50cm and exceptionally high phosphate values in Iona. These soils are considered to have been raised between the 7th and 11th Centuries, a major period of monastic activity. Barber cites further evidence from Easter Ross where introduced deep top soils ranging between 43 and 79cm occur within the vicinity of Fearm Abbey founded in AD1221 (Romans, pers comm). Barbour tentatively concludes with the working hypothesis that such introduced soils may be attributable to early Christian and later ecclesiastical settlement.

Beyond Europe, in Asia, Rosanov (1959) in the Khuanke Basin, China, identified an anthropogenic layer of between 30 and 80cm thick. Loess formed 70-80% of the total compost and was mixed with half rotted manure, excrement and household refuse. The Maoris of New Zealand transported and deposited sands and gravels forming a soil 20-55cm thick clearly out of place in the stratigraphic sequence (McFadgen, 1980). This enhanced the cultivation of the taro and kumara, the main cultigens of prehistoric Maori communities.

The material came from borrow pits and was directly applied; there is no evidence of organic fertiliser having been incorporated into the sands and gravels. Improved physical characteristics of the soil resulted and meant that the soils were lighter and had better moisture retention and drainage than the soils they had replaced. McFadgen (1980) identified two types of Maori "plaggen" soil. One type is where the underlying original top soil was preserved because of the application of a large quantity of sand and gravel in one major effort. At the other extreme mixing of the original land surface top soil with man deposited sands and gravels occur where the sands and gravels were added incrementally and ploughing resulted in mixing.

4:3 Sediment Accumulation and Habitation

Accumulation of sediments associated with habitation sites result because of the collapse of structures, intentional deposition to reduce the flood hazard and gradual accumulation as a result of the different activities of day-to-day living. Alteration of soil chemical properties attributable to anthropogenic habitation activity have been well documented (Lutz, 1951; Cook and Heizer, 1965; Griffiths, 1980; 1981; Conway, 1983; Konrad, 1983) but it is actual aggradation of material upon which attention is focused.

One of the best examples of distinctive forms of sedimentary deposition as a result of house structure collapse are the tells of the eastern Mediterranean and Middle East. Particle size analysis of a 180m diameter, 11m high tell at Sitagroi in north-east Greece indicated that collapse of house walls are responsible for the evolution of this tell. Furthermore the source of the building material could be traced to local alluvium (Davidson, 1973; 1976). The low clay content of the walls meant frequent collapse and therefore rebuilding of new structures was required. Thus collapse and subsequent rebuilding resulted in the gradual height increase of the tell.

Intentional construction was undertaken to overcome some set of environmental constraints. In Europe, raised settlement occurs as terps in the Netherlands, wurts in Germany or the "rubbish dump" settlements of Denmark. All had the initial common purpose of raising the settlement area of one or several farms above sea-level. Some terps in the Netherlands were later enlarged for arable farming (van Welsenes, 1969).

In Germany the building of the artificial wurt mounds began at the end of the 1st Century AD (Korber-Grohne, 1981). For each dwelling and adjacent store house, a long mound 0.7m high, 20-25m in length and 8-10m broad was constructed. The core of the mound was stable refuse which was packed into layers and then covered with a layer of clay sods before the house was constructed. Upon excavation the internal structure of the sods was found to be intact and therefore it is possible to postulate that they were taken from the immediate vicinity of the Wurt. During the 2nd century AD the wurts were systematically expanded by the addition of stable refuse and clay along the margins and top. The greatest expansion occurred in the 3rd and continued into the 4th century AD to provide more room for the handling of harvests and the household activities performed on the wurt. Botanical remains indicate that crop processing activities occurred in the immediate vicinity of the store houses. At the end of this expansion period, individual wurts had merged providing a settlement area arranged radially about a large central square of some 3ha.

The dwellings of the Dutch terps were made of wood, wattle, sods and rushes. Consequently the life span of these dwellings was short. After their demolition the remnants of the foundations were covered with earth and refuse to serve the purpose of a building site for the new dwellings. Thus the new dwellings were built on a higher surface. This procedure, similar to the tell evolution already mentioned, resulted in terp heights of between 5 and 7m (van Welsenes, 1969).

Sediment accumulation as a result of day-to-day generation of waste material take different forms depending on the functions controlling their evolution. Extensive areas of dark coloured anthrosol have arisen in Amazonia primarily as a result of residue from fires and, to a lesser extent, the decomposition of refuse. These soils occur within the extent of the former pre-contact Indian villages (Smith, 1980). Soil formed by similar processes has also been identified in north-east Thailand (Pendleton, 1943). It is estimated that the 80ha Manacapurn site in the Amazon could have been occupied by as many as 18,000 Indians, with the soil forming at a rate of 1cm every ten years.

Examples of spatially concentrated accumulation of waste materials are middens. The study of such features has traditionally been undertaken by archaeologists and there are several economic studies based on the contents of middens (eg Bailey, 1975). Midden structure and stratigraphy has, however, been largely ignored although this maybe of importance in the interpretation of such sites. One exception to this general trend is worth noting. The 62.5cm stratigraphy of a pre-historic Maori midden site on Ponui Island, New Zealand, was utilised to interpret the sequence of events involved in the midden evolution (Terrel, 1967). Layers A and D were established as natural deposits at the top and bottom of the mound respectively. The distinctive characteristic of Layer C was two pits utilised for cooking as evident by the red fire zone, charcoal and fragmented cooking stones. Thus the major activity during this period and at this point on the midden was cooking. Layer B contained three different phases. The lower phase represented either the formation of a midden dump which contained less shell or else was composed of material raked out of cooking pits. The second layer contained a cooking pit, while the third was a concentrated shell midden. Distinctive activities were thus recognised from stratigraphic observations and so the process of midden evolution was inferred.

4:4 A Generalised Conceptual Model of Anthropogenic Sedimentation

In reviewing the various studies carried out on anthropogenic sediments throughout the world, certain key questions emerge that need to be asked in relation to the formation of anthropogenic sediments. The first set of questions ask what factors were responsible for the initiation and cessation of anthropogenic sediments. One possible factor responsible for the initiation of anthropogenic sedimentation identified by the review above is an increase in population levels. This appears to have been the case for the South American raised field systems where exploitation of new ecological niches was required and also for the Amazon anthrosols which arose because of waste material generation by a large population. A second possible factor initiating anthropogenic sedimentation is a change in arable or settlement practice introduced by a new immigrant population. One example of this might be monastic communities introducing to Scotland the technique of plaggen manuring. Factors responsible for the cessation of anthropogenic sedimentation are not often touched upon in the literature although the cessation of plaggen soil formation is attributed to the introduction of the more convenient chemical fertilizers.

A second question of fundamental importance to elucidating the formation of anthropogenic sediments is for what purpose was sedimentary material moved from one part of the landscape to another by man. That is, what land use was practised in that portion of the landscape receiving the anthropogenic sediments. In the examples above, the plaggen soils of north-west Europe evolved as a result of the need for early arable farmers to maintain soil fertility levels. The tropical raised fields were to permit arable activity in areas of flood hazard, while the terpen and wurt sites permitted settlement activity in area of flood hazard.

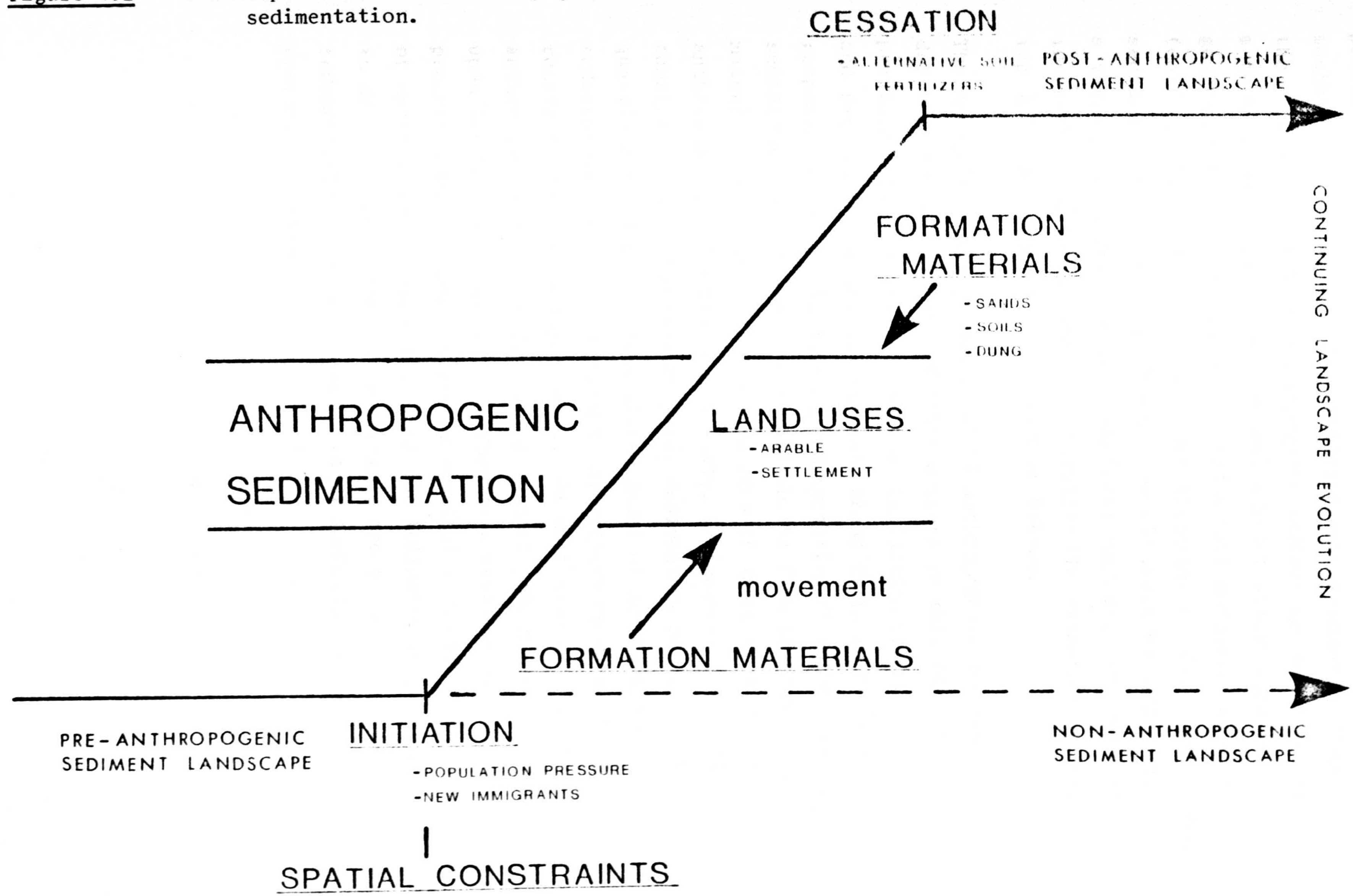
A third set of questions relates to the materials used in the formation of anthropogenic sediments. Within this set the questions asked are what were the materials of formation, where did these materials come from and how much effort was required by the society constructing the features under consideration? Thus for example the materials of the Maori plaggen soils were sands and gravels extracted from nearby borrow pits. Building materials for the tell at Sitagroi came from local alluvial deposits. In the construction of the raised field-canal network of Pulltrouser Swamp it is estimated that 6,000 worker years were required.

The final question to be asked is what factors are responsible for the spatial occurrence of anthropogenic sediments? The regional limits, for example, of the north-west European plaggen soils are controlled by physical and cultural parameters. At a more local level these plaggen soils are restricted to the oldest and best arable land.

Combining the four themes outlined in the above paragraphs permits the presentation of a generalised conceptual model of the anthropogenic sedimentary system (Fig 4:1). This model is deterministic in the sense that behavioural characteristics control anthropogenic sedimentation. Because of its generality the model can be applied to both the deep top soils and farm mounds. It can be considered as having two components. One component is what may be defined as the CONSTRAINTS on anthropogenic sedimentation. This includes the factors responsible for both the initiation and cessation of anthropogenic sedimentation together with the factors that restrict the spatial occurrence of such sedimentary processes. The concept of constraints as used here is one which is not unique to anthropogenic geomorphology. In the study of natural geomorphology there is increasing concern to identify factors responsible for the initiation and spatial distribution (or domains) of geomorphological processes (Thornes, 1983).

The second component of the model concerns itself with the PROCESS of anthropogenic sediment formation. Fundamental to the understanding of this process is an explanation for the movement of sedimentary material. This explanation, it can be argued, is to be found in the use to which man put that area of the landscape upon which anthropogenic sediments were deposited. Different land uses across the landscape are considered as potentially drawing different types and amounts of anthropogenic sedimentary materials. It is then necessary to identify as precisely as possible what the sedimentary materials were, where they came from and where within the anthropogenic sediment they were deposited. This therefore establishes the flow of sedimentary

Figure 4:1 A conceptual model of anthropogenic sedimentation.



materials. Taking this knowledge a little further it may be possible to establish how much effort was required by the society in question to create anthropogenic sediments. Thus the conceptual model of anthropogenic sedimentary processes is a form of the simple gravity model, a model widely used in geography to study both physical and social movements in space (Coffey, 1981). Land use(s) of the societies forming anthropogenic sediments create "gravity forces" towards which by human effort a variety of materials move. How these land uses and materials interact in space and time will regulate the evolution of deep top soil and farm mound formation in Orkney.

The generalised conceptual model of anthropogenic sedimentation derived from the studies of other workers in this field have provided a clear framework for the elucidation of deep top soil and farm mound formation. The task ahead is to identify factors responsible for the initiation and cessation of anthropogenic sedimentation in Orkney, to establish the flow of sedimentary materials in relation to the land uses of those areas receiving anthropogenic sediments and, finally, to identify the spatial constraints upon the anthropogenic sedimentary process. The questions posed by the generalised model of anthropogenic sedimentation can be sharpened up by presenting working hypotheses relevant to the Orcadian context. It must also be remembered that anthropogenic sedimentation is one process among many operating upon the Orcadian landscape as Chapter 2 established. Pedogenic processes in particular might be expected to modify the properties of anthropogenic sediments. What the following chapters attempt to do is to tease out the constraints and processes of anthropogenic sedimentation from the numerous other landscape forming processes operating in Orkney.

CHAPTER 5

INITIATION AND CESSATION OF DEEP TOP SOIL AND FARM MOUND FORMATION

5:1 Introduction

This chapter seeks to identify the factors responsible for the initiation and cessation of anthropogenic sedimentation in Orkney. Furthermore, attempt is made to establish the dates of this initiation and cessation. To achieve these objectives reliance is placed primarily upon a synthesis of archaeological, historical and etymological information. With this body of information it is possible to identify over what period in time the broad requirements for deep top soil and farm mound formation were met. How these requirements came into being and later ceased to exist is also identified. Radiocarbon dating, the most appropriate radiometric dating method, is presented as a secondary independent back-up approach in an effort to refute or support conclusions on anthropogenic sediment initiation and cessation based on archaeological, historical and etymological sources.

While there are substantial methodological difficulties with the above procedures, the goals of the chapter are possible by carefully piecing together the fragmentary and sometimes contradictory evidence. Some indication of these inherent difficulties are outlined once the general approach to the problem of elucidating the initiation and cessation of anthropogenic sedimentation in Orkney is given.

5:2 The Use of Archaeological, Historical, Etymological and Radiocarbon Evidence in Identifying the Initiation and Cessation of Anthropogenic Sedimentation.

It is fortunate that archaeologists and historians have already worked out a broad chronological sequence for the societies that have inhabited Orkney (Table 5:1). Within this chronological framework, the archaeological, historical and etymological record provides considerable insight into the settlement location and activities of these earlier societies. To elucidate the initiation and cessation of deep top soils, it is essential that these written records identify the plaggen manuring process. Earlier, in Chapters 1 and 3 the close similarities between the Orcadian deep top soils and the plaggen soils of continental north-west

TABLE 5:1

A GENERALISED CHRONOLOGICAL SEQUENCE FOR THE SOCIETIES THAT HAVE INHABITED ORKNEY

Society	Dates
Neolithic	c 3000 - 1850 B.C.
Early Bronze Age	c 1900 - 900 B.C.
Middle/Late Bronze Age	c 1000 - 200 B.C.
Iron Age	400 B.C. - 200 A.D.
Pictish Period	300 - 800 A.D.
(Celtic Mission Activity)	(600 - 800 A.D.)
Norse Period	800 - 1472 A.D.
Scottish Period	1472 - 1984 → A.D.
(Urban Migrants)	(late 1960 A.D. →)

(Source: See text and Forsythe, 1982)

Europe were pointed out. From these observations it was suggested that the deep top soils were the result of plaggen manuring of the early arable land. Thus the broad requirements for formation of Orcadian deep top soils are assumed to be similar to the European plaggen soils. These broad requirements are summarised from Pape (1970) as follows:

(1) A concentration of human population who cultivate crops as part of their economy.
(2) An agricultural system where mixing of cut sods and animal manure occurs, usually in a byre but alternatively in a compost heap outwith the farm buildings.
(3) An absence of alternative, more convenient, forms of soil fertilizer.

These three conditions must be met for plaggen soils to occur but even when this is so, it does not necessarily mean that plaggen manuring was happening. There is still the need for -

(4) The innovation of the plaggen manuring process.

Farm mounds are a considerably less well-known and understood phenomonen. Consequently it is not easy to identify the requirements for farm mound formation. Indeed it is part of the objective of this thesis to identify these formation requirements. All that can be stated is that on the basis of the Norwegian examples, farm mounds appear to be associated with human settlement and are formed primarily from the waste debris of that settlement over a long time period. (Bertelsen, 1979; Holm-Olsen, 1981; pers comm).

Thus the dated archaeological, historical and etymological records left by past societies is scrutinised to see at what period or periods in time the conditions for deep top soil and farm mound formation are to be found and then how these conditions came into being. Radiocarbon dating offers an independent means of checking the validity of conclusions drawn from these documented sources. This means of dating is of particular importance in the case of the farm mounds where little is known of formation requirements. Having outlined the broad procedures, it is now necessary to establish how they will work in practice and to pinpoint the problems associated with these methodologies.

5:2:1 Procedures and Problems with Archaeological, Historical and Etymological Information

The first avenue of investigation with the review approach is to establish the degree of spatial association between the deep top soils/farm mounds and the known dated prehistoric monuments or farm place names associated with a particular society. Of the several different avenues of investigation described in this section only this first avenue applies to the farm mounds. Prehistoric monuments of the sort found in Orkney and farm place names are considered to represent the occurrence of communities and so indicate areas of population concentration (Renfrew et al 1976). Based on the evidence in Chapter 3, 500 metres can be taken as the distance beyond which there is no significant relationship between an anthropogenic sedimentary unit and a farm. The major pitfall with this approach is that despite the good preservation of stone-built monuments in Orkney, the distribution maps produced by archaeologists of such monuments may well be incomplete. Schiffer (1976) identifies numerous cultural and natural factors which combine to remove the evidence of archaeological monuments, thus making the original distribution difficult to construct today. As an example from Orkney, Hedges (1975) comments that Bronze Age burnt mounds were until recently thought by modern farmers to be of little significance. Consequently many have been destroyed.

The use of place names in chronological studies also has inherent problems. With changing language and culture, farm names instead of becoming fossilized are perhaps more likely to be changed or altered by the new culture. If this occurs the date of settlement origin cannot be elucidated. Over and above the problems of obtaining an accurate settlement distribution for a given time period is the question of what a good spatial association between the remaining archaeological or place name record and deep top soils or farm mounds might mean. Even where there is a good degree of spatial association between the deep top soils or farm mounds and the archaeological sites or place names under consideration, the sedimentary features may still post-date the monument or place name. Such a situation would arise where the later settlements associated with the deep top soils/farm mounds saw the same advantages of a particular site for settlement as earlier communities.

A final problem relates to the location of anthropogenic sediments and pre-historic monuments or place names in Orkney. Deep top soils are confined to West Mainland and Stronsay while farm mounds are found only on Sanday and North Ronaldsay. Pre-historic monuments and place names are found throughout Orkney. It is necessary therefore to consider what spatial areas should form the basis for comparison of anthropogenic sediments with the tangible remains of earlier societies. An assumption was made that spatial factors restricts the occurrence of anthropogenic sediments to particular areas of Orkney, an assumption validated by the results of a later chapter. The basis for comparison of anthropogenic sediments with pre-historic monuments or place names are therefore taken as West Mainland and Stronsay for the deep top soils and for the farm mounds, Sanday and North Ronaldsay.

Notwithstanding the problems outlined above, it was still considered worthwhile to examine the degree of spatial association between anthropogenic sediments and pre-historic monuments or place names, provided appropriate caution is taken.

A second avenue of investigation, applicable to the deep top soils only, is to consider archaeological and historical evidence for arable activity in early societies. Artifactual evidence of ards and palaeobotanical evidence for cereal growth or weeds of cultivation are the major indicators of arable activity. This gives indirect evidence as to whether arable activity was being practised and therefore whether plaggen manuring of land was needed by the society in question. Alternatively, of course, it may be that lack of artifactual or palaeobotanical indicators of arable activity may be the result of site destruction processes.

The third indicator of plaggen manuring potentially having taken place lies within the building structure of a settlement site. Site plans from archaeological investigations are examined for areas where turf and animal manure may have been mixed prior to application to the arable lands. A byre or compost heap is considered to be indicative of such a mixing process. This does not necessarily imply that a turf/animal manure mix was applied to the arable land as a soil fertilizer. Innovation of the plaggen manuring technique would still be required.

Primarily related to the question of cessation of deep top soil formation is the presence of alternative forms of soil fertilizer to plaggen manure. It is generally agreed that the introduction of chemical fertilizer in the 19th Century saw an end to the needs for the plaggen manuring process both in Ireland and in continental north-west Europe (Pape, 1970; Conry and Mitchell, 1971). Historical information on Orkney is therefore examined to see if such a hypothesis is valid for the deep top soils and at what time this may have occurred. There are no anticipated problems in obtaining this information except to say that locally where chemical fertilizers were not available or could not be afforded, plaggen manuring may well have continued after this means of maintaining soil fertility had generally ceased. As recently as 1974 the use of sea-sand as bedding material for cattle was observed in the Dingle peninsula, Ireland, material which was probably then applied to the arable land (Conry, 1974).

5:2:2 Procedures and Problems with Radiocarbon

Radiocarbon dating, the independent means of obtaining dates of formation for deep top soils and farm mounds is also subject to major methodological problems. Valid interpretations of ^{14}C dates can only be made with a broad understanding of carbon biogeochemistry and the assumptions that are made in establishing a radiocarbon chronology. A brief resumé of radiocarbon theory and assumptions is given below with special emphasis on the peculiar problems associated with the radiocarbon dating of soils and archaeological sediments.

Naturally occurring ^{14}C forms in the upper atmosphere by the interaction of cosmic ray induced neutrons with nitrogen atoms of the atmosphere, viz

$$^{14}_{7}N + ^{1}_{0}n \rightarrow ^{14}_{6}C + ^{1}_{1}H$$

The radioactive ^{14}C is quickly oxidised to $^{14}CO_2$ and as such ^{14}C is introduced to the global carbon cycle. A small concentration of ^{14}C is assimilated into the carbonaceous tissue of all living plants and animals via photosynthesis and the food webs. At death the assimilation of carbon ceases and the ratio of radioactive to stable carbon ($^{14}C/^{12}C$) in the detrital material decreases exponentially in accordance with the c 5700 year half life for ^{14}C. A comparison of the $^{14}C/^{12}C$ ratio of a sample with that of recently grown material should therefore yield a measure of the time elapsed since the death of the sample (Fleming, 1976).

The precision of radiocarbon chronology and its universal application is however dependent on several assumptions and these are paraphased as follows by Browman (1981).

1. Radiocarbon in the sample being dated decays exponentially at a known rate and the initial measurement of that rate is adequate enough to make a reasonable computation of age.
2. Activity of the sample being dated can be measured and is being measured with acceptable accuracy.
3. The atmosphere is the only source of carbon for living organisms.
4. There is secular constancy,ie the concentration of radiocarbon in the atmosphere in any one place is constant through time.
5. At the death of a living organism, the sample will have a specific activity equal to the specific activity of the atmosphere, ie that no isotopic fractionation occurs and that thus all organisms have the same isotopic composition.
6. There is a principle of simultaneity, ie the ^{14}C concentration is the same for any two points on the earth's surface.
7. After the death of an organism there is isotopic integrity, ie no outside or extraneous material is added and the isotopic composition of the carbon in the deceased organism changes by radioactive decay alone.

Of these seven assumptions the first three are generally held to be valid. Assumptions (4) and (5) are known not to be valid but the causes of variation are known and at least partially understood. Corrections are now routinely applied so that accurate dates are obtained. In attempting to date soils and anthropogenic sediments by the radiocarbon method real problems lie in assumption (6) and (7). Problems associated with assumption (6) are now discussed.

The behaviour of nuclear bomb ^{14}C has demonstrated that in the atmosphere incoming ^{14}C is rapidly and well mixed. This is reflected in the ^{14}C concentration of terrestrial plants and animals. The situation with regard to marine carbon is however more complex and problematic. Sea-water has an apparent radiocarbon age because of the combination of late exchange through the atmosphere/ocean interface along with the oceanic carbon reservoir being 60-90 times that of the atmosphere. This results in an increased residence time for a carbon atom in the ocean. Furthermore, various water masses within the oceanic reservoir have different apparent ages because of variation in the speed of ocean water circulation which in turn determines oceanic carbon circulation. Finally, old carbon from the continents and ocean floor may enter the ocean water body although the significance is not known (Mangerud, 1972; Harkness, 1979). Clearly these observations have serious implications for the dating of both the deep top soils and farm mounds. Deep top soils may well contain seaweed which assimilates marine carbonate. Shallow coastal waters which are within the mid-latitude zone of 40°N - 40°S may in some cases have a relatively stable ^{14}C activity and so the concept of an apparent age adjustment could be applied (Harkness, 1979). Unfortunately Orkney is outwith this zone and furthermore if seaweed has been mixed with terrestrial material in the soil system in unknown quantities, it will be virtually impossible to establish an accurate calendar date of formation from radiocarbon ages. The only hope is to demonstrate that seaweed has not been utilised in the formation of the radiocarbon dated deep top soil profile. The implications for the farm mounds are equally important particularly as shell is one of the materials found in the mounds that has dating potential. Reliable radiocarbon values from shell material can be obtained where stable carbon isotope values are available and oceanic upwelling effects have been studied (Taylor and Slota, 1976). Alternatively the apparent age of shell material can be obtained by studies of paired shell/ charcoal,wood, sediment samples from the same stratigraphy (Gillespie and Polach, 1975). Recently Harkness (1983) has established a c 405 $\pm$40 radiocarbon years apparent age for marine shells of the British coast. If this is taken as accurate then it may well be possible to achieve accurate calendar dates from the radiocarbon age of shell material.

Assumption (7) is the second major problem area when attempting to date soils and archaeological sediments by the radiocarbon method. Radiocarbon measurements may not indicate the absolute age of a soil because of the complexity of soil genesis. Penetration of rootlets, bioturbation, percolation of soluble humic substances, ageing effects from minerogenic carbon and the admixture of plant residues result in the organic content of a soil being a mixture of a unknown number of compounds of unknown chemical composition and age (Scharpenseel, 1971; Mathews, 1980; Geyh and Roeschmann, 1983). Additional problems are that ploughing may result in humus rejuvination eliminating soil radiocarbon age/depth relationship in the plough layer while steepening this gradient between the plough layer and the undisturbed horizons (Gerasinov, 1974). Scharpenseel et al (1968) identified older soil material underlain by younger material in radiocarbon dated plaggen soils. Such a phenomenon they attributed to either vertical transport of humic substances or, alternatively, the different age of plaggen material at the moment of deposition. Another problem is the possibility of the original top soil, prior to plaggen deposition, being mixed with the deposited material. The original top soil will have an indeterminate radiocarbon age and thus will alter the radiocarbon age of the applied plaggen material. Radiocarbon dating of the Irish plaggen soils suggested that they may be up to 1,265 years old when in fact it seems that they are less than 300 years old (Conry and Mitchell, 1971). The radiocarbon dates were considered to give an untrue reflection of the actual age of the plaggen soils because of the apparent mixture of the older buried profile with the most recent plaggen material.

In short the plaggen soil system is a dynamic part of the carbon cycle and so the relative age of carbon in soils will be constantly changing. Thus when a radio-carbon age is obtained from a plaggen soil profile it is the apparent mean residence time that has been measured rather than the true age of the soil profile. Much effort by numerous workers has gone into attempting to reduce the gap between the apparent mean residence time and the true age of soil formation. A closing of this gap depends on whether or not biologically inert carbon can be isolated from soils and dated. Biologically inert carbon is generally considered to be the oldest carbon in the soil and a number of methods have been used to fractionate out this carbon. These methods have included fractionation according to particle size, fractionation by extraction with organic solvents of increasing polarity, subfractionation of humic acids and humin samples by gel permeation into samples of various particle sizes, fractionation by step-wise continuous alkali extraction and lipid extraction (Scharpenseel, 1976a; Sheppard et al 1976). Alkali solubilization of humus that separates humins, humic acids and fulvic acids,and successive acid hydrolysis that solubilizes increasingly resistant products are the two main extraction methods used in order to isolate the oldest soil fraction. Despite the hopes that these two extraction methods would indeed isolate inert carbon it seems unlikely that this is the case. Gilet-Blein et al (1980), for example, examined ^{14}C dates of these different carbon fractions in relation to the known dates for different soil/sediment types. They concluded that ^{14}C dates were always too young and therefore were unreliable indicators of absolute soil age. Even if such procedures could elucidate the true ages of the soil material in a plaggen soil context it would not give the dates of deposition which is of primary interest to this thesis.

Dating of archaeological sediments is no less problematic, problems which stem from assumption (7) of radiocarbon chronology. Many of the points considered in relation to plaggen soils above are equally applicable to archaeological sediments and therefore it is not necessary to repeat them (Waterbolk, 1971). One additional major reason for differences between ^{14}C ages and the true age of an archaeological stratum is anthropogenic turbation (Wilkomm, 1983). This is simply another problem to compound the difficulties of interpreting radiocarbon ages of anthropogenic sediments. Clearly extreme caution has to be taken in interpreting the twenty radiocarbon dates determined for this thesis by the N.E.R.C. Radiocarbon Laboratory, East Kilbride (Harkness and Wilson, 1972).

5:3 Identifying Relationships Between Orcadian Cultural Groups and Deep Top Soils

The above paragraphs have outlined the procedures together with the associated problems, to obtain an explanation for the initiation and cessation of deep top soil and farm mound formation. The discussion that follows is chronological, based on the sequence of societies that are known to have inhabited Orkney over the millenia (see Table 5:1). Because the deep top soils and farm mounds are two quite distinctive sedimentary units, it was considered prudent to examine them separately. The methods and principles outlined above are now carried out in relation to the deep top soils commencing with the Neolithic inhabitants of Orkney.

5:3:1 The Neolithic

Of the 81 identified monuments (ie chambered cairns, settlement sites and henges) associated with the Orcadian Neolithic (c 3000 - 1850 B.C.) only 22 fall into the areas of West Mainland and Stronsay where deep top soils are evident (Fraser, 1983). Of these 22 monuments only one, the settlement of Skara Brae is within 500 metres of any of the 40 deep top soil units (Fig 5:1). This means that only 2.5% of the deep top soils are associated with a Neolithic monument. There is therefore a negligible degree of spatial association between Neolithic settlement distribution and the deep top soils. It seems unlikely therefore that Neolithic society could be responsible for the construction of deep top soils. Such a view is supported by the bone evidence from Neolithic sites which points to a predominantly pastoral economy (Renfrew, 1976). There is however some evidence for arable activity. This includes imprints of barley on pottery from the Skara Brae settlement (Clarke, 1976), cereal pollen preserved in peat and turves beneath the Maes Howe

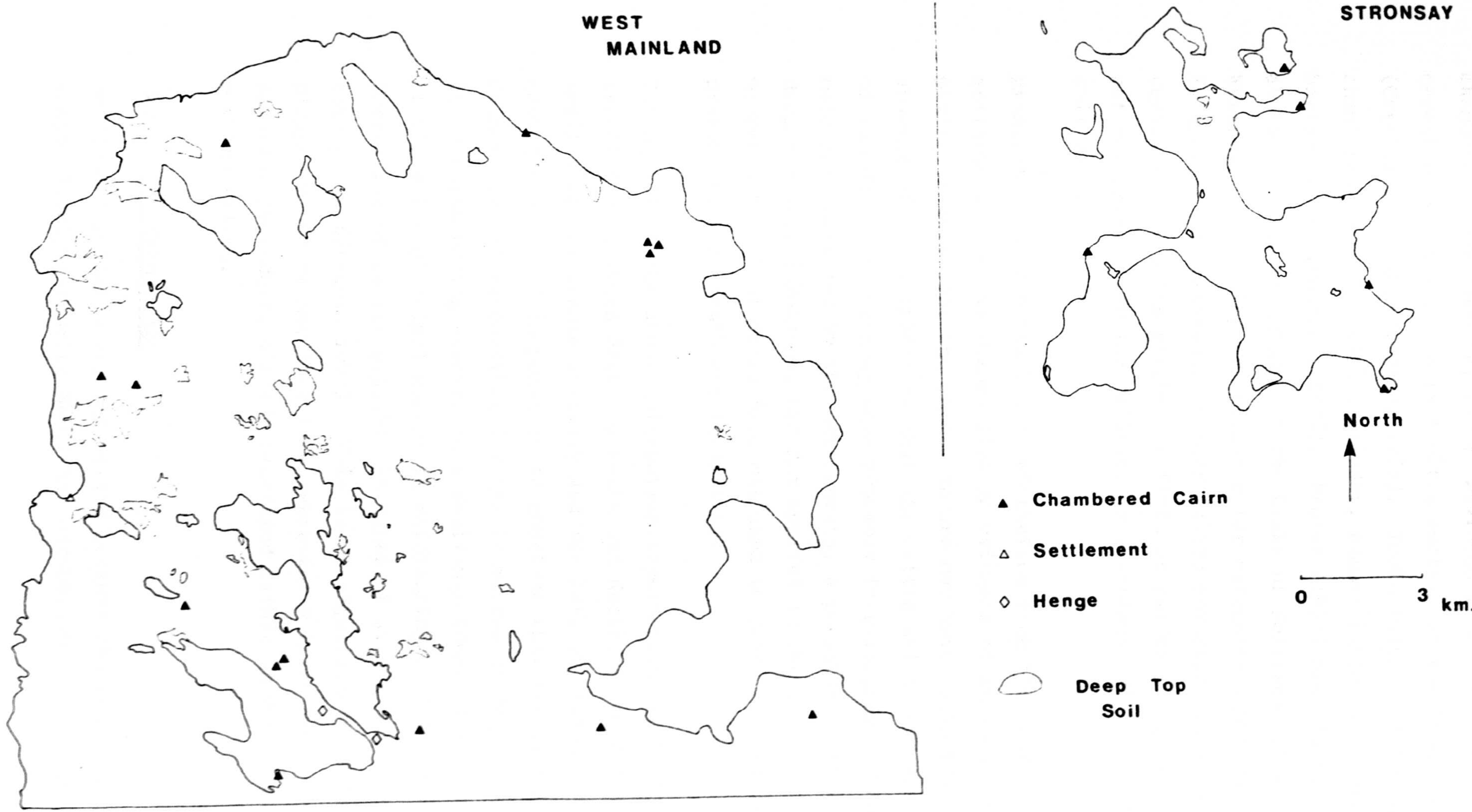


Figure 5:1 The distribution of deep top soils and Neolithic monuments in West Mainland and Stronsay.

chambered cairn (Godwin, 1956; Davidson et al 1976) and, again cereal pollen preserved in a ditch section at the Stones of Stennes (Caseldine and Whittington, 1976). Tools found in the Quanterness chambered cairn included a grinder, almost certainly indicative of barley growth (Renfrew, 1979). Fraser (1983) reports plough marks at the base of the midden at the Links of Noltland settlement site, Westray. Archaeological evidence for extensive arable practise is however non existent. Fraser (1983) envisages cultivation consisting of a few patches of field or garden plot, certainly not consistant with the relative extensiveness of a deep top soil unit.

Examination of the available information from the four Neolithic settlement sites in Orkney give no evidence of an area where mixing of turf sods and animal manure may have taken place. The absence of byres indicates that the cattle which were the mainstay of the Neolithic economy were probably free-ranging. Midden material generated by the settlements, a possible material of deep top soil formation, was not applied to the land. Instead midden material at Skara Brae was used to cover the settlement, presumably for warmth and insulation.

Taking all of the above information together,the lack of spatial association between deep top soils and Neolithic monuments, the small scale of arable activity and the lack of evidence for sods/ manure mixing, it is possible to conclude that Neolithic man in Orkney was not responsible for the formation of deep top soils. It is worth noting however that Neolithic communities were aware of the value of animal manure in maintaining soil fertility. Corralling of cattle possibly in zones of arable activity did take place (Fraser, 1983). This is of significance in that plaggen manuring may therefore represent a later development of manuring procedures already practised rather than a completely new innovation.

5:3:2 The Bronze Age

Settlement patterns for the period between the end of the comparatively extensive Neolithic occupation. (c 1900 B.C.)

and the middle-late Bronze Age settlements of 1000-200 B.C. are not clear. A few beakers, cists and barrows, which are probably early Bronze Age are present in Orkney along with some standing stones. These however are few and no systematic work has been carried out to establish the settlement pattern, if any, and settlement activities of early Bronze Age Orkney. It is not possible therefore to make any statements about the origins of deep top soils in this period.

Middle to late Bronze Age settlement patterns, c 1000-200 B.C., based on thermoluminescence dating of fire affected stones, can be identified from the occurrence of burnt mounds. A burnt mound is a low heap of fire affected stones intermixed with blackened earth, ash and charcoal. Excavation of a burnt mound, Liddle in South Ronaldsay, established that adjacent to the mound lay a small oval house. There was no evidence for a byre. Furnishings were evident as well as a large hearth and stone trough, found in all burnt mounds so far excavated. Water was placed in the trough and boiled by means of placing heated stones in the water-filled trough. By this means meat was cooked. The stones and ash were then discarded, hence the formation of the burnt mound (Huxtable et al 1976; Hedges, 1974). These features clearly point to a distinctive permanent settlement type of which over 200 are known in Orkney. Of these, forty-three occur in West Mainland with only sixteen within 500 metres of any of the mapped deep top soil units. A further ten burnt mounds are found in Stronsay, none of which show any spatial association to the deep top soil units on that island (Fig. 5:2). Thus only 40% of the deep top soils in West Mainland and Stronsay are associated with burnt mounds. It seems unlikely therefore that Bronze Age communities were responsible for the formation of deep top soils.

Artifactual material from excavations of burnt mounds is scarce but does include ards, certainly indicative of arable activity. Palaeobotanical analysis of burnt mounds at Liddle, Beaquoy and Fan Knowe identified cereal and weed pollen together with ruderals associated with cultivation (Hedges, 1974; Jones, 1974). Jones (1974) concluded that the early Bronze Age exhibited evidence of

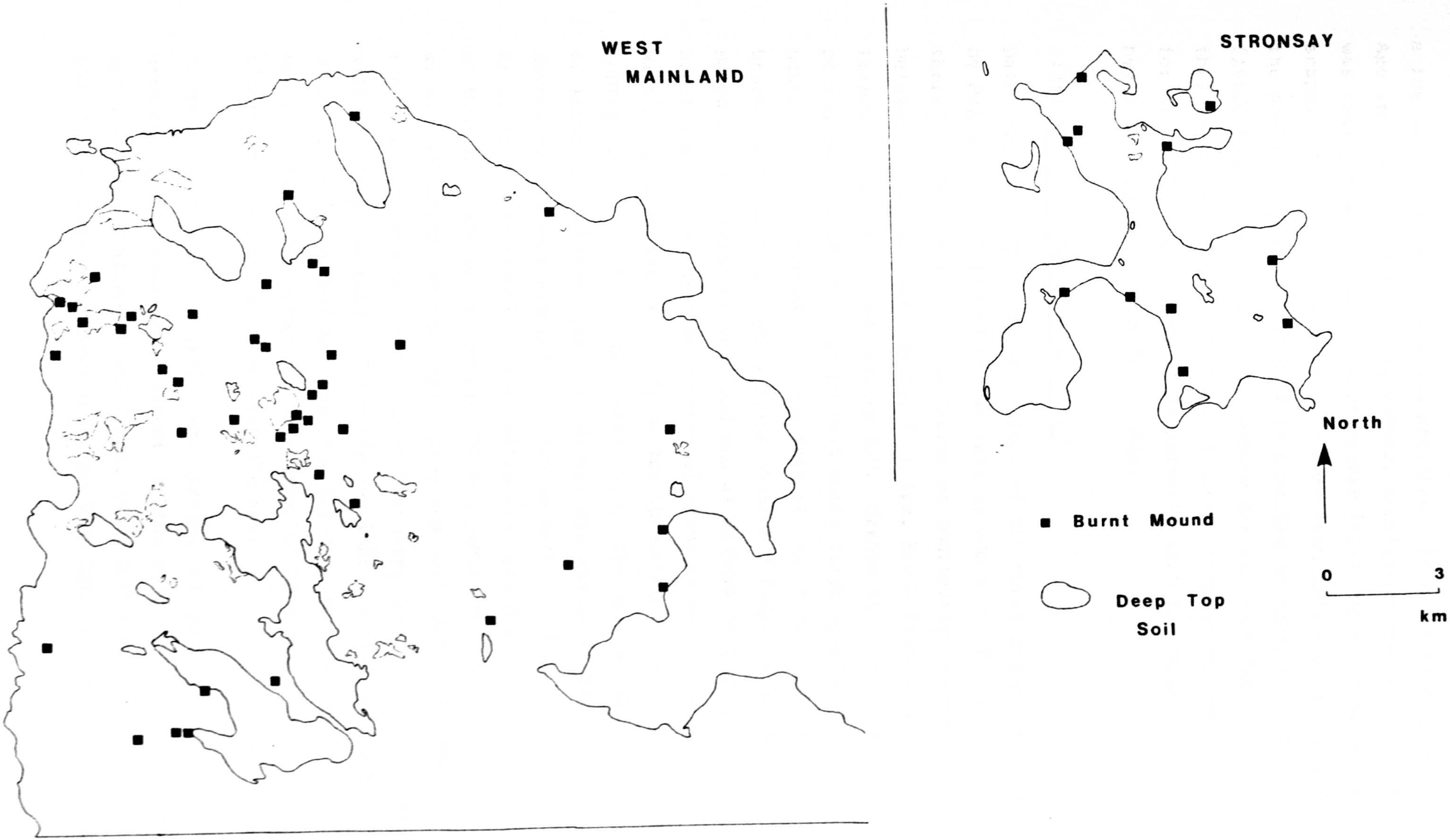


Figure 5:2 The distribution of deep top soils and Bronze Age burnt mounds on West Mainland and Stronsay.

a low intensity, mixed farming practice. From the middle Bronze Age into the early Iron Age, however, consistant cereal cultivation was taking place making a considerable impact upon the local landscape. This impact though was no more than that associated with the Neolithic period. Thus it is possible to agree with Childe (1962) that the economy of the Bronze Age was much the same as that of the Neolithic. In view of these observations then, as for the Neolithic period, it is unlikely that the deep top soils began to form during the Bronze Age.

5:3:3 The Iron Age, Broch Period

Dates for individual stones of some of the burnt mounds examined by Huxtable et al (1976) are as late as 200 B.C. It is likely therefore that there is some degree of continuity and overlap between the Bronze Age and the Iron Age, Broch Period, which lasted until the second century A.D. Orkney over this time period was peopled by a group that built large round defensible houses known as brochs. By the late second century A.D. the broch towers were gradually being abandoned and/or modified. Noteably at Gurness on Mainland and at Midhowe on Rousay, the broch towers were used as sources of stone to build new dwellings within the immediate vicinity of the abandoned broch. Such activity continued up to the fourth century A.D. The spatial distribution of these broch sites, like the Bronze Age and Neolithic age sites, demonstrate a poor spatial association with the deep top soils (Fig. 5:3). Thirty-nine broch sites are recorded within the area of West Mainland under consideration of which only twelve are within 500 metres of the mapped deep top soil units. Of the four possible brochs identified on Stronsay, none are associated with the deep top soil. These figures indicate that only 30% of deep top soils in West Mainland and Stronsay are associated with broch sites, a percentage value suggesting that there is no significant relationship between the two.

Although some arable activity was carried out judging from the archaeological remains, the extent of this practice was like earlier ages, limited (Callendar and Grant, 1934; R.C.A.M.S., 1946). A pastoral economy predominated in the Iron Age augmented by fishing

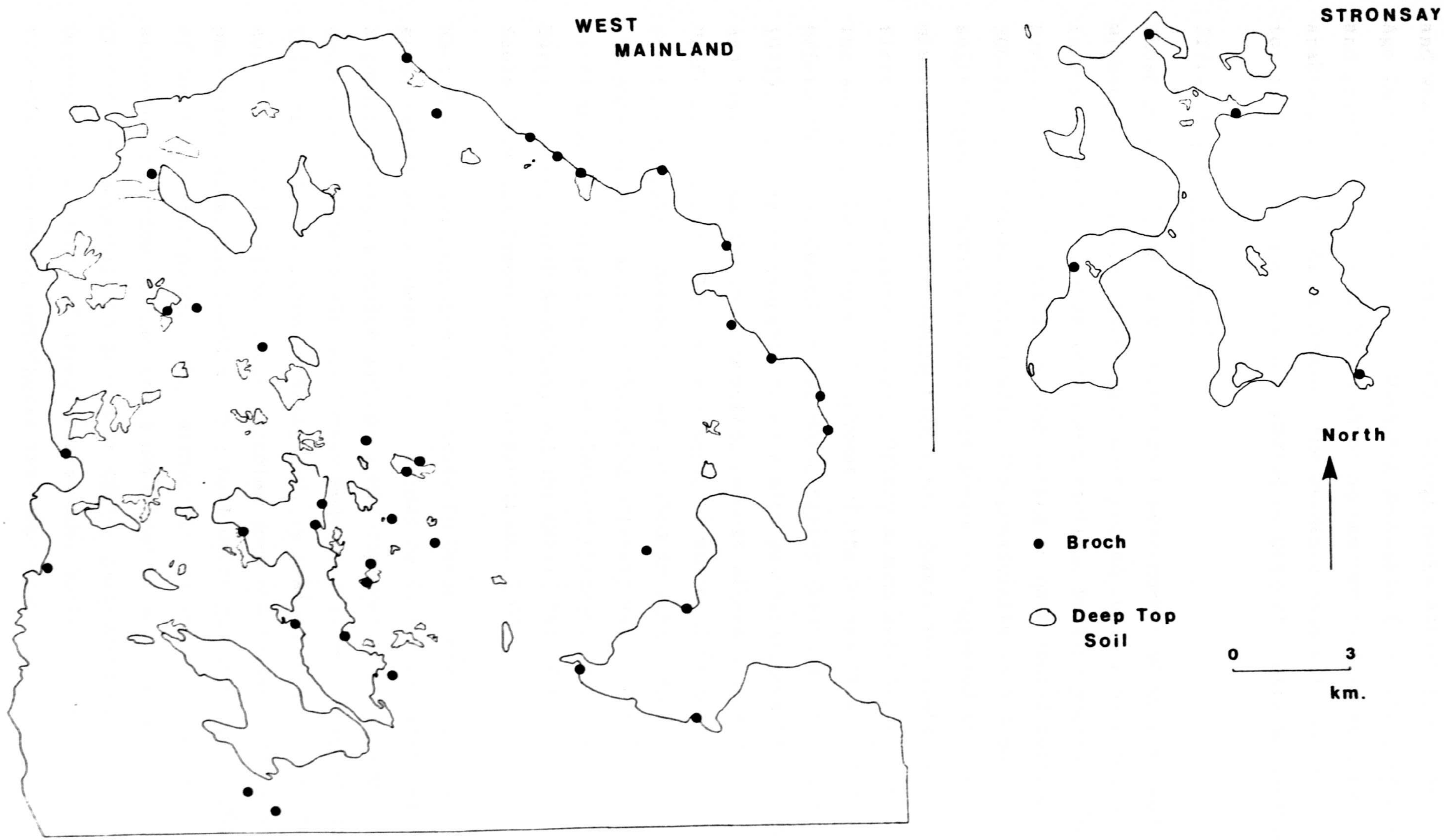


Figure 5:3 The distribution of deep top soils and Iron Age brochs on West Mainland and Stronsay.

and whaling (Wainwright, 1962). Plough marks attributed to the Iron Age in a buried soil on the Deerness peninsula (Limbrey, pers comm) and grinding tools from broch sites do however testify to some arable practice. Again however the evidence points to no deep top soil formation during this period of Orkney's cultural history.

5:3:4 The Pictish Period

Those people living in the post broch settlements of Gurness and Midhowe together with those that constructed subterranean houses in Orkney are the bridge into the historical Pictish period. This period of Orkney's culture is considered to have lasted between 300-800 A.D. (Wainwright, 1962). The possibility that deep top soils began to develop during this period is suggested by Celtic missionary activity stemming from Iona. Cormac was probably the first Celtic missionary to reach Orkney around A.D. 580 pioneering the way for the solid establishment of the Celtic church well before the commencement of the Norse period (Radford, 1983; Cant, 1972). That these evangelists were also practical agriculturists and lived among the local populace is well attested in Adomnans "Life of Columba". They were a separate movement from the eremitic monastic communities established in remote spots during the same period. Hints of Christian activity within Pictish settlements is suggested by the finds of Christian objects at Burrian broch, North Ronaldsay and the Celtic bell from the Saevar Howe settlement mound, Birsay (Lamb, 1983).

What makes Celtic missionary activity in Orkney potentially of great importance to deep top soil formation is the discovery of a comparatively extensive anthropogenic top soil on Iona, the centre from which Celtic missionary endeavour stemmed (Barber, 1981). This top soil, described in Table 5:2, is associated with the Abbey and shows similarities to the Orcadian deep top soils. Very high phosphate values are found in this soil which has developed independently of the underlying pedon. The introduction of this cultivated anthropic epipedon in Iona could have been as early as the 7th Century, well within the period of Celtic missionary activity in Orkney. As a result of these observations Barber (1981) has presented the working hypothesis that improved techniques of

TABLE 5:2

ANTHROPIC EPIPEDONS FROM IONA

(From Barber, 1981)

Profile Type Level	Type A Description	Type B	Type C
0 cm	Ap1: Very dark grey-brown loam with abundant roots, worm casts. Loose uncemented springy, occ. grits very humus rich. Fairly sharp boundary to:	As Type A	As Type A
15 cm	Ap2: Dk grey-brown stony loam 10% stones (predom.6-20 mm) rounded. Uncemented very crumbly porous with abundant worm casts. Top of the layer formed by a line of stones 20-40 mm. Less than 2% charcoal. Sharp boundary to:	As Type A	As Type A
50 cm	Bs: Iron stained very stony gravel with sand, angular grits very variable cementation. Lower boundary not seen.	AE:(relict) Grey silt fine and stone - free well sorted, uncemented few roots. Some relict rooting rarely penetrating to next layer. Lower boundary abrupt to :	AE: DK grey sand humus rich with root mottlings. Uncemented has an irregular but distinct upper boundary and an irregular diffuse lower boundary to:
60 cm		Bs: Orange coarse sand with silt some decaying granitic pebbles without bleaching rings.	Ea: Light grey sand. Stone free uncemented well sorted, some root mottling Wavy boundary merging to:
70 cm		This Ae/Bs sequence is repeated up to six times.	Bh: Dark grey sand with 10% stone (6-20 mm), root mottling coming in from above but not penetrating far through. Sharp flat transition to:
76 cm /			

TABLE 5:2

TABLE 5:2 Cont'd

Profile Type Level	Type A Description	Type B	Type C
76 cm			Bs: Ochreous coarse sand with large (30%) boulders often indurated. Poorly cemented root mottles.
110 cm		C: Coarse sand with 10% boulders of indurated granitic gneiss. This layer is continuous whereas the upper alternating sequence layers are lenticular. Raised beach material.	C: Raised Beach.

agriculture, including the use of introduced soils, came to the north-west Atlantic seaboard via the early Christian church. In view of the above discussion it appears feasible that the innovation of deep top soils could have been introduced with Celtic missionary activity between A.D.600 and A.D.800, the later Pictish period.

Of the Pictish settlements themselves, is there any evidence of the possibility of the plaggen manuring technique having been utilised? Unfortunately, for a number of possible reasons, little remains of Pictish structures in this critical A.D.600 - 800 period. Some authorities consider Norse farm names to have been new names applied by Norse settlers to earlier Pictish settlement sites (Fellows-Jensen, 1984). The degree of spatial association between Norse farm names and deep top soils is very good (see next section) but excavation evidence does not support the hypothesis of much arable activity in this period. The 7th Century Pictish levels at Buckquoy, Birsay, revealed no byre and little palaeobotanical evidence or artifacts to suggest arable activity (Ritchie, 1977). Similar observations emerge from excavations of the Pictish layers at Skail, Deerness (Gelling, 1984). Bone evidence from Buckquoy tantilisingly suggests that most animals were slaughtered in their first year, implying that very few would be kept over winter in a byre. Furthermore, those animals that were kept were probably tethered outside thus removing the need for a byre.

Just as at the post-broch settlements of Gurness and Midhowe,a pastoral economy seems to have predominated over the Pictish period. Thus the conclusion is that despite Celtic missionary activity there is really no grounds for assigning the innovation and commencement of deep top soil formation to this period.

5:3:5 The Norse Period

Evidence pointing to the possibility of plaggen manuring in the Norse period, which current academic opinion considers to have commenced with peaceful colonization c 800 A.D. is more forthcoming. Most of the Norse settlement sites so far excavated in Orkney and in Scotland have byres dating from the earliest phase of Norse settlement (Cruden, 1965; Ritchie, 1974; 1977). In the early Norse farmstead byre at Buckquoy, contained in the silty material of the drain, were plant cells resembling those of grass (Ritchie, 1977). Whether this material was brought into the byre as fodder or as bedding is unclear but does serve to emphasise the movement of organic and possibly inorganic materials into the byre. This silty drain material was of further interest in that it yielded a total P_2O_5 value of 660 mg/100g, a similar total P_2O_5 value to those found in the deep top soils (see Chapter 3). Small (1968) notes that in Norway prior to the Norse migration,the cow was the basis of the agricultural regime with stress placed on the cultivation of fodder to allow as many animals as possible to be overwintered in the byre. That many animals were also overwintered at Norse period Buckquoy is suggested by the age of the animal bones found. Animal bones were older in the Norse layers of Buckquoy than those of the Pictish layers. Little evidence remains for arable activity at the Buckquoy site during the Norse period but a possible threshing barn built cross-wise to the prevailing wind supports a hypothesis of considerable arable activity. Here then is evidence to suggest that some of the requirements for plaggen manuring were present. Arable activity was practised, as it always had been, but now a byre was used if not each night at least over winter to house cattle thus generating plaggen manure.

It can also be demonstrated that the Norse settlement pattern is strongly related to the location of deep top soils. Currently the best way of examining Norse settlement patterns is to use farm place names which in Orkney are 99% Norse (Marwick, 1952). A list of the names of farms on or immediately adjacent to the deep top soil units is given in Table 5:3. Only two of the forty deep top soil units in Orkney are not associated with Norse farm name elements, an exceptionally good spatial association (95%). Some indication of the ages of the Norse farm place names is also given in Table 5:3 based on Marwick's categories. Marwick (1952) considered the following Orcadian place name elements as diagnostic of farm settlement age.

1. Boer (Old Norse : farmstead) Indicates the earliest Norse settlement, c 800 A.D.

2. Skáli (Old Norse : a hall) Indicates buildings erected immediately after the first phase of settlement.

TABLE 5:3

PLACE NAMES ASSOCIATED WITH THE DEEP TOP SOIL UNITS

Key to Categories :

1 - 7	Chronological Indicators of Settlement (See Text)
+	Norse Farm Name mentioned in'Orkney Farm Names'.
NP	Name not present in 'Orkney Farm Names'.

Deep Top Soil Unit No. (Ref Fig 5:4)	Associated Place Names (After Marwick, 1952; 1970; Ordnance Survey 1:10000 Maps)	Marwicks Chronological Categories (See Text)
Birsay Parish		
1	Earls Palace	(Earl Robert Stewarts Palace of 1514)
	Birsay	7
2	Garthsetter	5
	Vinbrake	7
	Boardhouse	1
	Wattle	1
	Meran	7
	Grindally	+
	Scotabreck	7
3	Bea	1
	Ingsay	+
	Fea	7
	Curcum	+
4	Stanger	4
	South	NP
	Breckbie	7
	Groo	7
	Yeldabreck	7
	Skidge	+
	Lea	7
5	Hundland	4
6	Gridgar	4
	Steadaquoy	6i
	Flaws	+
	Brockan	7
	Netherskail	2
	Langskail	2

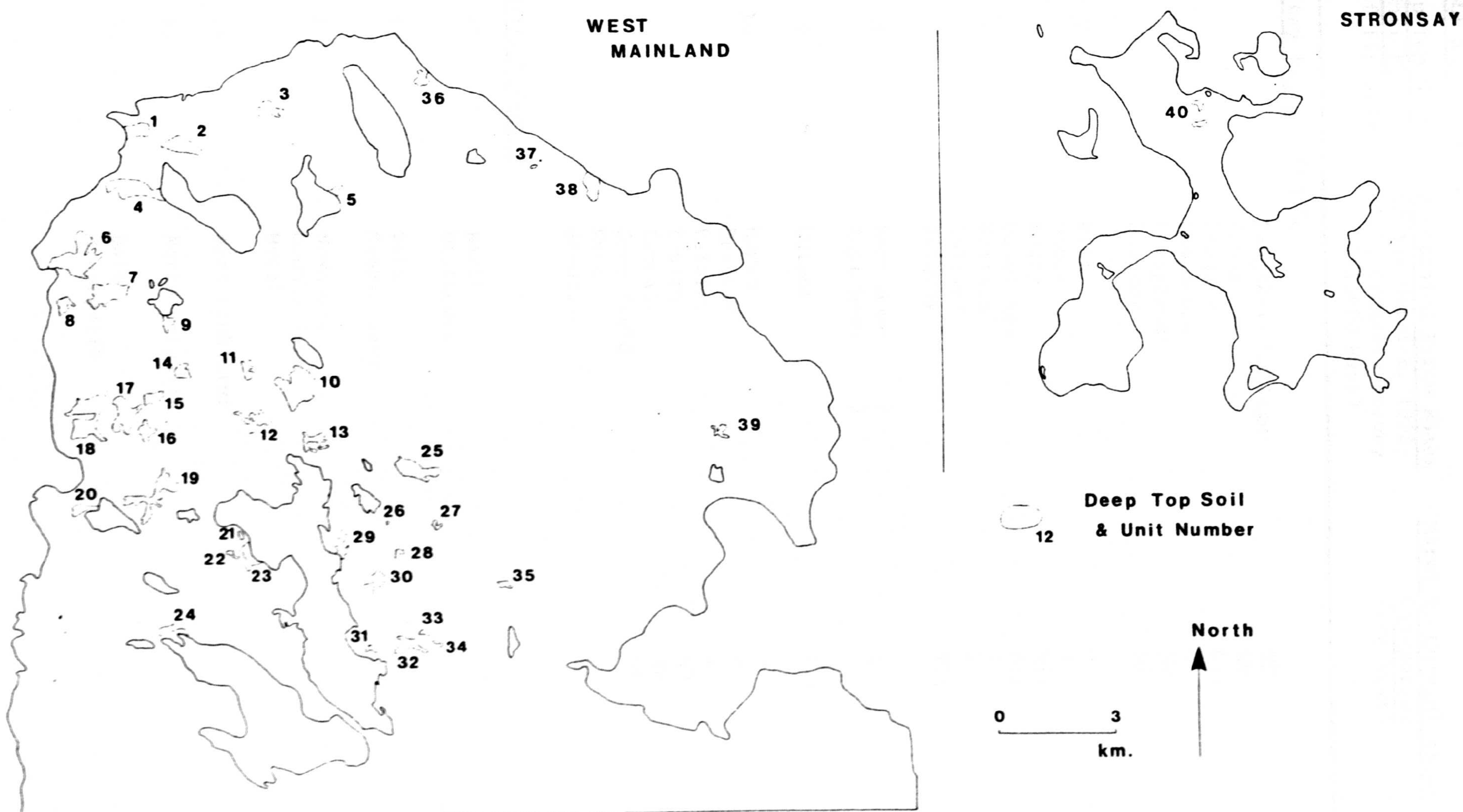


Figure 5:4 Deep top soil unit numbers (see Table 5:3).

TABLE 5:3 Cont'd

Deep Top Soil Unit No. (Ref Fig 5:4)	Associated Place Names (After Marwick, 1952; 1970; Ordnance Survey 1:10000 Maps)	Marwicks Chronological Categories (See Text)
Birsay Parish Cont'd		
	Langskail Cottage	NP
	Crook	NP
	Leaquoy	6ii
	Cumlaquoy	6i
	Craiglands	NP
	Quaquoy	6i
7	Muce	+
	Scorn	7
	Leary	6ii
	Quoylonga	6ii
	Britain	7
	Holland	7
	Ritquoy	7ii
8	West Howe) East Howe)	7
9	Quinni	6ii
10	Howan	7
	Breckan	7
	Velzian	+
	Teuath	NP
	Lymdale	NP
	Greenfield	NP
	Muce	+
	Glendale	NP
Sandwick Parish		
11	Warth	6i
	Westhouse	NP
12	Vola	+
	Benzieclett	+
13	Newhouse	NP
	Dounby Farm	1
	Hyval	+
14	West Linklater	+
15	North Unigarth	4
16	Bain	+
	Housegarth	4

Deep Top Soil Unit No. (Ref Fig 5:4)	Associated Place Names (After Marwick, 1952; 1970; Ordnance Survey 1:10000 Maps)	Marwicks Chronological Categories (See Text)
Sandwick Parish Cont'd		
17	Scarwell	7
	Quoys	6ii
	Stove (Skorwell)	7
	Iverack	NP
	Newark	NP
	Hazelwood	NP
	Daisybanks	NP
	Quarrybanks	NP
	Bristol	NP
	Snea	NP
18	New Hooveth	+
	Instabillie	+
	Huan	7
	Hyval	+
	Skabreck	7
	Kingshouse	NP
	Looath	+
19	Keirfield	+ (relatively modern from c.1600's)
	Linday	+
	Quean	6ii
	Cumbla	+
	Housnea	+
20	Skail	2
21	No adjacent farm	
22	Feaval	+
	Doehouse	(Founded by Sinclair Earls c.1550)
23	Laith	+
24	Grind	+
	Easter Voy	7
Harray Parish		
25	Corrigal	7
	Corston	3
	Kingshouse (Mydgarth)	4
	Garth	4
	Harfislea	NP
	Nessbreck	NP
	Midhouse	NP
	Nestaben	+
	Upper Bigging	+

TABLE 5:3 Cont'd

Deep Top Soil Unit No. (Ref Fig5:4)	Associated Place Names (After Marwick, 1952; 1970; Ordnance Survey 1:10000 Maps)	Marwicks Chronological Categories (See Text)
Harray Parish	Cont'd	
26	Cuppin	7
27	Garth	4
	Harray Lodge	NP
	Aldersyde	NP
	Lynnside	NP
28	East Garth	4
	Caperhouse	+
29	Bigging	+
	New Bigging	+
	Old North Bigging	+
	Nistaben	+
	Beboran	1
30	Netherbrough	7
	Ballarat House	NP
	Pow	+
	Biest	+
	Netherburn	NP
	Maesquoy	6ii
	Curcabreck	+
	Yeldavale	+
31	Ness	7
32	Hybreck	7
	Vola	+
	Nistaben	+
	Fursbreck	7
33	Kenwood	NP
	Northhouse	NP
34	No adjacent farm	
35	Winsetter	5
Evie Parish		
36	Midhouse	+
37	Feoloquoy	6ii
38	Dyke	+
Rendall Parish		
39	Lower Bigging	NP
	Hackland	4
Stronsay		
40	Whitehall (originally Strenzie)	7

3. Stadr (Old Norse : farm) Indicates a secondary settlement, either the result of a second wave of Norse migration, or expansion of the original settlement.

4. Land (Old Norse)
Gardar (Old Norse : A farm)
Bólstadr (Old Norse : A farm settlement)

These three elements seem to belong to the same phase of settlement arising well before the end of the 800s (Wainwright, 1962) but were secondary settlements.

5. Setr (Old Norse : dwelling place or homestead) These place names are younger than those above. Some arose before 900 A.D. but the majority arose after 900 A.D. These farms were peripheral to the primary settlements.

6. Kví (Old Norse : A cattle fold) These are comparatively late farmsteads, few of which are likely to have arisen before 900 A.D. as is evident from their peripheral location relative to the earlier farmsteads. Some of these quoy farmsteads were skatted (taxed) by the Norse taxation system and these skatted farmsteads represent early extension of the older settlements. Many quoy farmsteads are not however skatted suggesting that they only came into existence once the early tax system had become fossilised, probably in the 13th Century. These quoy farmsteads are thus younger than their skatted counterparts. In Table 5:3 skatted and unskatted quoys are labelled 6i and 6ii respectively.

7. Nature Names (eg Haughr - Old Norse : a mound; Strandir - Old Norse : beaches; Brekka - Old Norse : a slope)
This class of names is included in Table 5:3 as some names of this type may indicate original Norse settlements.

Although Sigmundsson (1984) would support much of Marwick's place name interpretations, some of its finer chronological detail has been criticised. Wainwright (1962) considers the farm name element Skali to indicate simply a detached building or shed with the name remaining in use till well after the 800s. Nicolaisen (1969) based his criticisms on the Norse place name distributions found in the Scottish Isles and Mainland Scotland. He views Stadr as the primary Norse settlement name, Setr as the name applied to farmsteads during the mid 800s consolidation and expansion period and Bólstadr applied when Norse power was at its most extensive. Fellows-Jensen (1984) considers Baer to be an unreliable indicator of settlement age and Bólstadr as being younger than the Stadr place name element. Here is not the place to discuss the merits of different scholarly view-points. Instead the point to be made is that farm names associated with the deep top soils cover the entire Norse settlement and consolidation period in Orkney (Table 5:3). Whether the deep top soil began to evolve at some point in time after this period has still to be discussed. For the moment what can be stated is that it was certainly possible for deep top soil formation to begin with the Norse colonization period of c 800 A.D.

The single radiocarbon age from the lower zone of the plaggen horizon beside Netherskail, probably one of the earliest Norse settlements, confirms the Norse age origins of this particular deep top soil. It does, however, yield a younger age than A.D. 800. (Table 5:4). Calibration of the b.p. age yields a date of c 1040 A.D. (Stuiver, 1982). Radiocarbon dates comparing different materials from the Langskail farm mound suggested that the soil/sediment material in this mound predated deposition by some 220 years (See Section 5:5:2). If this figure is applied to the deep top soils then the origin of the Netherskail deep top soil profile is late 12th or early 13th century, according to radiocarbon chronology. Stable carbon isotope analysis indicates that carbon from marine sources has not been introduced to this profile (See Section 8:3:1). Thus the calibrated and adjusted radiocarbon age of the Netherskail deep top soil can be considered to represent the commencement of deep top soil formation at this location.

The discussion so far may be summarised by stating that radiocarbon dating of the Netherskail deep top soil points to this soil's origins in late Norse period. This is despite the archaeological and etymological evidence which suggests that it was possible for deep top soil formation to begin as early as A.D. 800, with the

TABLE 5:4

RADIOCARBON DATES AND $\delta^{13}C$ VALUES FROM THE NETHERSKAIL DEEP TOP SOIL PROFILE, ORKNEY

(See Appendix III)

RADIOCARBON DATES

Depth (cm)	Uncalibrated ^{14}C Age (b.p.)	Calibrated Age (AD) (After Stuiver, 1982)
25	437 ± 52	1440
65 - 70	928 ± 53	1040

^{13}C VALUES

Depth (cm)	$\delta^{13}C$‰ (Relative to PDB Standard)
20	- 28.6
40	- 28.6
60	- 28.7
80	- 27.6

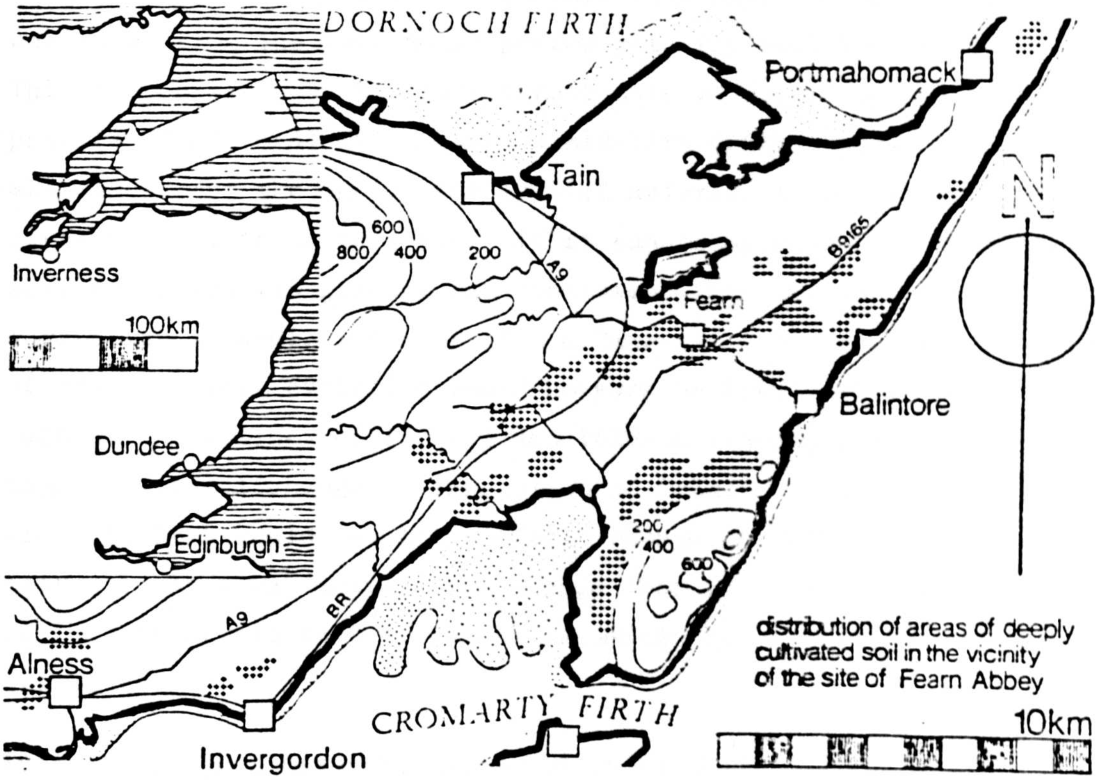
initial phase of Norse settlement in Orkney. There is therefore a gap of some 400 years between the potential for plaggen manuring and the actual commencement of plaggen manuring. Thus it is necessary to identify what factor or factors triggered the onset of deep top soil formation in the late 12th or early 13th Centuries; what factors shifted the potential for plaggen manuring of arable land into actual plaggen manuring.

One factor of potential importance was a rapidly increasing population from the 1100s to the early 1300s. An earlier phase of population expansion, during the 9th Century, resulted in some of the early Norse settlers moving on to Iceland, Faroe, England and Normandy (Fellows-Jensen, 1984). The response to the 1100-1300's period of population expansion was to increase arable productivity, achieved partly by increasing the arable acreage. Reclamation of hill land peripheral to earlier settlements permitted the establishment of new farmsteads and many of the Quoy and Setr named farms are considered to have their origins at this time. There was also expansion of arable land closed to the primary settlements. An area of arable land known as the Townsland, held communally, came into being during the late Norse period of population expansion (Thomson, unpublished manuscript). Whether late Norse farmers were experimenting out of necessity with new methods of maintaining and increasing soil fertility by making use of the resources at hand cannot now be ascertained. It is certainly possible that plaggen manuring was a spontaneous development in response to population pressure and in view of the long tradition of Orcadian arable activity. It is also possible that with increasing population new means of getting rid of the increasing amount of byre wastes was required.

An alternative to the spontaneous development theory relates to the founding of the monastry at Birsay. Earl Thorfinn, having received absolution from the Pope in Rome, decided to build a minster at Birsay during the late 1000s and early 1100s, the period immediately prior to the commencement of deep top soil formation (Orkneyinga Saga : 31; Lamb, 1983). Monastic communities in Scotland of many different orders have been considered as major modifiers of the landscape and innovators of agricultural development (Coulton, 1933). Gilbert (1983) and Romans and Robertson (1975) identify the role of the Borders monastries in changing waste land into arable land and good grazing land. Barber's (1981) hypothesis that improved techniques of agriculture were introduced to the north-west Atlantic seaboard via the early Christian church has already been presented. Information of more significance to this thesis comes from Mr J C C Romans who, while carrying out the soil survey of Easter Ross identified introduced man-made deep top soils up to 79cm thick (Romans pers comm). These top soils are all in the vicinity of Fearn Abbey but cover a large extent of Easter Ross (Figure 5:5), on a similar scale to the deep top soils of Orkney. Romans considers deep top soils to have commenced formation during the monastic period and argues that such soils are also found at Insch, Aberdeenshire (Glentworth, 1944) and also, possibly, in Strathmore. Elsewhere in northern Europe, large monastry-farm complexes have been identified in Greenland and Iceland (Gad, 1970) although the farm may pre-date the monastry. It should also be noted that throughout Europe during the medieval period it was the monastic communities which were innovators of specialized agricultural techniques as a result of their rules of handiwork and agricultural endeavour (Wilkinson, 1980). In Orkney during the late Norse population expansion, any efficient means of maintaining soil fertility and reclaiming arable land would have been quickly accepted, particularly in an integrated society under the authority of earls and local nobles (Cant, 1984). There is therefore considerable support for the monastic community at Birsay having introduced the technique of plaggen manuring to the Orcadian agriculturist.

While it is possible to identify with reasonable accuracy the period when deep top soils began to form, it has not proved possible to identify the precise causes of innovation. An increase in population with the accompanying need to increase agricultural output meant that the technique of plaggen manuring was probably quickly accepted. Whether the technique was a spontaneous innovation by the local populace or introduced by the monastic community at Birsay cannot be ascertained. It is possible to develop these hypotheses further; for example, the inventiveness and independence of the Orcadian and the monastic connection of Birsay with Hamburg and Bremmen,

Figure 5:5 The distribution of soils in the neighbourhood of Fearn Abbey (after Barber, 1981).



The distribution of introduced soils in the neighbourhood of Fearn Abbey (with kind permission of J C C Romans) which are towns located in areas of north-west European plaggen soils. There is, however, no conclusive proof one way or the other. Both hypotheses are therefore presented as possible causes of deep top soil innovation in Orkney.

5:4:6 Evidence from the Post Norse Settlement to the Agricultural Improvements

By the 12th century Norse settlement patterns and practices were well established. These would remain much the same until the agricultural improvements and enclosures which began in the mid-19th Century. It is likely therefore that deep top soil formation continued from the late Norse period into the Medieval period. This is confirmed by the radiocarbon date at 25cm from the Netherskail profile (Table 5:4) which gives a mid-15th Century age. Making allowances for the age of the applied material (c 220 years), it gives a mid-17th Century age. If it can be assumed that deep top soil evolution was gradual and consistent, then the radiocarbon ages suggest an accumulation rate of c 0.9mm/year. Short term cessation of deep top soil evolution would however be likely with events such as the famines of 1339-41 and 1628-36 (Thomson, 1978). The major political change of annexation of Orkney to the Scottish crown in 1472 would result in little change in agricultural methods. This was despite the change from a free-holding system of land tenure to that of feudalism which this historical event initiated.

That the plaggen manuring system of sustaining soil fertility levels was utilised in 18th and 19th century Orkney is clear from the historical literature. Educated ministers resident on the islands and early travellers wrote of seaweed, turf, ash, manure, marl, sillocks (young coalfish) and soot being applied to the arable land. Of these materials seaweed was of major importance in the sustaining of soil fertility levels in the arable land (Brand, 1701; Barry, 1805; Forsyth, 1805; Old Statistical Account, 1791-1799). However seaweed was frequently only part of a broader system of land fertilization (Pococke, 1747-1760; Old Statistical Account, 1791-1799; Pringle, 1874; Fenton, 1978). Turf pared over several acres of the common land was the first part of this system, being used as a fuel source thus generating ash or else used in the byre as animal bedding where it was impregnated with dung. Composting of byre material, earth, manure and seaweed prior to the spreading of this mixture of materials on the arable land was normally practised. Spatial variability in manuring practice probably existed over Orkney as is hinted at in Table 5:5. Certainly, inland districts lacking seaweed put a greater emphasis on turf. Here then is direct evidence for plaggen manure forming an integral part of the medieval agricultural system in Orkney.

By the 1870s however a new system of agriculture had arrived. Hill land reclamation, drainage, new cultivars and new fertilizers were all introduced to Orkney with the "new" agriculture. Peruvian guano, lime and town dung from Stromness were increasingly used to fertilize the land as the early system of agriculture with its soil fertilizers based on the indigenous resources of the township, broke down (Fenton, 1978). These observations accord well with those of Ireland and north-west Europe where the cessation of plaggen soil formation is related to the introduction of new methods of soil fertilization by way of chemicals in the 19th Century (Conry, 1974). Plaggen manuring of soils in Orkney is considered therefore to have ceased in the mid-19th Century. Extrapolation of calibrated and adjusted radiocarbon dates would indicate that plaggen accumulation at Netherskail ceased c 1870 A.D. (Table 5:4).

5:3:7 Conclusions : The Initiation and Cessation of Deep Top Soil Formation

All evidence points to the initiation of deep top soils during the Norse period of Orkney's cultural history. Archaeological, historical and etymological evidence indicates that although arable activity and manuring had been practised since the Neolithic period, it was only with Norse colonization that appropriate conditions were introduced to make plaggen manuring a possibility. The implications of Norse colonization relative to plaggen manuring were an increased population density with accompanying intensified arable activity

TABLE 5:5

MAJOR MATERIALS APPLIED TO ARABLE SOILS IN THE PARISHES OF ORKNEY WHICH HAVE DEEP TOP SOILS

(Based on the Old Statistical Account 1791-1799)

PARISH	MATERIALS APPLIED TO THE SOIL
Birsay	Seaweed; House dung
Harray	Marl
Sandwick	Earth; manure; seaweed; marl.
Evie	Seaweed.
Rendall	Earth; dung

and the introduction of the byre. The byre meant it was possible to overwinter cattle indoors and there is some archaeological evidence to suggest that turf sods were used as bedding. Accumulated byre waste could then be later applied to the arable land as a fertilizer.

Although the potential for plaggen manuring had been present in Orkney since the earliest phase of Norse colonization, radiocarbon dating of the deep top soil at Netherskail indicates a later date of origin. Allowing for the age of the material deposited, it is suggested by the radiocarbon dated profile that deep top soil formation began in the late 12th or early 13th centuries. This implies a gap of some 400 years between the commencement of plaggen manure generation in byres and its actual use as a soil fertilizer. The main stimulus to the use of plaggen manure as a soil fertilizer, and hence the initiation of the deep top soil formation, was the increasing population over the 12th and 13th Centuries. This resulted in an increase in the arable acreage and, it is suggested, the use of plaggen manure to maintain soil fertility in intensely cultivated fields. The innovators of plaggen manuring still remain uncertain. One possiblity is that it was a spontaneous innovation by the local populace in response to the need for increased agricultural productivity. Alternatively there is evidence to suggest that the process of plaggen manuring was introduced to Orkney via the monastic community at Birsay. If one were forced to give a verdict, more support might be given to the latter hypothesis. This is because earlier in the Norse period, during the 9th Century, an increasing population in Orkney resulted in migration. The later population increase of the 12th and 13th Centuries was met by agricultural intensification and organisation of the land by the formation of the township. This suggests some degree of integrated social organisation which included an overlying authority of earls and local nobles. Within this integrated society the monastic community at Birsay would have played an important part, not least in the area of agricultural improvements including the use of plaggen manuring.

Factors causing the cessation of deep top soil formation are more easily identified. It is estimated that deep top soils continued to develop for some 750 years until the agricultural improvements of the 19th Century introduced new types of soil fertilizer. With these new fertilizers the less convenient plaggen manure fell out of favour and ceased to be applied to the arable land. Radiocarbon dating of the Netherskail deep top soil profile suggests that deep top soil formation in Orkney ceased c 1870 A.D.

5:4 Identifying Relationships between Orcadian Cultural Groups and Farm Mounds

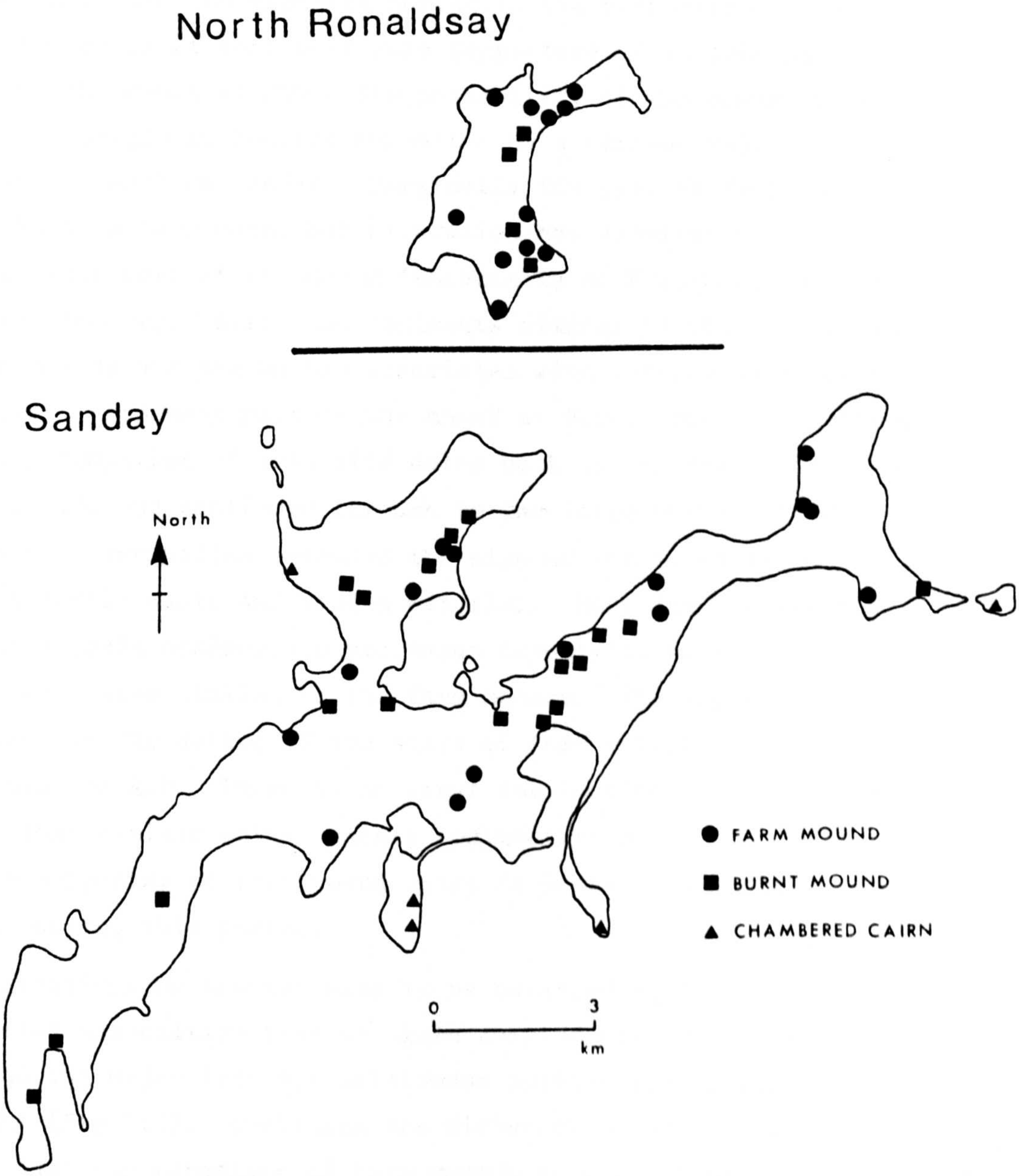
The range of procedures available for identifying the origins of the Orcadian farm mounds is restricted to a consideration of farm mound/early settlement pattern relationships and radiocarbon dating. Consequently discussion of farm mound origins is more limited than for that of the deep top soils. Piecing together the few fragments of evidence that are available does however allow some general conclusions to be advanced for farm mound origins.

5:4:1 Archaeological, Historical and Etymological Evidence

Farm mounds are a class of archaeological monuments independent of the known Neolithic and Bronze Age settlement pattern. Figure 5:6 demonstrates the lack of spatial association between farm mounds and chambered cairns of the Neolithic period. While farm mounds are found widespread throughout Sanday and North Ronaldsay, chambered cairns are few in number and restricted to the remote nesses and headlands of Sanday. It seems unlikely therefore that Neolithic society in Orkney was responsible for the major anthropogenic sedimentary processes that resulted in farm mound formation. Such a conclusion is parallel to that reached for the Bronze Age period. Of the 18 known burnt mounds on Sanday and 4 on North Ronaldsay, only 4 can be said to be associated with farm mounds (Fig 5:6). By contrast to the above there is some indication that farm mound formation may have commenced in the Iron Age and so discussion of farm mound origin properly begins with the Iron Age.

Like some farm mounds in north Norway there is some indication that the Orcadian examples may in some cases be Iron Age in origin (Holm - Olsen pers comm).The evidence is however vague and difficult

Figure 5:6 The distribution of farm mounds, Neolithic monuments and Bronze Age burnt mounds on Sanday and North Ronaldsay.

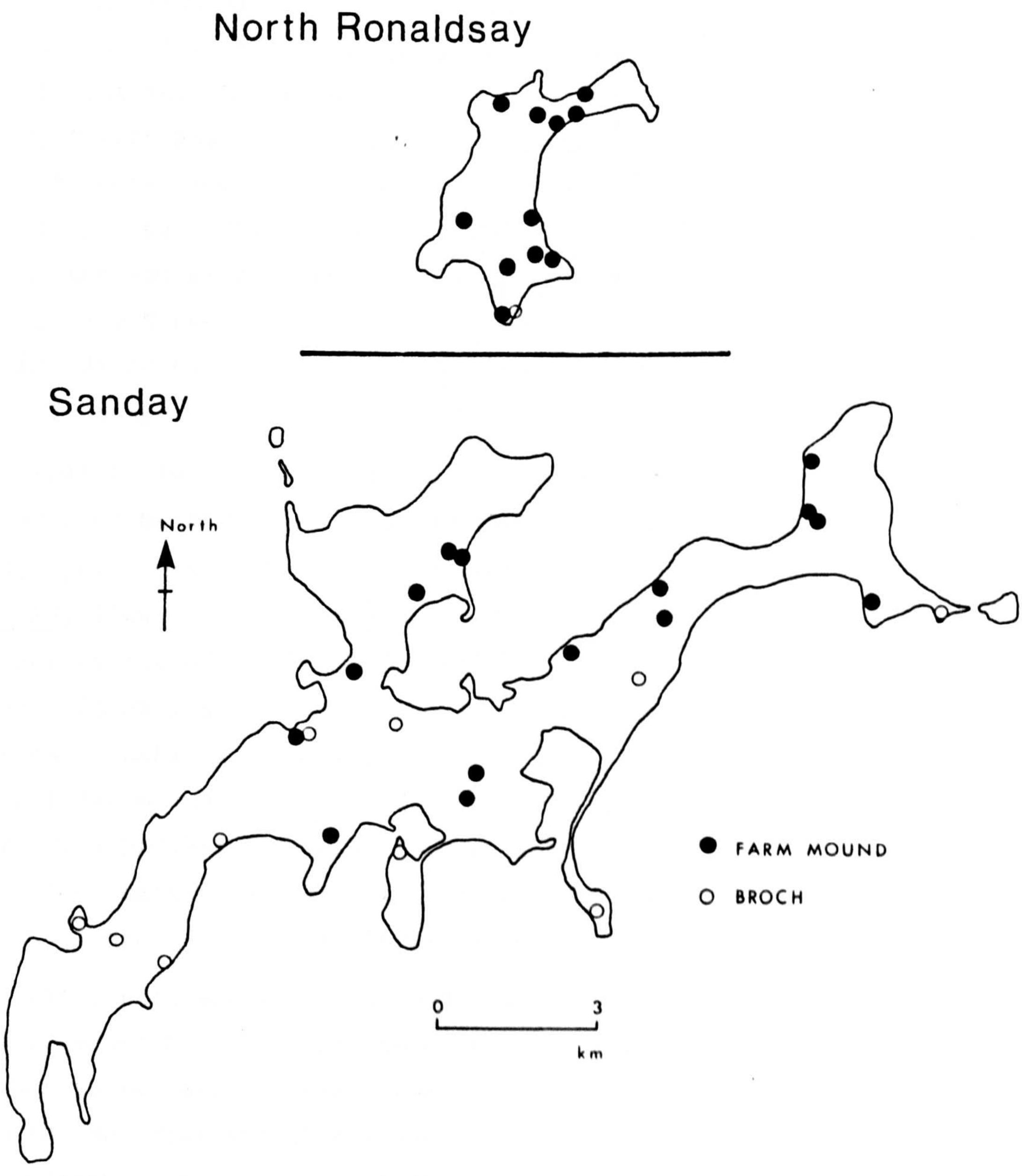


to substantiate but is presented here as an indicator to keep the possibility of an Iron Age origin open. A so-called "broch and picts house" along with a silver ring and bone weaving combs are indicative of the Iron Age origins of the mound at How (HY 6606 3927; reported by R.C.A.M.S.(1980). Unfortunately there is no record of stratigraphic relationship between this "broch" and the farm mound. It also must be noted that the Iron Age artefacts could simply represent heirlooms passed through the generations, or they could have been lost and subsequently buried in the farm mound. The above evidence is at very best only suggestive of an Iron Age origin for the mound at How. The possibility of the mounds being Iron Age in origin is however supported by a current major excavation at Pool on Sanday. Originally the site at Pool was thought to be a farm mound but excavation has revealed that buildings form the major part of the mound (University of Bradford, Interim Excavation Report). Soils and sediments similar to those found in the farm mounds and presumably associated with settlement activity constitute a component part of the mound at Pool. Based on pottery sequences, occupation of this site dates back to the first few centuries A.D. and continued through to the later Norse period. Each phase of occupation extended the size of the mound through dumping domestic waste and midden material. Here then is evidence for anthropogenic sedimentary processes associated with settlement activity at a site similar to the farm mounds. The significant observation is the dating of the start of this activity to the early centuries A.D. There is no great imaginative leap required to argue that similar anthropogenic sedimentary processes could have been happening at farm mound sites on Sanday and North Ronaldsay during this period.

Such observations do however have to be balanced against the poor spatial association that is again evident between the farm mounds and the major Iron Age settlement pattern manifested by the brochs (Fig 5:7). Combining the different strands of evidence suggests that the formation of farm mounds as a group was gradual, possibly over several centuries, with the first mounds of the group beginning to evolve during the A.D. Iron Age period.

Further support for an early A.D. commencement of some farm mounds

Figure 5:7 The distribution of farm mounds and Iron Age Brochs on Sanday and North Ronaldsay.



comes from etymological evidence. Much of the discussion pertinent to the use of place names as chronological indicators has already been advanced in an earlier section (Section 5:3:5) to which reference should be made. Lamb considers some six of the farm mound place names on Sanday and three on North Ronaldsay to be important indicators of farm mound age (Table 5:6; Fig 5:8; see in Davidson et al 1983). With the exception of Tofts these names are "nature-names" which may be placed in class 7 of Marwick's categories (Marwick, 1952; Table 5:3). It is worth reiterating Marwick's postulation that while some nature-names may indicate original Norse settlements they do not provide any basis for chronological placing. Here though it would seem significant that Norse names such as "mound", "slope", "rocky emminance", "hill" and "broad shield" were applied to farm mounds which are of course mounds, slopes, etc, in the Sanday and North Ronaldsay landscape. The implication therefore is that the farm mounds were already in existence during the 9th and 10th Centuries when the primary Norse place names were applied. This would place the farm mounds as having commenced certainly in the Pictish period, if not the Iron Age.

It is possible to take issue with this interpretation of events as has been done by Norwegian scholar Dr P Andersen of Oslo University (pers comm). He would contend that Old Norse, Fjallr (in Bea<u>field</u>) always means mountain not hill or mound implying a misinterpretation of the "field" element of the place name. Old Norse Klettr (Cleat) means rockly knoll, while Old Norse Haugr (How) and Old Norse Brekka (Stenna<u>breck</u> etc) could be so named because of a nearby natural mound or slope. Thus place name evidence, whilst suggestive of a pre-Norse origin for the farm mounds is not conclusive. The other place names associated with farm mounds do little else than suggest their Norse Age (Table 5:6).

There is little evidence from documented sources to suggest when farm mounds ceased forming but there is some indication that this occurred before the agricultural changes of the mid-1800s. The writer in the New Statistical Account of 1845 for the parish of Cross and Burness, Sanday, records the occurrence of the mounds and states that they are the result of the accumulation of farm manure over many years "during times when people were too indolent

TABLE 5:6

PLACE NAMES ASSOCIATED WITH FARM MOUNDS

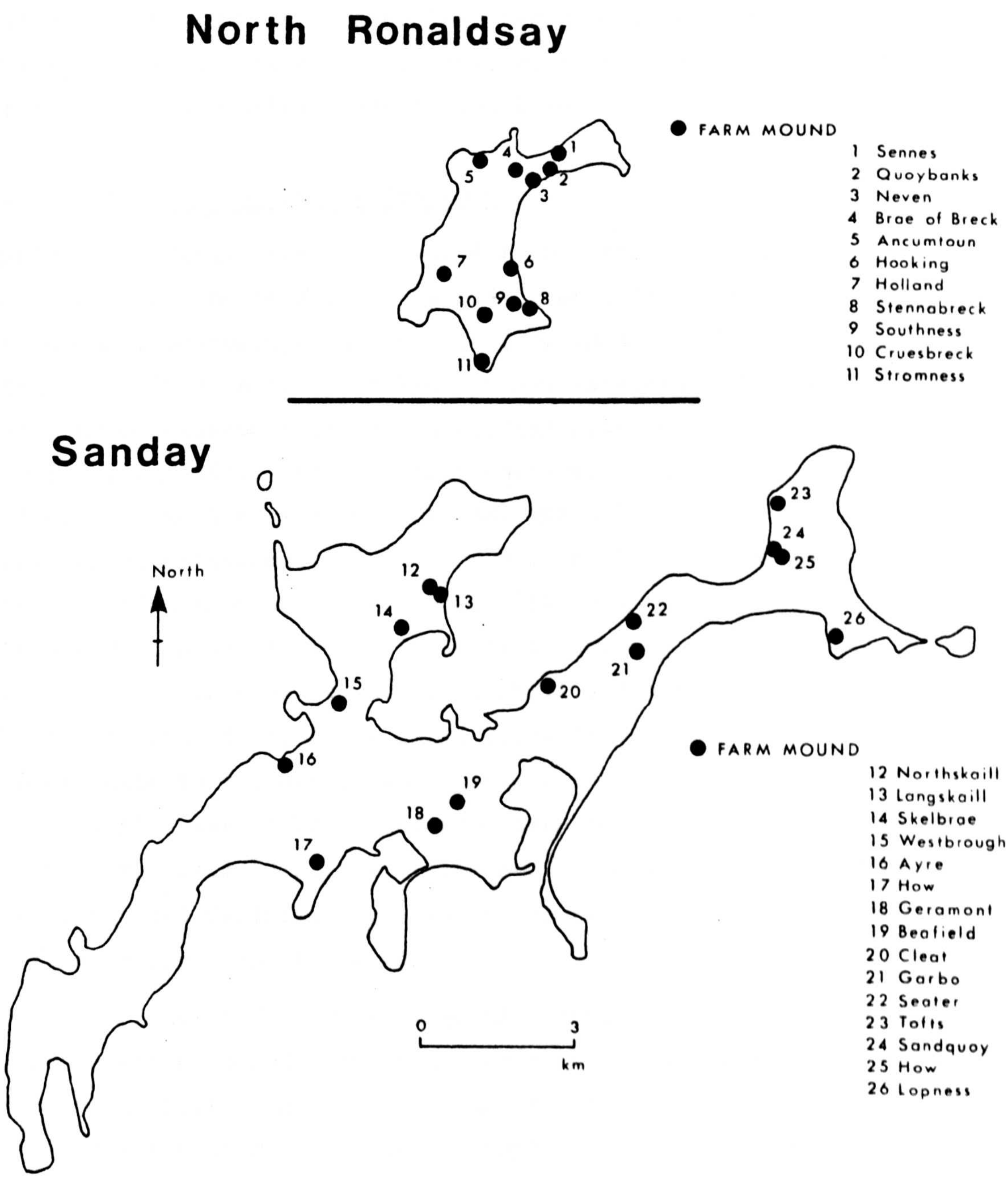
(i) Those considered by Lamb (pers comm) to be indicative of pre-Norse origins.

Present-day Name	Proposed Old Norse Name	Translation
Sanday		
How	Haugr	Mound
How	Haugr	Mound
Cleat	Klettr	Rock; Rocky Emminence
Beafield	Baejar-Fjallr	Hill of the 'Baer'
Skelbrae	Skjaldbreir	Broad Shield
Tofts	Topt	House site
North Ronaldsay		
Brae of Breck	Brekka	Slope
Stennabreck	-Brekka	Slope
Cruesbreck	-Brekka	Slope

(ii) Other farm mound place names (after Marwick 1952)

Name	Language of Origin	Translation
Sanday		
Ayre	Old Norse	Hill
Lopness	" "	Outleaping Hill
Langskail	" "	Long Hall
Northskail	-- Not mentioned --	
Sandquoy	Old Norse	'Quoy' of sand farm
Seater	" "	A homestead
Westbrough	" "	A fortress
Geramont	" "	Personal name
Garbo	-- Unknown -	
North Ronaldsay		
Ancumtoun	Old Norse	Meadow
Hooking	" "	Burn-Mill
Neven	-- Not mentioned --	
Quoybanks	-- Not mentioned --	
Strømness	-- Not mentioned --	
Sennes	Old Norse	Ness (headland) of seals.
Southness	" "	A headland
Hollandstoun	" "	High land

Figure 5:8 Farm mound distribution and names on Sanday and North Ronaldsay.



or too prejudice to apply it to the soil". The past tense of this statement implies that farm mound formation had ceased by the time of writing. At what precise time farm mound formation ceased must however remain speculative based on such evidence.

There is need for a tighter chronology to identify the initiation and cessation of farm mound formation than is provided by archaeological, historical and etymological evidence. In an effort to obtain such a chronology recourse is made to radiocarbon dating. With a better defined chronology more accurate statements about farm mound origins may be possible.

5:4:2 Radiocarbon Dating Evidence

Radiocarbon dates were available for four farm mounds, three on Sanday and one on North Ronaldsay (Table 5:7). Of these four, two mounds, Westbrough and Skelbrae, yield dates when corrected (Stuiver, 1982) in the post 7th century category. Two radiocarbon dates were obtained from the underlying peat of the Westbrough profile (Fig 5:9). The resultant uncorrected age values were as follows:- SRR 2349 - 1330 $\pm$60bp and SRR 2350 - 1360 $\pm$50bp. One radiocarbon measurement for clayey soil at the base of the Skelbrae mound yielded a date of 1360 $\pm$80bp (SRR 2351) (Fig 5:10). As already discussed at length in Section 5:2:2 it is impossible to assign an absolute age to archaeological sediments of this nature. Notwithstanding this, it is still possible to assign a post 7th century date to the particular point in the profiles from where these samples were taken. Because there is still some mound material below these dated samples it seems most likely that the mounds at Westbrough and Skelbrae began to evolve either during the late Pictish or early Norse period.

Radiocarbon dates from Westbrough also serve to widen the perspective on processes of mound formation. Sedimentary material above the dated peat in the Westbrough profile consists of tip-like lenses similar to those outlined at Pool. This is suggestive of a relatively slow but persistent accumulation. The radiocarbon dates, although separated by c 0.5m of peat, are identical within the analytical confidence limits. This suggests a virtually instantaneous accumulation period in contrast to the possibly slower accumulation above.

TABLE 5:7

RADIOCARBON DATES FROM FARM MOUNDS ON ORKNEY

Profile No	Depth (cm)	Material Dated	^{14}C Age bp	Corrected Date (A.D.) (After Stuiver 1982)
Southness, North Ronaldsay				
1	30	Soil/sediment	560 ± 60	1410
1	38	Soil/sediment	390 ± 50	1460
1	38	Shell	870 ± 150	1180
1	61	Soil/sediment	480 ± 60	1430
1	61	Shell	510 ± 60	1420
3	15	Soil/sediment	490 ± 50	1430
3	67	Shell	740 ± 70	1280
3	140	Soil/sediment	1000 ± 60	1010
Langskail, Sanday				
1	165	Soil/sediment	820 ± 80	1220
1	265	Soil/sediment	910 ± 50	1050
1	265	Shell	1060 ± 60	995
1	325	Soil/sediment	1010 ± 70	1010
1	325	Shell	1110 ± 60	910
1	325	Charcoal	1190 ± 90	840
1	405	Shell	1170 ± 50	880
Westbrough, Sanday				
1	150	Peat	1330 ± 60	670
1	200	Peat	1360 ± 50	660
Skelbrae, Sanday				
1	190	Soil/sediment	1360 ± 50	670

Figure 5:9 Location of radiocarbon dated samples from the Westbrough farm mound profile.

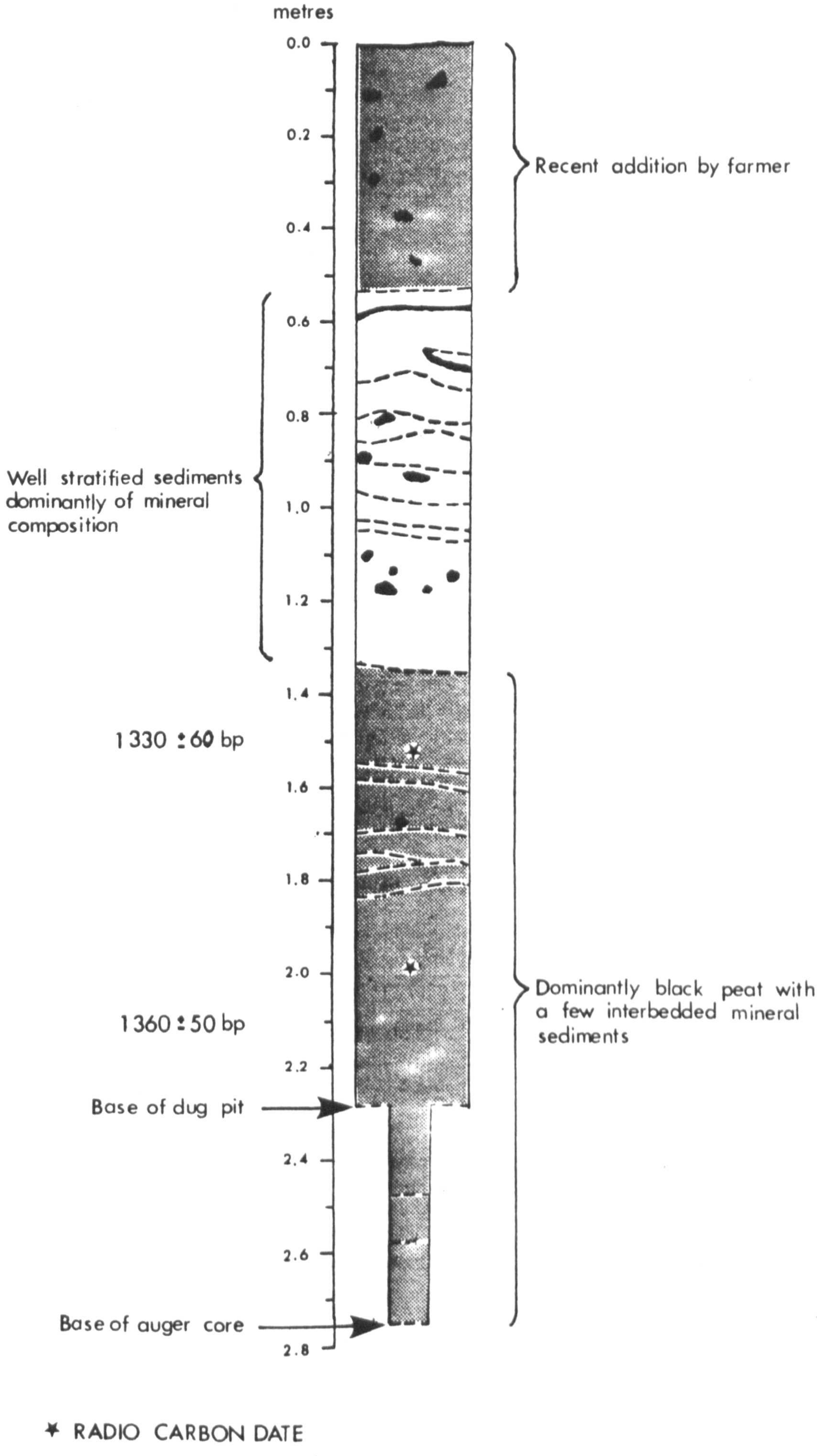
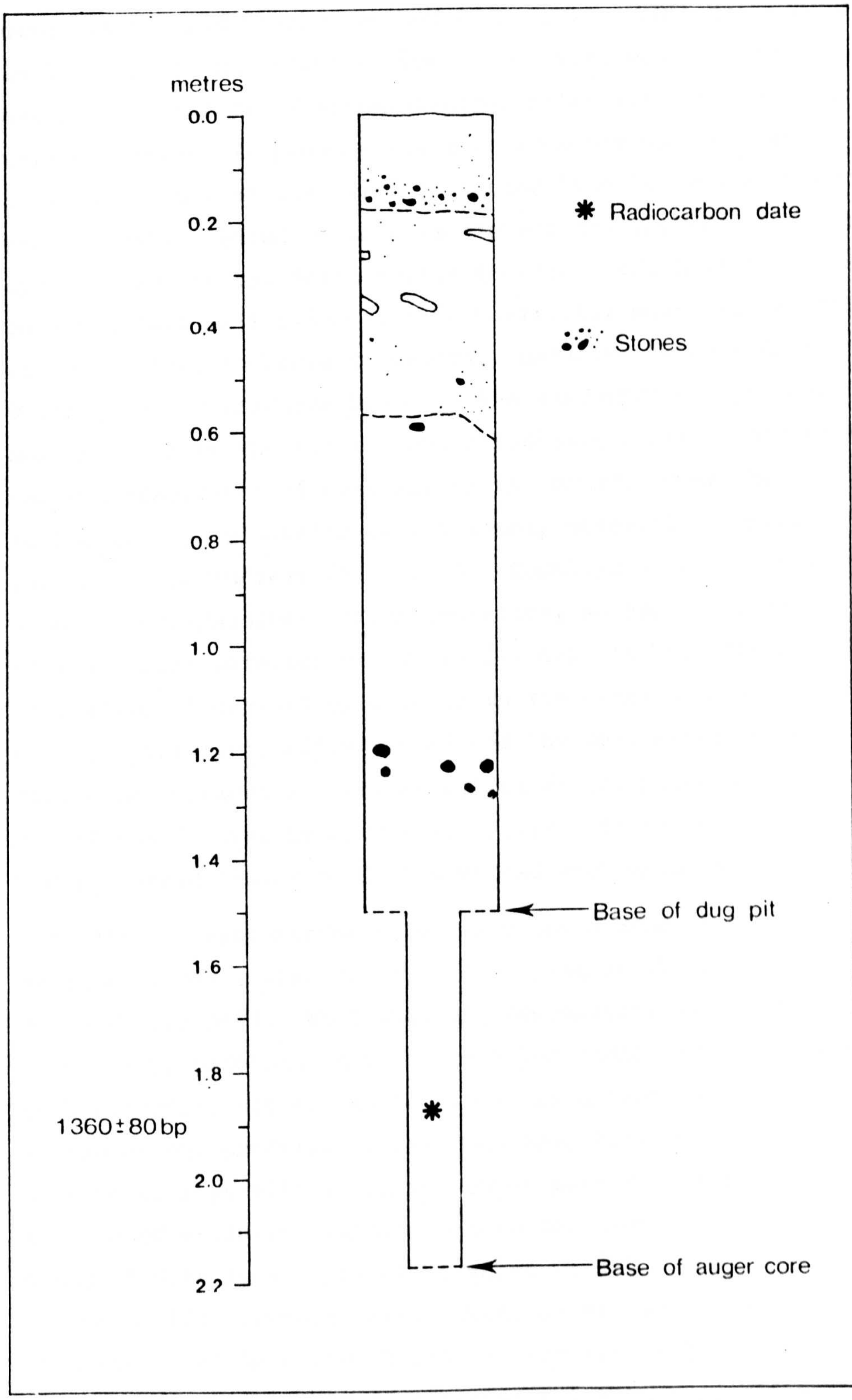


Figure 5:10 Location of the radiocarbon dated sample from the Skelbrae farm mound profile.



The Langskail farm mound provided the best sequence of radiocarbon dates from a farm mound. Three different types of material from the Langskail profile, shell, charcoal and soil/sediment, were dated by the radiocarbon method (Fig 5:11). This provided some indication of the uncertainties associated with the radiocarbon age interpretation of archaeological materials. Marine shells were considered to provide the most accurate age evaluation if it is assumed that they were collected live for use as food or fishing bait. Based on this assumption and applying a 400 year apparent age to the dated shells (Section 5:2:2), it is possible to state that initiation of this particular mound was in the early to mid-13th Century, several centuries later than the Westbrough and Skelbrae mounds. The age/depth relationship demonstrated by the shell samples indicate a steady and relatively rapid accumulation of material in the mound. Over the 200 years following the initiation of the mound, material accmmulated at a rate of c 1.09cm/year (Fig 5:12). Comparison of the shell dates with the soil/sediment dates indicates, as expected, that the soil/sediment material pre-dated its deposition. The over-estimation of deposition date is in the order of some 220 years. Charcoal material, often considered the best material for radio-carbon measurement in archaeological sites, predated its depositional layer by around 475 years. It is probable that bog preserved timber or driftwood had been used as a fuel source.

The suite of radiocarbon dates from the Southness farm mound, North Ronaldsay, were not as encouraging as these from the Langskail mound (Table 5:7). What they did demonstrate were some of the theoretical problems in interpretating radiocarbon ages from archaeological sites. Radiocarbon age determinations were made in two of the profiles of the Southness farm mound (Fig 5:13). Results from profile 1, in the upper part of the mound, suggest that mound evolution continued into the medieval period. The youngest date in the profile 1 suite is 390 $\pm$ 50bp giving a corrected 15th Century date. Other dates in this profile indicate that there has been some degree of profile disturbance. The age/depth profile yields no discernable relationship; if anything there is some degree of reversal (Fig 5:14). These results do not however

Figure 5:11 Location of radiocarbon dated samples from the Langskaill farm mound.

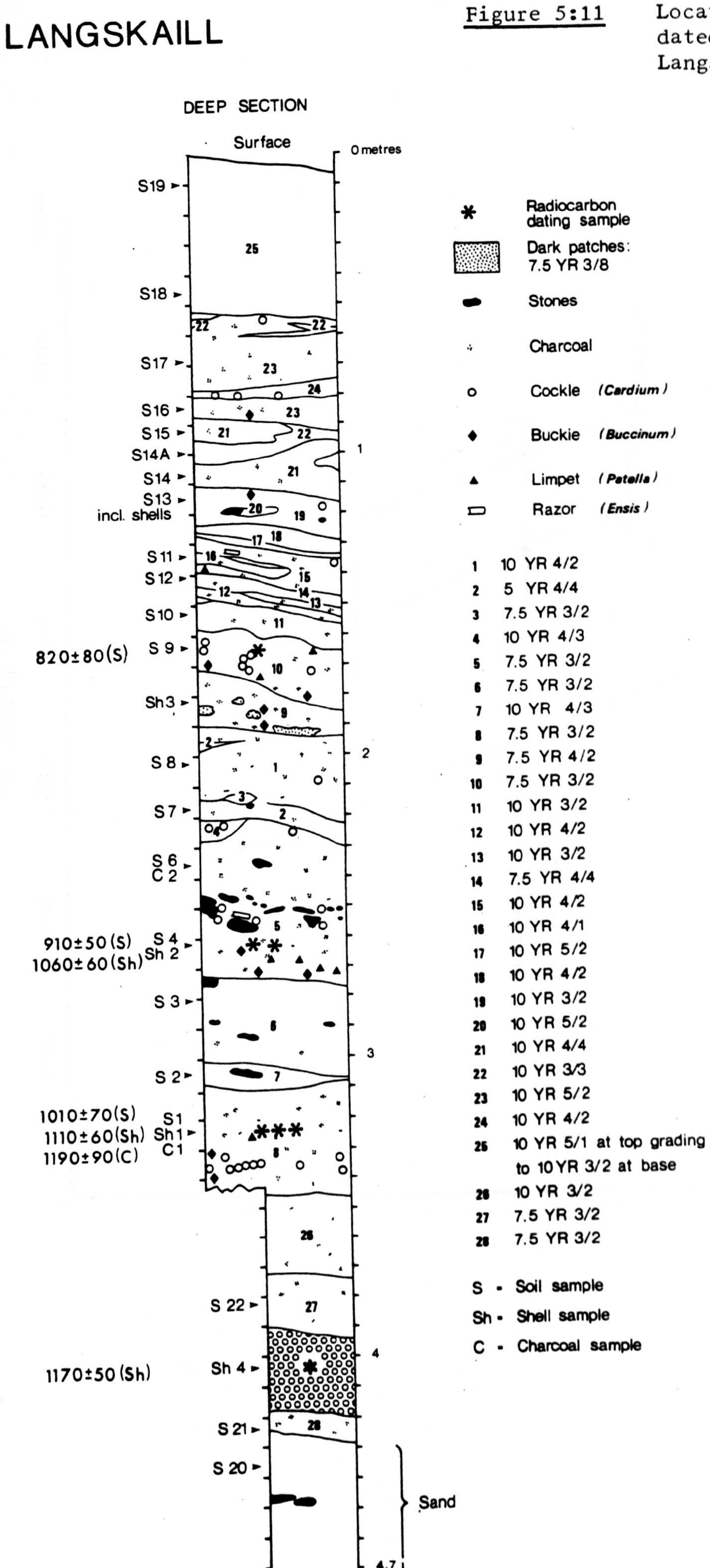


Figure 5:12 Radiocarbon age/depth relationships in the Langskaill farm mound.

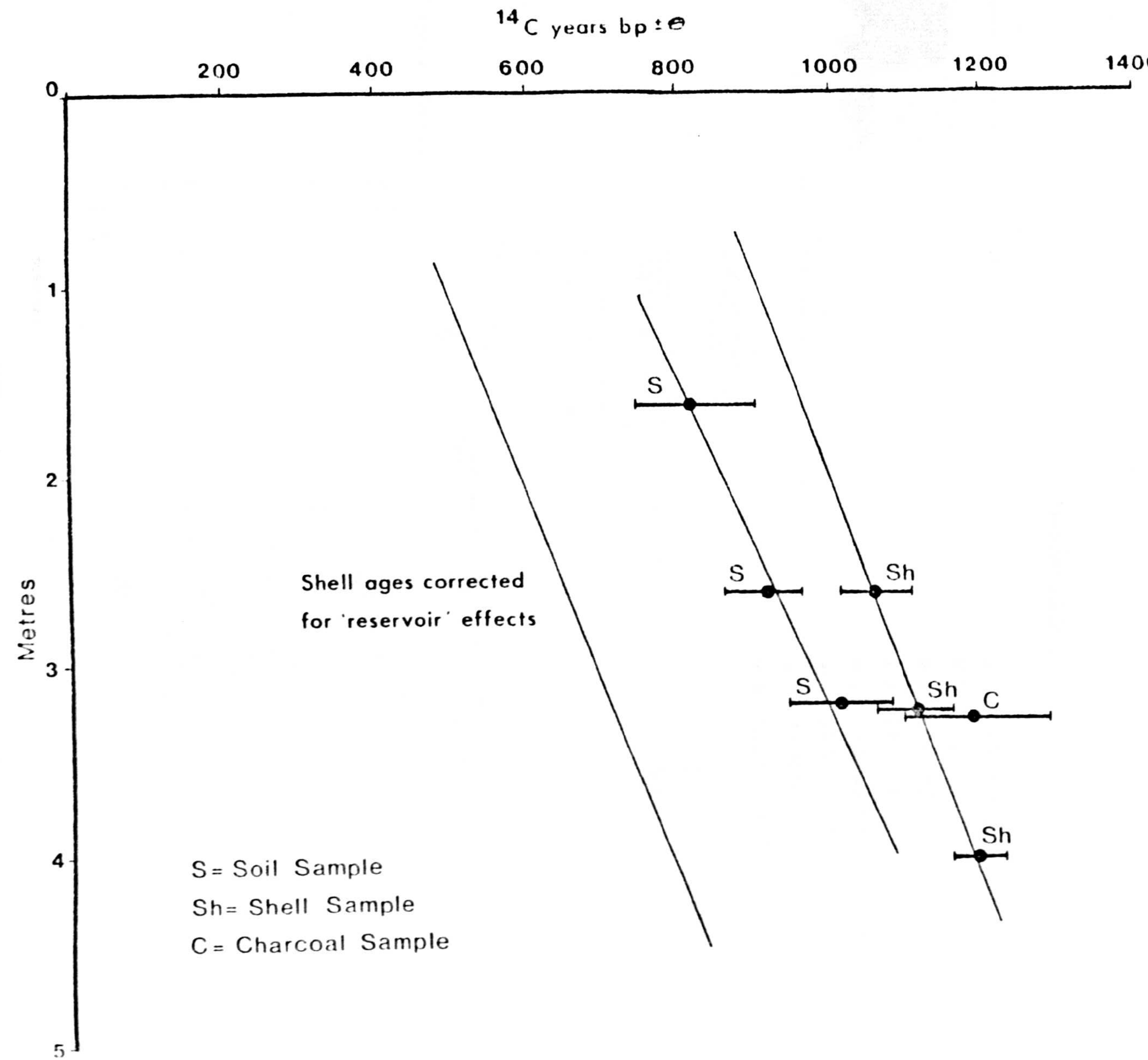


Figure 5:13 Location of radiocarbon dated samples from Southness farm mound profiles.

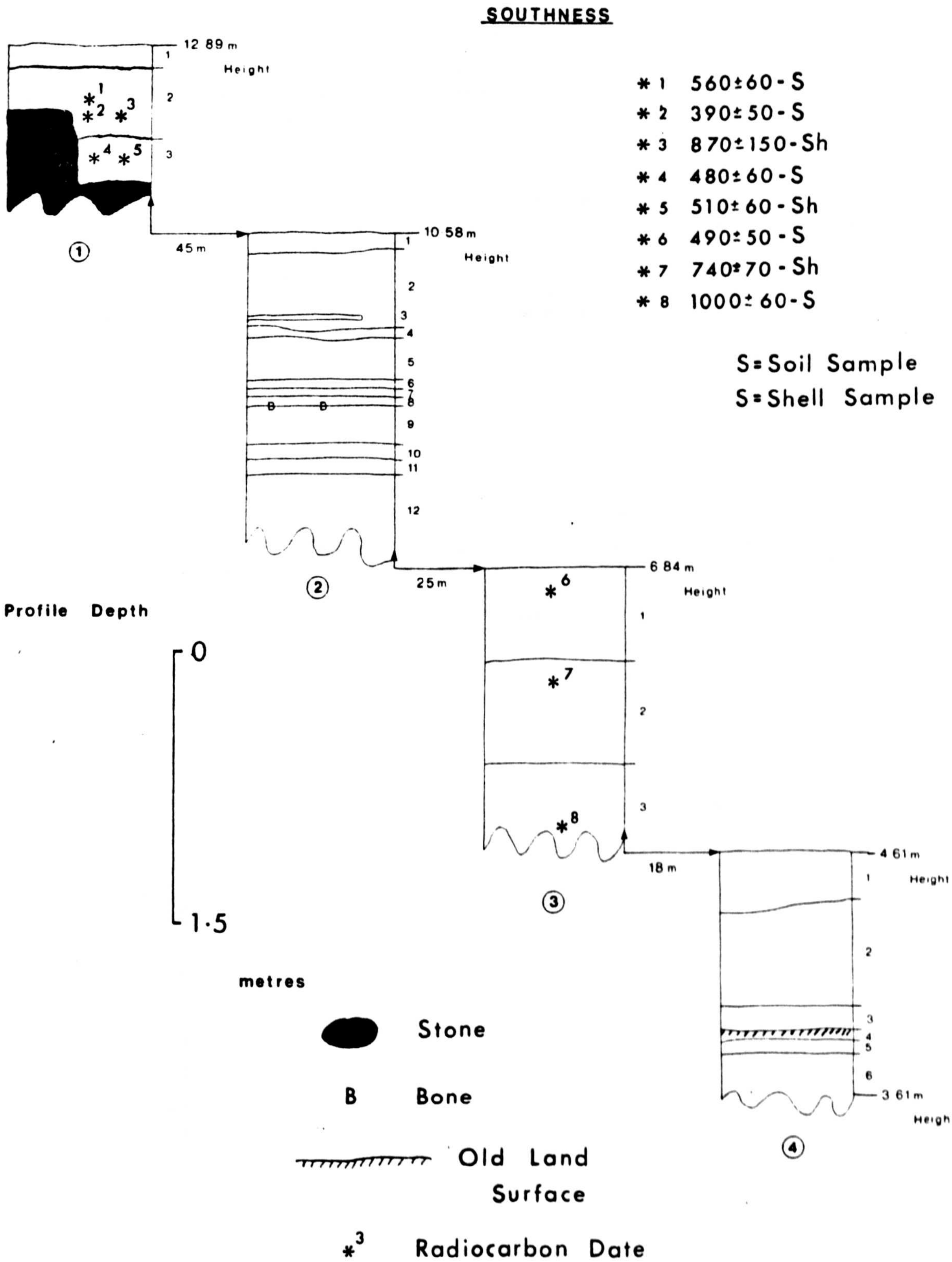
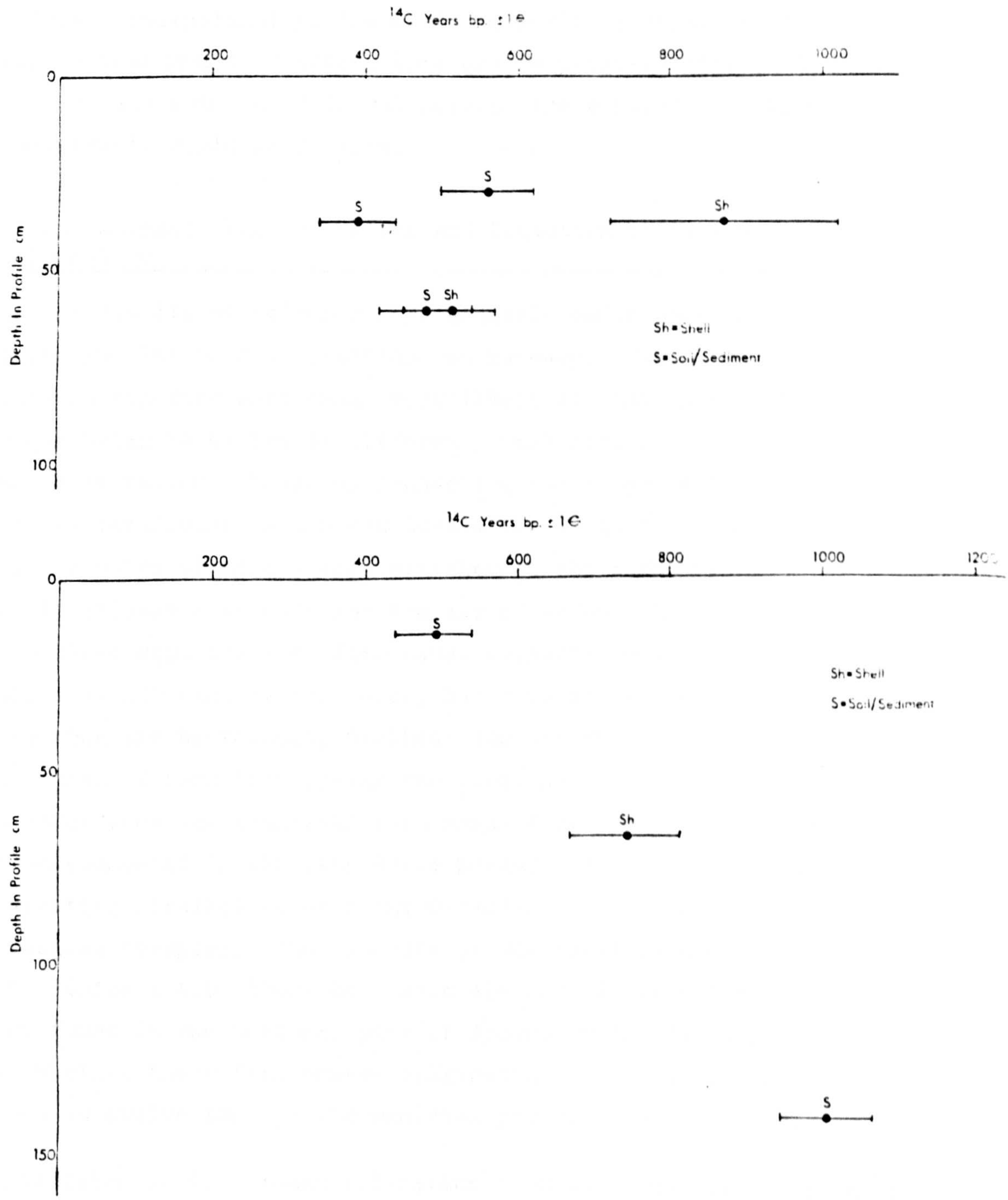


Figure 5:14 Radiocarbon age/depth relationships at Southness.



take away from the fact that this mound was still evolving during the Medieval period. Profile 3 yielded a reasonable age/ depth gradient from the early Medieval period at 15cm depth back to the mid-Norse period (Fig 5:14). Given the slope position of this profile on the mound,it is possible that older material has slumped down the slope giving an older radiocarbon age for anthropogenic deposition at this part of the mound than is actually the case. This notwithstanding, the dates from this profile serve to demonstrate that mound evolution here was in progress through the Norse period and into the Medieval period from a point of origin that conceivably could be Pictish.

5:4:3 Conclusions: The Initiation and Cessation of Farm Mound Formation

Despite the paucity of evidence some general conclusions about farm mound initiation and cessation can be made. Taking all observations together what seems most likely is that individual farm mound began to evolve at different times over at least a thousand year period. Based on archaeological evidence the earliest indication of farm mound initiation is in the Iron Age. Later dates of origin are furnished by the radiocarbon dates. If allowance is made for the age of organic materials prior to their deposition as farm mound formation material (estimated as 220 radiocarbon years, based on the Langskail profile) then the Westbrough, Skelbrae and Southness farm mounds commenced formation during the early Norse period. Radiocarbon dates from the Langskail farm mound suggests that here formation commenced in the late Norse period. There is perhaps an interesting parallel between the Orcadian farm mounds and the Norwegian examples. The majority of Norwegian farm mounds began to evolve c A.D. 1300s but there are certain Iron Age examples found in the northern part of Andoya (Holm-Olsen, pers comm). Whether those farm mounds originating in the Iron Age continued to evolve through the Medieval period is not yet clear.

Any explanation of farm mound initiation in Orkney must incorporate the three distinct periods of formation outlined above, Iron Age, early Norse and late Norse. To this end the explanation in the following sentences is advanced as hypotheses to be tested by further examination of farm mounds in Orkney. Farm mounds associated with the Iron Age (and possibly Pictish period) have evolved because of the preference of Norse settlers to construct their settlements on existing occupation sites (Ritchie, 1983). Under these circumstances farm mounds similar in type to the mound at Pool (Hunter, unpublished manuscript) would develop with a relatively high proportion of the mound being building construction material. The major impetus to farm mound formation was therefore the Norse colonization of the early 9th Century. Immigration to the northern isles of Orkney was however probably of sufficient volume to require the development of completely new habitation sites. Farm mounds at Westbrough, Skelbrae and possibly also Southness, whose origins can be dated reasonably accurate to the early Norse colonization period, can be considered as new habitation sites, landscape areas not previously occupied by the pre-Norse inhabitants. The later dates or origin for the Langskail farm mound (early 13th Century) also represents the development of a new habitation site, this date of origin coinciding with a phase of population expansion in Orkney. Here again then pressure on land resources encouraged the development of new settlement sites.

Initiation of farm mound formation in Orkney points clearly to Norse origins and was a practice initiated up until the late Norse period. Factors responsible for the initiation of farm mounds were therefore the expanding Orcadian population due to Norse immigration and the consequent Norse settlement practice of developing habitation sites either on top of existing pre-Norse settlements or, when pre-existing sites became unavailable, by creating new habitation sites. What the particular reasons for this Norse habitation activity of mound formation were will be explored in subsequent chapters.

Rates of deposition in farm mound formation are demonstrated to vary markedly. An extreme example is the deposition of peaty material at the base of the Westbrough farm mound. Large amounts of this material appear to have been deposited almost instantanesously. More usually tip-lines are evident in the mound suggesting a slower but continuous rate of deposition. Radiocarbon dates from the Langskail farm mound indicate a steady accumulation rate of c 1.09cm/year. Differences in rates of deposition within and between farm mounds presumably reflect the ability of the associated farm to generate anthropogenic sedimentary material. Alternatively these different deposition rates may indicate different reasons for deposition.

The limited radiocarbon dating of upper farm mound horizons and extrapolation of radiocarbon ages to other farm mounds suggest that cessation of farm mound formation may have been quite early in the Medieval period, towards to the end of the 15th century. If this is so it would point to the farm mounds being peculiarly Norse in their construction. Whether cessation of farm mound formation meant a decline in population density or a change in settlement practice cannot be ascertained with any degree of certainty. As an alternative hypothesis to late 15th century cessation, it may be that while deposition ended on one particular part of a mound at this time, later deposition at other parts of the farm mound may have occurred. Only further radiocarbon dating will resolve this issue.

In conclusion, it would appear that the farm mounds represent a Norse culture phenomenon. What would be of interest to know is whether or not Norse settlers in Sanday and North Ronaldsay brought this habitation practice with them or whether the farm mounds represent features peculiar to Norse colonization in the northern isles of Orkney. Further study into the origins of these Norse settlers would be welcomed but that task must wait the attention of other workers. For the moment progress into elucidating farm mound formation in Orkney is made by attempting to identify the processes of formation.

CHAPTER 6

PROCESSES OF FORMATION 1 : MULTIPLE WORKING HYPOTHESES AND SAMPLING PROCEDURES

6:1 Introduction and Objectives

It is, at this stage of the thesis, worth referring back to Chapter 4 where the conceptual model of anthropogenic sedimentation together with the vocabulary of that model was presented. In that chapter it is observed that deposition of sedimentary materials in the landscape by man is normally associated with some purpose, to fulfil some function. Such functions (or land uses) and their intensities can be thought of as establishing gradients down which sedimentary materials transported by man flow. Thus there are two twin tasks to be accomplished in elucidating the processes of anthropogenic sedimentation. One is to resolve the functions (or land uses) associated with deep top soil and farm mound formation. The second is to identify the materials used to create anthropogenic sediments and the source of those materials. Together these two sets of parameters control the formation of anthropogenic sediments.

The location and chronology of anthropogenic sedimentation in Orkney has been established in previous chapters and so it is possible to use historical and early cartographic evidence to gain a first indication of formation processes. This is achieved by comparison of pre-agricultural revolution township maps, which indicate broad areas of different land use, with the location of anthropogenic sediments. Documented historical information adds to our understanding of formation processes by indicating the sorts of activities associated with these land use areas. Such activities included the deposition of sedimentary materials. Taking these lines of investigation together narrows the questions to be resolved and permits the presentation of hypotheses of deep top soil and farm mound formation processes which will be tested in the next two chapters.

6:2 Location of Anthropogenic Sediments within the Agrarian Landscape of Orkney during the Iron Age, Norse and Medieval Periods

Detailed examination of 17th and 18th Century legal manuscripts enabled Clouston (1919, 1922, 1932) to identify five major types of land use which together made up the organisation of the Orcadian township in these two centuries. The traditional township in Orkney was arranged in a concentric pattern within which individual rights and sense of ownership decreased from the centre to the periphery (Thomson, unpublished manuscript; Fig 6:1). The township may have had one core as in the case of townships with Bu's (or head houses) or several cores without any head house (Clouston 1919). Either way the core(s) consisted of loosely nucleated Tofts (Old Norse : House sites) which included the farm house itself and the "house freedoms". These "house freedoms" were any outbuildings as well as the midden area, farm yard, kail yard and garden patches. There was therefore considerable diversity of activity within the Tofts.

Surrounding the Toft, whatever age that Toft might be, was the land known as the Tunmal (Old Norse : Tún Vollr = Townfield). Here tún is meant in the Icelandic sense of the word of enclosed infield. This land was the oldest and best arable land in the township. It was not held in scattered rigs but rather in large blocks which were attached to each house in a semi-permanent if not permanent way. Some authorities are of the opinion that because the Tunmals were not liable to redistributed, being retained by the nearby Toft, this land was kept in continuous cultivation and received the best manure through the centuries (Marwick, 1952; Fenton, 1978). Furthermore it is known that if the Tunmal land had to be divided amongst several inheritors it would sometimes be divided into blocks, one part of the Tunmal being as fertile as the other. What was probably more common was for the Tunmal to be left intact with the eldest son receiving the house and Tunmal, the other sons being compensated with cattle and moveable goods. The management of the Tunmal was therefore quite different from the run-rig Townsland which lay beyond the

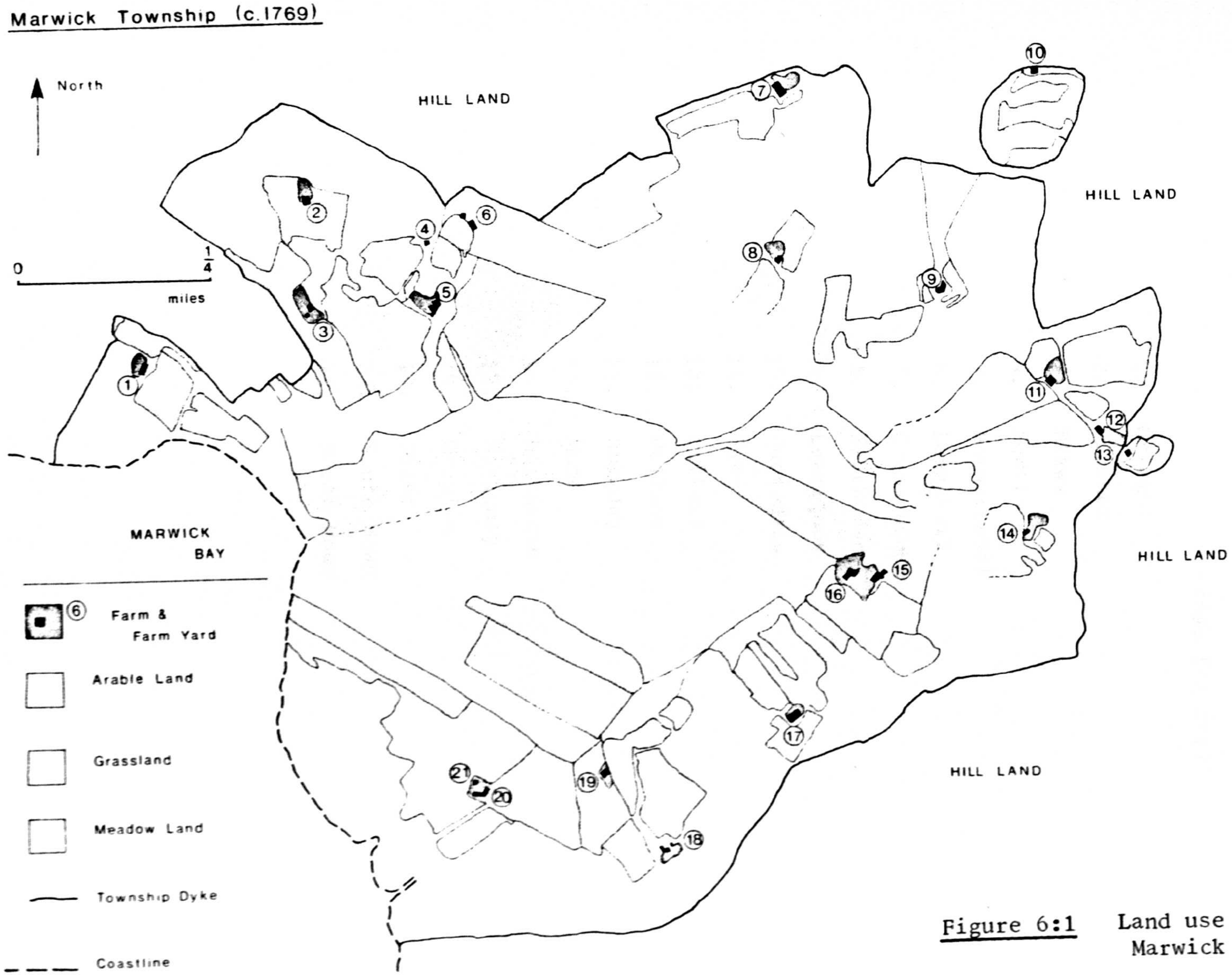


Figure 6:1 Land use in the early Marwick Township.

TABLE 6:1

FARM NAMES OF THE MARWICK TOWNSHIP
(c 1769)

(See Fig 6:1)

1. Gridgar
2. Brocken
3. Flaws
4. Howers
5. Netherskail
6. Langskail
7. Couperhouse
8. Nearhouse
9. Learaquoy
10. Quoyodals
11. Skorn
12. Britain
13. Holland
14. Rorquoy
15. Muce
16. Nesthouse
17. Garaquoy
18. Gerstie
19. Gyren
20. South Howe
21. North Howe

Tunmal, often separated by a turf dyke known as the Auld Bow. Townsland consisted of cultivated rigs interspersed with areas of rough grassland, the Backs. On occasions these Backs were brought into cultivation. Whenever dispute over arable rig land allocation arose complete redistribution of this land took place, based on the Solskrite (sun division) method of division (Dodgeson, 1980; Göransson, 1961). Once division had taken place, trading often occurred in an effort by the farmer to obtain rigs next to his Tunmal. In larger townships farmers sometimes held freedoms in the Townsland. This unit of land was known as the Inskyft. No other person had rights within the Inskyft thus making it legally no different from the Tunmal. Whether this meant a similar arable practice as well is not known.

Meadowland was the term applied to all uncultivated portions of the township,particularly those areas which were wet or boggy. This land changed hands anually. Here the rough grass was often cut to provide fodder for cattle in the winter. Almost always a turf dyke enclosed the whole township, incorporating the Tofts, Tunmals, Townsland and Meadowland. Remnants of these dykes may be seen today as for example in Marwick (Plate 6:1). Frequently the sea or a loch would also serve as a boundary for the township. Beyond this enclosure lay the uncultivated Hill which served as common grazing for the entire community. In the summer months animals other than those tethered were driven onto the Hill beyond the township.

The above discussion portrays the township organisation in Orkney during the 17th and 18th centuries. Clearly, however, this pattern was not static back into the Iron Age when townships are most likely to have originated (Marwick, 1952). The most important change in the landscape economy of the townships between the Iron Age and the late Medieval was the extension of area under cultivation. This was mainly carried out during the late Norse period (12th and 13th centuries) and was achieved in two ways. One was the establishment of new Toft sites on the Backs, each allocated their own Tunmal. The second method was the introduction of the run-rig Townsland

PLATE 6:1 Early turf hill dyke, North Marwick.

which developed out of the early Tunmal land in the 12th, 13th or early 14th Centuries (Thomson, unpublished manuscript). Clearly then one area of land may have had two or more uses throughout the history of the township. In particular, Townsland will have originated at the expense of Meadowland as will additional Tunmal and Toft areas. It is also worth pointing out, although there is no record of this, that activities within the Toft area might be expected to have changed considerably. Great care is therefore required when interpretating the early land use of an area in view of the superimposition and varying duration of land uses within the township.

There are for Orkney several detailed maps of townships drawn prior to the agricultural improvements of the mid-1800s. These show distributions of the land use types described in the above paragraphs. Comparison of anthropogenic top soil depth distribution in Marwick (Fig 6:2) with the c 1760s land use map (Fig 6:1) demonstrates that areas of increased soil depth are restricted to the arable land. It can also be observed that there are areas of arable land that have no increase in top soil depth. Clearly there must have been differences in arable practice or duration that resulted in deep top soils in one part of the arable land but not another. More specifically in view of the discussion of township organisation just given, it is possible to hypothesise that deep top soils represent the Tunmal with the remaining arable areas being the rig land. Early maps showing township organisation are also available for Birsay and the Hybreck district. Comparison of deep top soil location with the arable land in these two districts also indicates that deep top soils are found in only part of the arable land. Thus it is possible to hypothesise that deep top soils were formed in that part of the township known as the Tunmal.

Comparison of farm mound location at Westbrough with the 1817 land use pattern of the Westbrough township (Fig 6:3) indicates that the mound lies within the farm and farm-yard zone - the Toft. Early maps of the Tofts and Lopness areas of Sanday also indicate the Toft location of the farm mounds. In general farm mounds are in close proximity to a farm building (see Chapter 3) so it can

Figure 6:2 Top soil depth in the Marwick Drainage Basin.

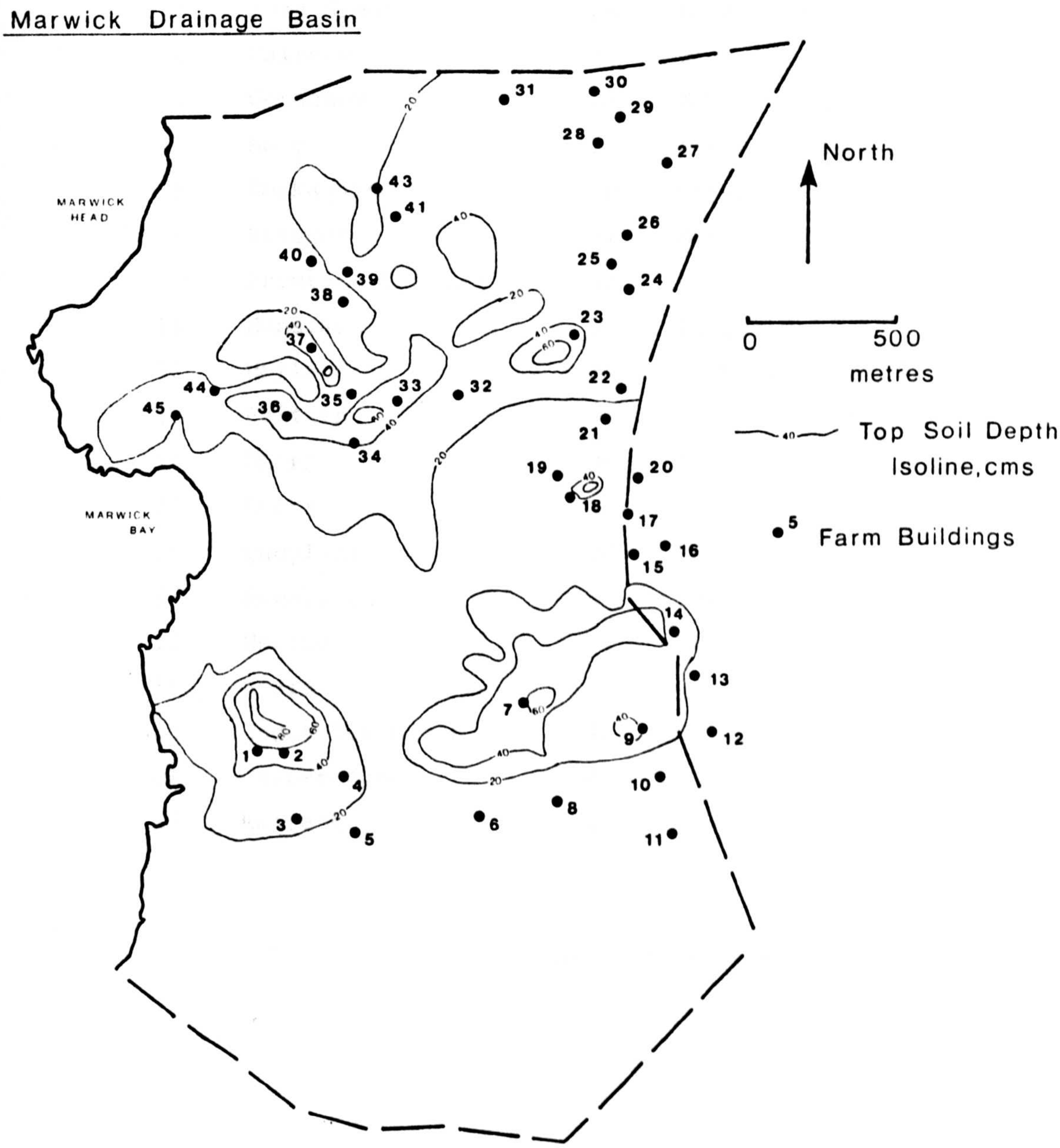


TABLE 6:2

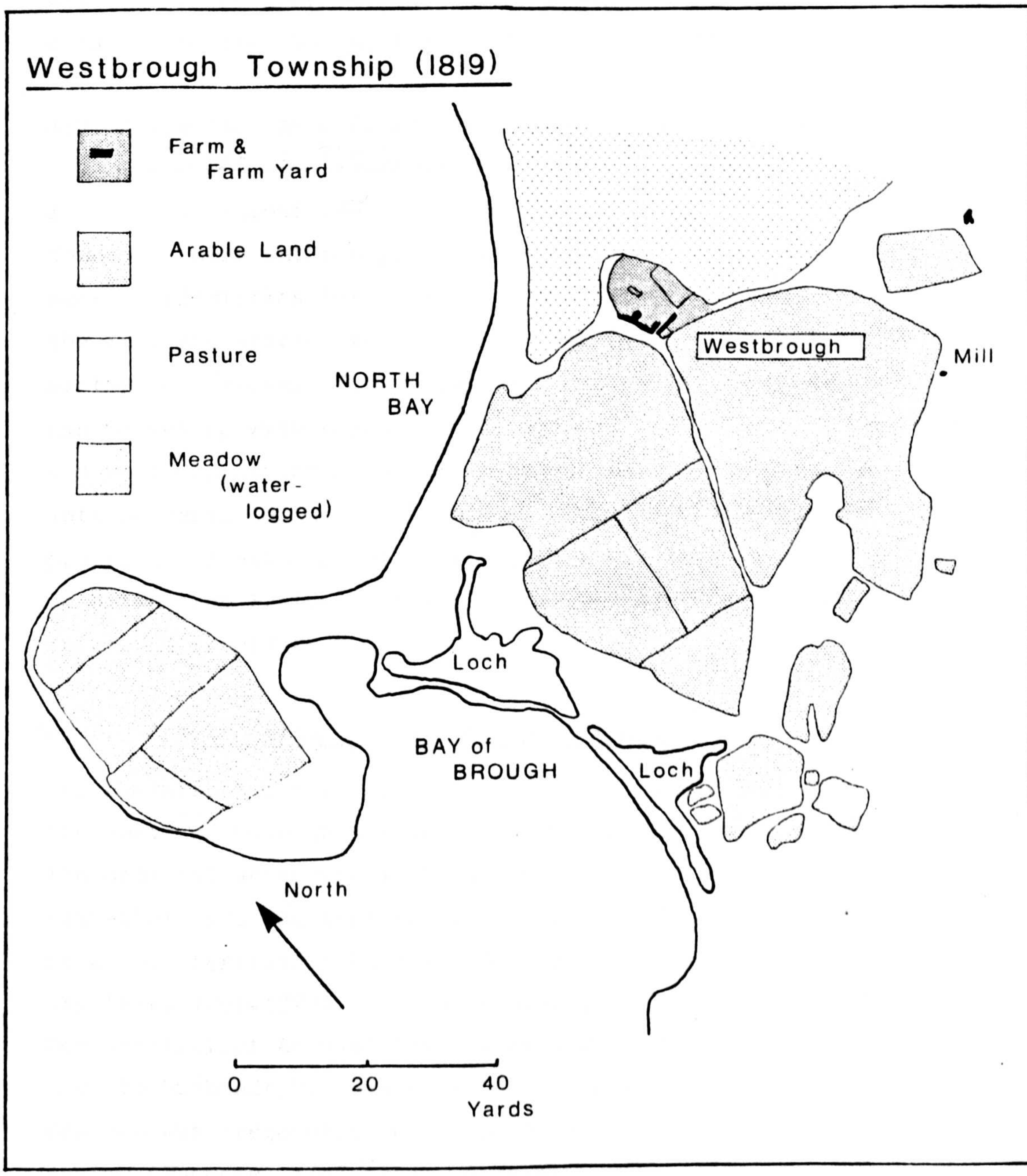
CONTEMPORARY FARM NAMES IN MARWICK

(See Fig 6:2)

1	West Howe	23	Leoquoy
2	East Howe	24	Windbreck Cottage
3	West Green	25	South Waird
4	East Green	26	Windbreck
5	Gairsty	27	Roseview
6	Geraquoy	28	North Waird
7	Muce	29	Breck Cottage
8	Corkaquina	30	Chinglo
9	Ritquoy	31	Marwick House
10	Primrose Cottage	32	Crook
11	Hundland	33	Langskail
12	Holland	34	Netherskail
13	Britain	35	Langskail Cottage
14	Skorn	36	Flaws
15	Leary	37	Brockan
16	Quoylonga	38	Skaraquoy
17	Howabreck	39	Cumlaquoy
18	Nearhouse	40	Mid Comloquoy
19	Stara	41	Quaquoy
20	Upper Howabreck	42	Craiglands
21	Cooperhouse	43	Steadaquoy
22	Rubreck	44	Gridgar

(After O.S. Maps 1:10000)

Figure 6:3   Land use in the early Westbrough Township.



safely be assumed that all farm mounds lay within the Toft.

Formation of deep top soils can in view of the above discussion be considered in terms of arable activity and possibly forms the Tunmal. Farm mound formation can be related to the activities associated with the Toft. What the range of activities associated with these two zones of the township were can in some measure be established from the written historical records.

6:3 Activities Associated with the Toft and Arable Areas of Orkney : The Historical Record

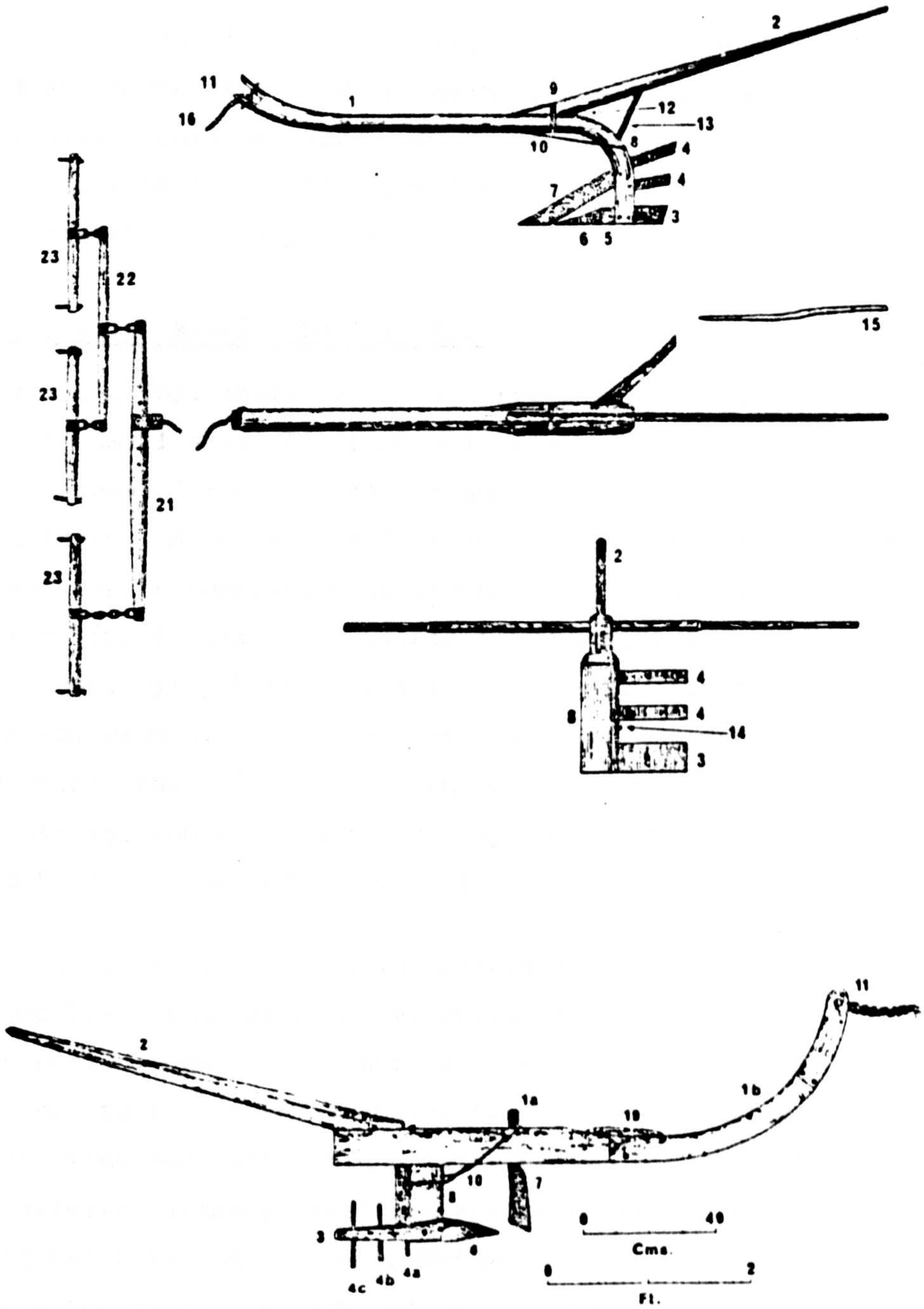
Section 6:2 identified the broad functional areas of the Orcadian township where anthropogenic sediments are to be found. This section identifies the numerous human activities associated with the Toft and arable areas of the township as evidenced by the historical record. It is from this record that working hypotheses can be set up with regard to the materials, the mode of deposition and post depositional human activities associated with the anthropogenic sediments of Orkney. Together they represent the processes of anthropogenic sedimentation. Much of this section is drawn from Fenton (1978), an outstanding work to which reference should be made.

6 :3:1 Arable Activities within the Township

The historical literature on Orkney gives ample testimony to the sorts of materials applied to the arable land. In describing the medieval agricultural system what apparently struck earlier travellers and educated residents was the emphasis on seaweed as a soil fertiliser (Brand, 1701; Barry, 1805; Forsyth, 1805; Sinclair, 1791-1799). Indeed Fenton (1978) quotes from the Old Statistical Account that seaweed was "the very backbone of the old husbandry". Other references give information on how seaweed was frequently incorporated into a wider land fertilisation system (Pococke, 1747-1760; Sinclair, 1791-1799; Pringle, 1874; Fenton, 1978). This sytem involved the paring of turves over several acres from the common hill land which then had several possible uses before being applied to the arable land. The turves could be burnt in the hearth producing ash which was then either put into the byre to soak up liquid or were applied to the fields direct. Another possibility was that the turves were put straight into the byre as bedding thus being mixed with manure from cattle grazing on the hill pasture during the day. When the byre was full the contents were transferred to a compost midden. This could consist of earth, seaweed and byre material. Calcareous sea sand was frequently applied and turf could be added directly to this compost midden. The compost was then spread on the arable land. Other material referred to but of less importance included marl, sillocks and soot. The above description provides the general picture of the materials applied to the arable land but spatial variations existed at two different scales. At the regional scale inland districts lacking seaweed put a greater emphasise on turf. More locally there was a major difference in manuring techniques between the infield and outfield (Tunmal and rig land?). The outfield crop of black oats did not always receive manure and when it did the manure was of a poorer quality. Bere, the infield crop, was manured regularly (Fenton, 1978).

Tilling of the arable land - the physical re-organisation of the soil - was carried out by the delling spade or the plough (Fig 6:4). Cultivation by spade was in all probability a 16th Century introduction to Orkney. It was used by the poorest farmers with the smallest fields and where small fields were created by farm fragmentation. Small fields meant that the plough was too cumbersome for use. Plough cultivation is an older tradition probably having been in use since the Neolithic (Fenton, 1978). During the period under consideration by this thesis,ploughing was carried out by means of the one-stilted Orkney plough. Originally this consisted of a stone share and mould strokers which did not properly turn the soil but rather broke it into pieces leaving half the surface unturned. Later one-stilted ploughs became iron-shod. The plough in Orkney was pulled by horses or oxen, driven by one man behind who followed an assistant who sorted the shallow furrows with a spade. Only after the mid-19th Century, after the period of deep top soil formation, was the one-stilted

Figure 6:4 The early Orkney plough.
(from Fenton, 1978).



plough superceded by the heavier lowland Scottish two-stilted plough with mould boards. Other preparations of the planting surface included hoeing to fill in old furrows prior to planting, breaking up clods with a heavy mallet or by dragging a heavy flagstone across the field, and harrowing with a small, light harrow of which the teeth were frequently missing. Each of these activities outlined above would result in the physical re-organisation of the soil/sediment matrix, traces of which may remain within the deep top soils.

6:3:2 Activities Within the Toft Area

In the Orcadian Toft there was great diversity of activity within an extremely small area. Figure 6:5 is a schematic diagram showing functional areas of the recently abandoned site at Southness, North Ronaldsay. Although the features identified are comparatively modern they can be considered as giving a good indication of the diversity of functional areas within the Orcadian Toft. The dwelling house, byre, barn, stack-yard, kailyard (garden), compost heap, midden, corn-kiln, sheds and stables were all to be found within the Toft area. Each of these functions could have, in theory, contributed in varying degrees to farm mound formation by the accumulation of sedimentary materials.

Turf was one of the basic building materials for construction of the long-house and outbuildings during the Norse and immediate pre-Norse period. Walls were normally composite having an inner stone facing, turf core and an outer facing of turf or of alternate courses of stone and turf. Stone later became the dominant building material although turf and thatch continued in use as roofing materials (Plate 6:2). One possible contributing factor to mound formation is the collapse of turf houses with new ones built on top, a process analagous to the Tells of the Middle East. The original stone material would be re-used to construct the next generation of buildings. Such a process of formation might be expected to exhibit distinctive morphological characteristics within the mound. In the central dwelling itself a number of activities would result in distinctive physical and chemical

Figure 6:5 Functional areas of the Southness farmsteads.

: A schematic diagram.

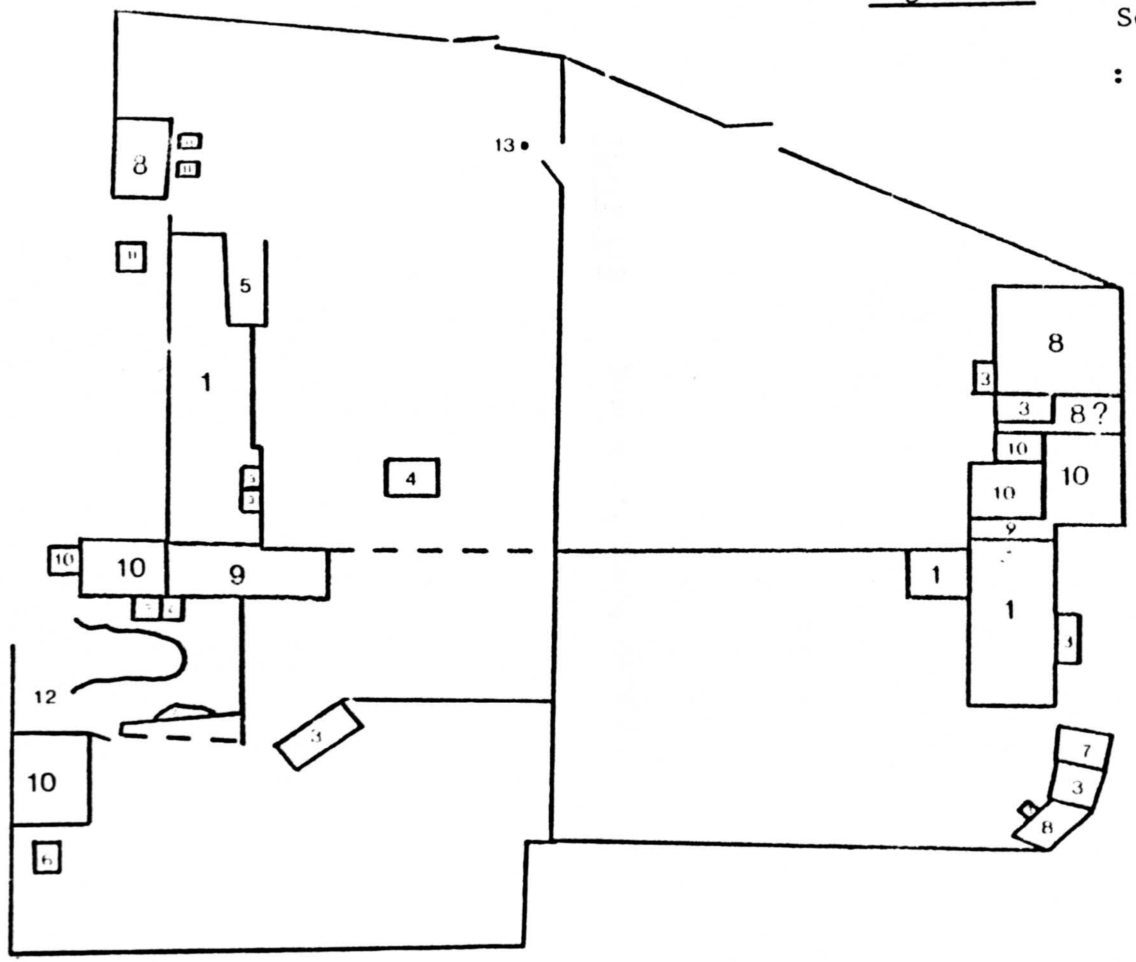
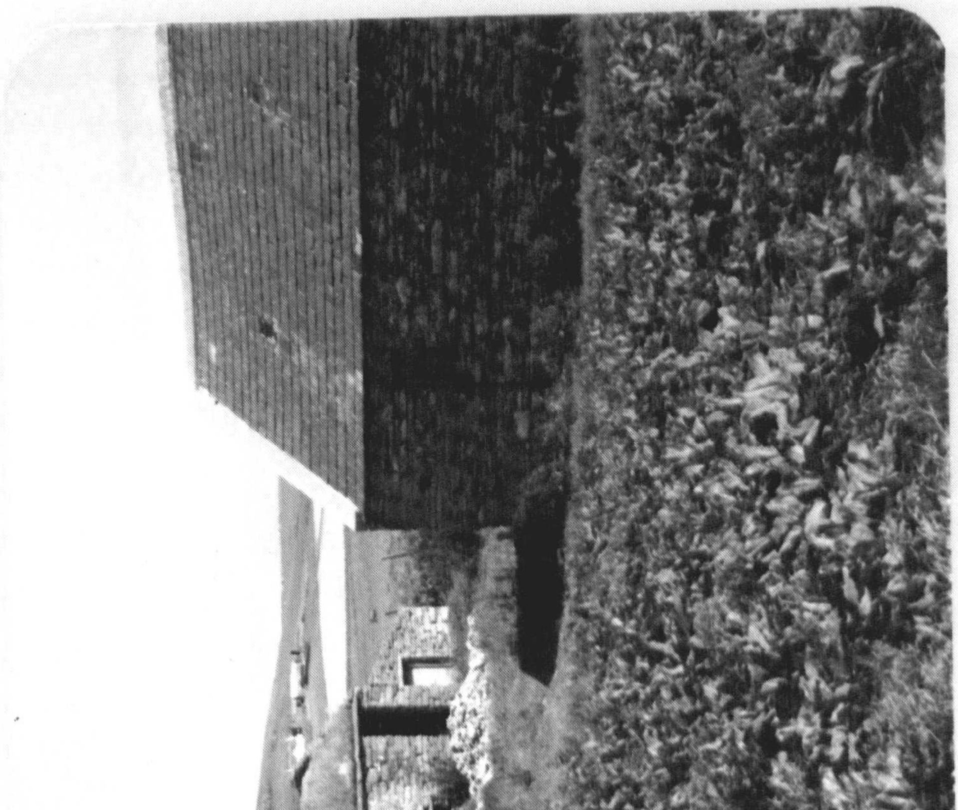


PLATE 6:2 Turf roof, Muce, Marwick.

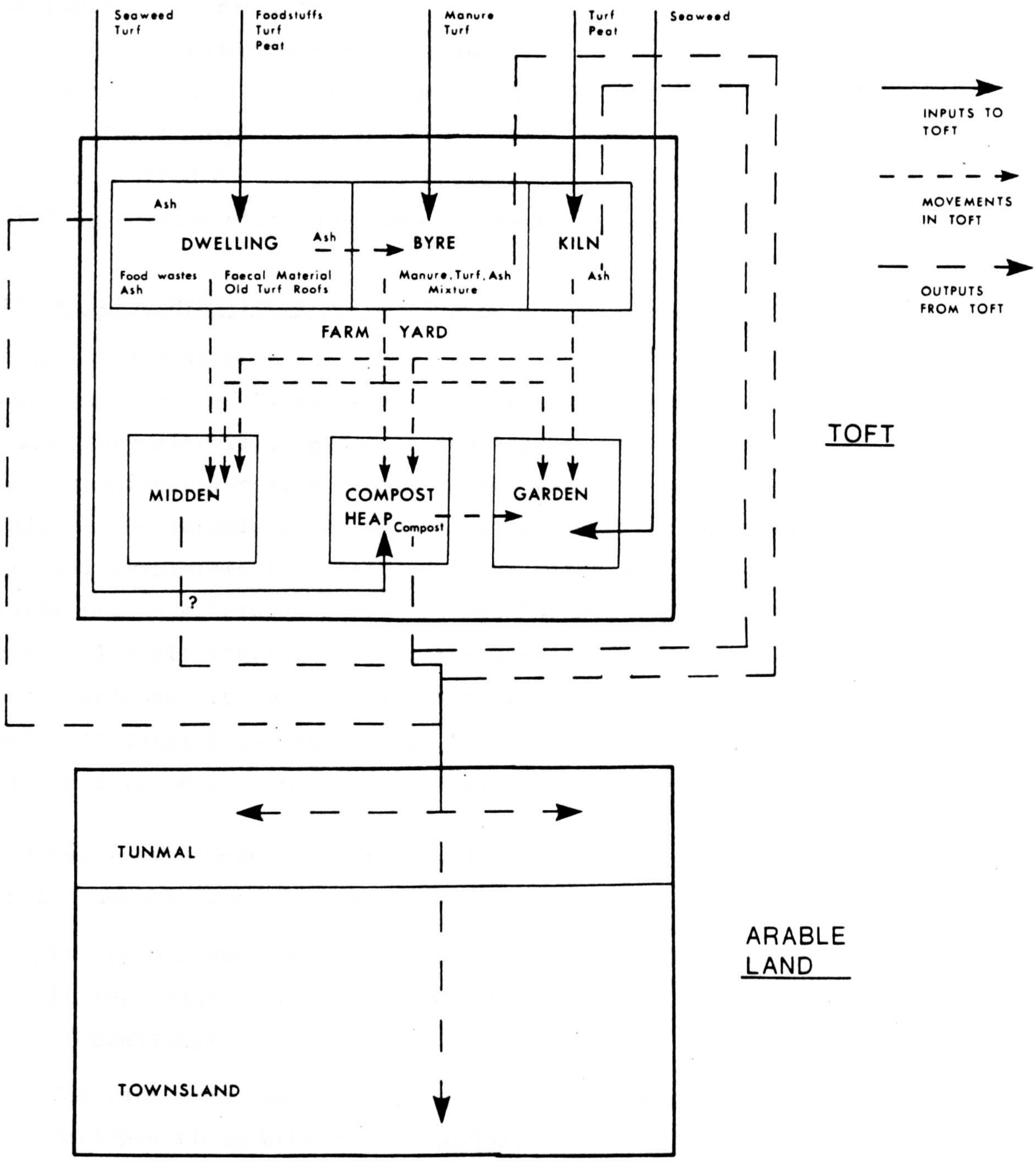


characteristics. Hearths combusted a wide variety of different materials including peat, turf and domestic rubbish. In Sanday and North Ronaldsay where peat and turf were scarce cow-dung and seaweed were also burnt. Raised sleeping areas, a characteristic of Norse settlement might be expected to have less trampling effect in comparison with surrounding areas and may be preserved within collapsed house structures. Cattle stalls and drains in the byre end of the long-house might also be expected to have distinct physical and chemical sediment characteristics due to cattle trampling and manure deposition. Build-up of manure and bedding material within the byre may have contributed to mound formation in conjunction with turf walling collapse of the byre. Later stone-built outhouses included barns and drying kilns. It is unlikely that grain winnowing, grinding and storing in the barn contributed to the raising of farm mounds but the drying kilns of larger farms could generate significant quantities of ash.

Outwith the buildings but still within the Toft area, gardening areas, compost heaps and middens were to be found. Farm gardens probably originated fairly late on in the history of the Tofts, with kail grown from the 17th Century, although kail has been known in Scotland since the 15th Century. Later crops grown in the kail yard or garden included turnips, potatoes and hay. Gardens were frequently fertilized with manure and seaweed and thus may have been zones where sediments accumulated. Cultivation by means of the delling spade would mean the re-organisation of garden patch soils. Compost heaps consisted of material ultimately destined for the arable land and so this activity probably contributed little to farm mound formation. Middens were different in that it was here that the bulk of the Toft site waste accumulated. Ash, food remains from terrestrial and marine sources, discarded turf roofs, byre and stable manure would all contribute to the formation of a midden and so to the formation of a farm mound.

The above discussion is summarised in Figure 6:6 which illustrates the movement of sedimentary materials into, through and out of the Toft area. One additional observation can be made from this Figure and relates to the relative accumulation of sedimentary

Figure 6:6 Movement of materials into, through and out of the Orcadian Toft.



material within the Toft zone. Of the seven functional areas identified by this Figure,two would appear to have no output, only the input of material. By implication therefore these two functional areas, the midden and the garden might be expected to have the greater degree of sediment accumulation over time and so contribute most to farm mound formation. Other functional areas do have outputs and therefore the accumulation of sediments will be limited except perhaps where collapse of turf based buildings occured with subsequent re-building on top.

6:4 Working Hypothesis of Anthropogenic Sedimentation in Orkney

It is clear that both the arable areas and Tofts of the Orcadian townships are net "importers" of a considerable variety of sedimentary material. Based on the historical evidence,hypotheses under consideration with regard to the formation of the deep top soils can be formulated as a null and alternative hypothesis. The null hypothesis is stated as there being no difference in arable practice between deep top soil and non deep top soil arable areas. The alternative is that the deep top soils can be considered as the intensively cultivated Tunmal which received the most soil fertility maintaining material. The possible activities associated with deep top soil formation are outlined in Table 6:3.

Four major hypotheses of farm mound formation are apparent. These can be summarised as follows:

1. The farm mound originally was the dwelling area, being formed by turf house collapse and the building of a new generation of dwellings on top.
2. The farm mound was originally the byre area with turf wall collapse along with the accumulation of bedding material and manure being resposible for mound formation.
3. Addition of material to the garden or kail yard plot resulted in mound formation.
4. The farm mound represents the midden area where the wastes of the Toft accumulated.

These four hypotheses are elaborated in Table 6:4.

TABLE 6:3

HYPOTHESES OF DEEP TOP SOIL FORMATION

Function	Sedimentary Materials	Depositional Organisation	Post Depositional Re-organisation (i) Anthropogenic	Post Depositional Re-organisation (ii) Non-Anthropogenic
Arable : Tunmal or Townsland	Turf	Unstructured, Random Deposition?	Ploughing	Pedogenesis
	Manure		Spading	Diagenesis
	Turf/ manure mix		Hoeing	
	Seaweed		Harrowing	
	Earth		Flattening	
	Marl		Crop root activity.	
	Sillocks			
	Soot			
	Beach sand			
	Ash			

Activities in the Tunmal and Townsland were much the same except possibly in terms of volume of material applied to each area and in intensity of cultivation.

TABLE 6:4

HYPOTHESES OF FARM MOUND FORMATION

Function	Sedimentary Materials	Depositional Organisation	Post Depositional Re-organisation (i) Anthropogenic	Post Depositional Re-organisation (ii) Non-Anthropogenic
*1. Dwelling Area	Turf Peat Food Stuffs	Structured-High Degrees of organisation	Disturbance due to rebuilding activity. (Trampling effects? compaction?)	Dwelling collapse Pedogenesis Diagenesis
*2. Byre	Turf Ash Manure (via cattle)	Structured-High Degrees of organisation	Disturbance due to rebuilding activity. (Trampling effects? compaction?)	Byre collapse Pedogenesis Diagenesis
*3. Garden Plot	Turf Seaweed Ash Manure/Turf "Compost"	Unstructure random deposition.	Tillage Crop root activity	Pedogenesis Diagenesis
*4. Midden	Discarded turf roofs Ash Manure/turf Food wastes Faecal Material	Thin, sequential banding	None	Pedogenesis Diagenesis
5. Raised Living Platform	?	?	?	Pedogenesis Diagenesis
6. Unknown Function(s)	?	?	?	Pedogenesis Diagenesis
7. Any Combinat-:ion of above functions super-imposed or toget-:her	Any of the above	Any of the above	Any of the above	Pedogenesis Diagenesis

* Based on historical evidence

To these four hypotheses an additional three must be added as they are potentially of relevance to the Orcadian situation. Thus fifth hypothesis is that the mounds are deliberately raised as a settlement platform in areas of poor drainage or sand blow. This would make the farm mounds analagous to the Terpen sites of north west Europe (see Chapter 4). A sixth hypothesis under consideration is that the formation of farm mounds is the result of some anthropogenic process not identified by the above five hypotheses. Finally it is necessary to bear in mind that the farm mounds could have been formed by any combination of the above six hypotheses.

Now that the working hypotheses of anthropogenic sedimentation processes in Orkney have been established it is necessary to test and evaluate them. The following chapter (Chapter 7) attempts to identify the land uses of areas where anthropogenic sedimentation has occurred and, further, attempts to elucidate the intensity of those land uses. In achieving this the gradient controlling the movement of sedimentary materials by human effort will be established. Chapter 8 seeks to identify what the anthropogenic sedimentary material was and where it came from. The final Process of Formation Chapter (Chapter 9) will bring together the two major strands of material identification and functional analysis in order to make a coherent statement about the processes of deep top soil and farm mound formation in Orkney. Prior to this, however a selection and sampling strategy is required for the anthropogenic sediments that will enable the elucidation of both land uses and materials of formation. This strategy is now presented.

6:5 Sampling Procedures to Test the Multiple Working Hypotheses

The fact that the two anthropogenic sedimentary systems under consideration are almost certainly fossil (see Chapter 5) meant that direct observation of deep top soil and farm mound formation processes was not possible. Consequently sedimentological and pedological methodologies are required to elucidate both the land uses and materials controlling anthropogenic sediment formation as outlined in the previous section. Considerable amounts of field and laboratory effort were therefore required and so it was necessary to restrict analysis to three of the anthropogenic sedimentary units in Orkney. Attention focusses on one deep top soil unit, West Howe in Marwick (HY 23 35) and on two farm mounds, Westbrough (HY 663 423) and Skelbrae (HY 676 438), both on Sanday. These three anthropogenic sediments had been examined in the reconnaissance survey (see Chapter 3). The sampling strategy in and around the anthropogenic sediments of interest was controlled by the dual tasks of elucidating land uses and materials of formation.

6:5:1 Selection and Sampling of Soils and Sediments in and Around the West Howe Deep Top Soil

Selection of the deep top soil unit at West Howe (Plate 6:3) was conditioned by its relatively small size and the fact that early cartographic information showing broad township land use divisions was available for Marwick (see earlier in this chapter). Also of importance was the West Howe deep top soil units'proximity to the coast. This implied that seaweed may have been used in the formation of this particular top soil. The use or non-use of seaweed as a soil fertilizer is of potential significance to the formation of deep top soils.

Nineteen profiles were considered in the attempt to elucidate the processes of deep top soil formation at West Howe (Table 6:5). A transect line running down the north facing slope of the Marwick Drainage Basin in a north-west direction formed the basis of sampling (Fig 6:7). This line ran through the Howe farm buildings and, on the basis of early cartographic evidence (Fig 6:1), incorporates arable land areas, farmyards and hill land of the pre-agricultural revolution township. Twelve profiles were exposed at 50m intervals along this transect line from a point centred on the Howe farmyard. This strategy gave four profiles dug in the area mapped as deep top soil by the reconnaissance survey (Fig 6:8) seven in non-deep top soil arable areas of which three were below and four above the deep top soil unit and one profile from the farmyard zone. A further five randomly selected profiles were

PLATE 6:3 West Howe, Marwick.

TABLE 6:5

TOTAL NUMBERS OF PROFILES FROM DIFFERENT FUNCTIONAL AREAS CONSIDERED BY THIS CHAPTER

West Howe

Deep top soils at West Howe	4	
Other arable areas (non deep top soil)	7	(From Author's
Other deep top soils in Marwick	2 -	reconnaissance survey)
Hill land	1	
Meadowland	2	
Grazing land	1	
Undisturbed profile	1	
Farmyard Zone	1	
=	19	

Westbrough

Farm mound	5	(1 from D A Davidson)
Arable land	1	
Meadowland	1	
Grazing land	1	
=	8	

Skelbrae

Farm mound	4	(1 from D A Davidson)
Non farm mound	2	
=	6	

Grand Total	33

Figure 6:7 Location of sample profiles in Marwick.

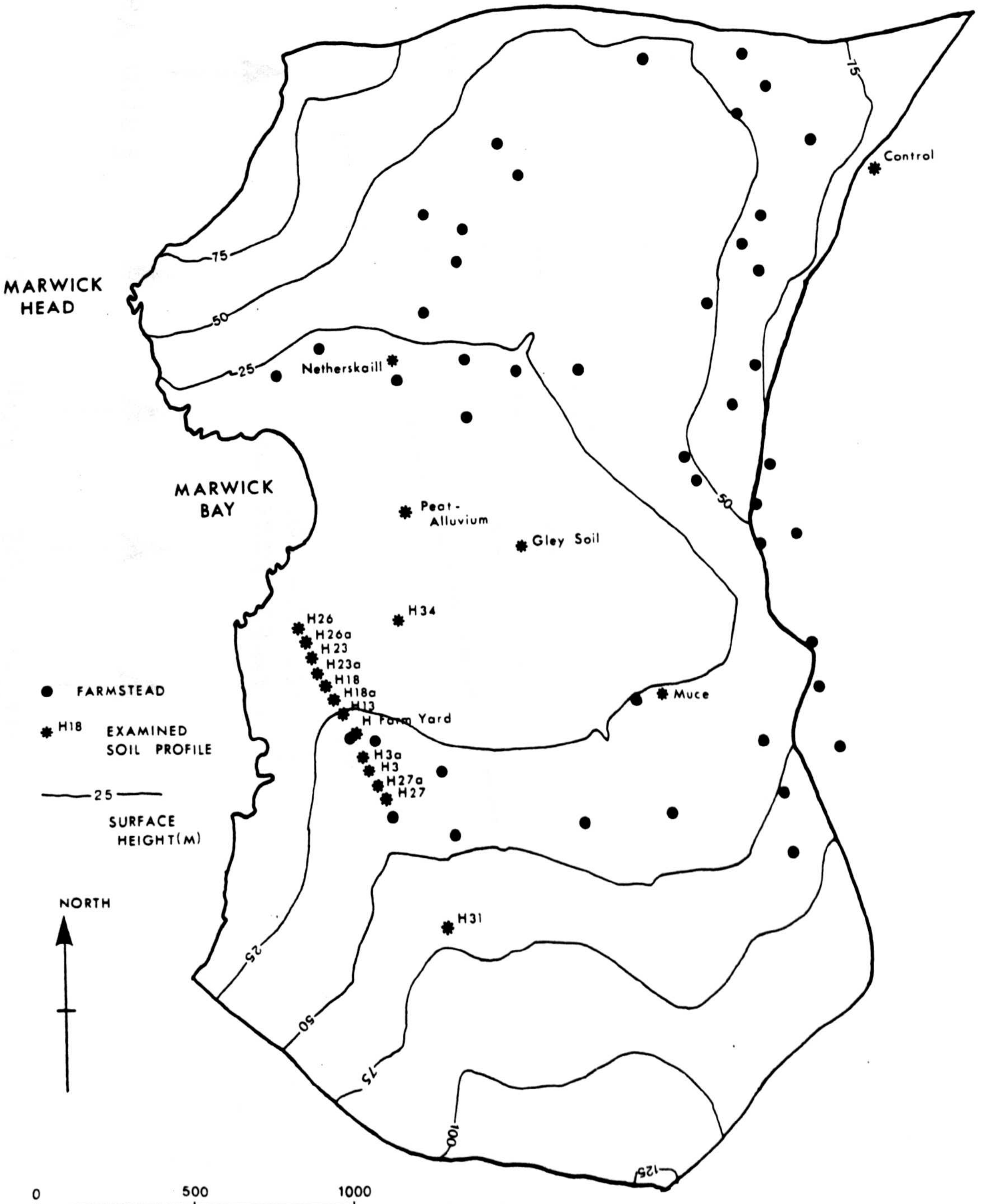
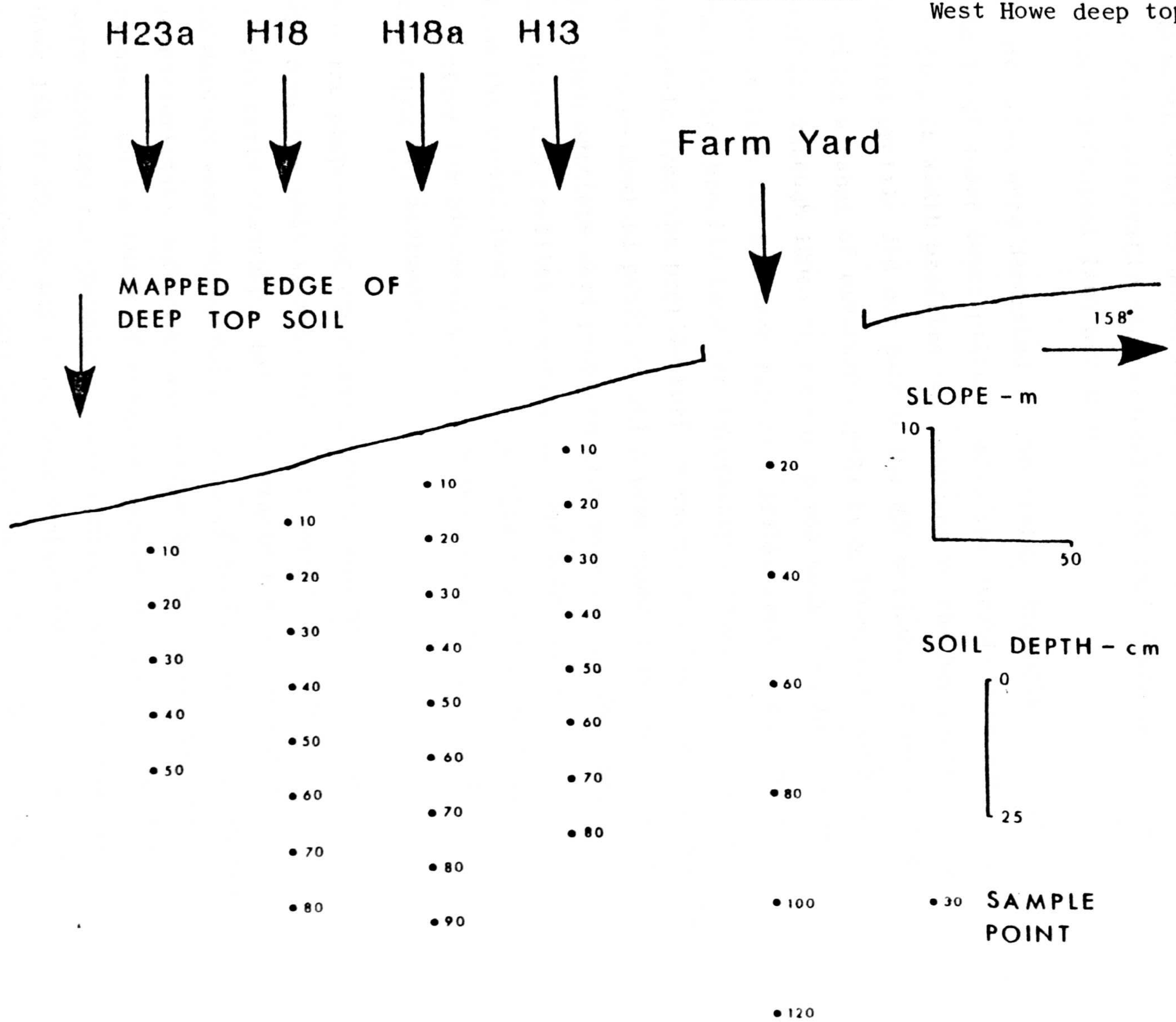


Figure 6:8 Sampling points within the West Howe deep top soil.



exposed beyond this transect line, within what was thought to be the other land use areas of the early township, based on the early cartographic evidence. One profile was dug in each of the following areas; grasslands, alluvial soil meadowlands, gley soil meadowlands, hill land which today has been reclaimed for agriculture and hill land which today is unreclaimed. These nineteen profiles provided a reasonable representation of soil characteristics in these different land use areas.

All profiles were described in the field. Appendix IV provides details of these descriptions. With the exception of the farmyard profile, 1m width profiles were exposed to the B/C horizon. The farmyard profile did not expose the B/C horizon. These profiles provided a range of exposure depths from 150cm for the farmyard profile, through 100cm in some deep top soils to 28cm for one profile from the non-deep top soil arable land. Sampling of the exposed profile face for laboratory analysis was at 10cm intervals from the profile surface except for the farmyard profile and the meadowland profiles which were sampled at 20cm intervals. Two thin sections were prepared from each of the Howe 13, Howe 18 and Howe 23A profiles S horizons. One thin section was prepared from the unreclaimed hill land profile A horizon which acted as a control for discussing the micromorphological properties of anthropogenic sediments.

For the purposes of elucidating early land uses associated with the deep top soil at West Howe in relation to other land uses of the early township, all the nineteen examined profiles in Marwick were considered in terms of their field morphological characteristics and their laboratory derived total phosphate values. On the basis of total phosphate values, five samples were selected for phosphate fractionation analysis, from profile Howe 18A at 10, 20 and 60cm, from profile Howe 23 at 20cm and from the unreclaimed hill land profile at 20cm. This it was hoped would permit further differentiation of arable land use in the early Marwick township. The seven prepared thin sections were also used in this task of identifying the precise function of the deep top soil at West Howe.

For the purposes of elucidating the sedimentary materials used in deep top soil formation the seven profiles from anthropogenic sediments in Marwick were considered. These profiles were the four from the West Howe deep top soil together with the profiles at Muce, Netherskail and the West Howe farmyard. Samples from these profiles were subject to particle size and $\delta^{13}C$ analysis to characterise and identify inorganic and organic materials of formation. Other profiles were also subject to particle size analysis in an effort to identify sources of deep top soil material. Profiles examined were the hill land profile (Howe 31), the two profiles from the meadowland (Howe Peat-Alluvium and Howe Gley Soil), two profiles from the early arable land lying below the deep top soil (Howe 26 and Howe 23) and the profile from the grazing land (Howe 34). The profile from the unreclaimed hill land was included in this analysis as a control. In addition, five types of the material suspected of being utilised in deep top soil formation were analysed for particle size characteristics. Turf roofing material was gathered from an outhouse beside the West Howe farm (HY 232 235); samples of a turf/manure mixture came from Cruesbreck, North Ronaldsay (HY 762 524); peat ash was supplied by the Orkney Field Centre, Birsay (HY 248 276); wind blown sand material came from the Bay of Skail, West Mainland (HY 234 196) and beach sand samples were taken from Marwick Bay (HY 229 243). The same seven profiles from anthropogenic sediments in Marwick analysed for particle size characteristics were also anslysed to determine the $\delta^{13}C$ values. Carbon containing materials suspected of being utilised in deep top soil formation,for which $\delta^{13}C$ values were obtained, were the turf/manure mixture from Cruesbreck, the peat ash from the Orkney Field Centre, shelly sand from the Bay of Skail, straw/manure mixture from Southness, North Ronaldsay (HY 762 524), seaweed from the Marwick shore (HY 229 243) and Calluna/Nardus vegetation organic litter which overlay the unreclaimed hill land soil profile. Soil samples taken from this profile were also examined by $\delta^{13}C$ analysis to act as a control profile for comparison with soil material taken from the deep top soil and farmyard of West Howe.

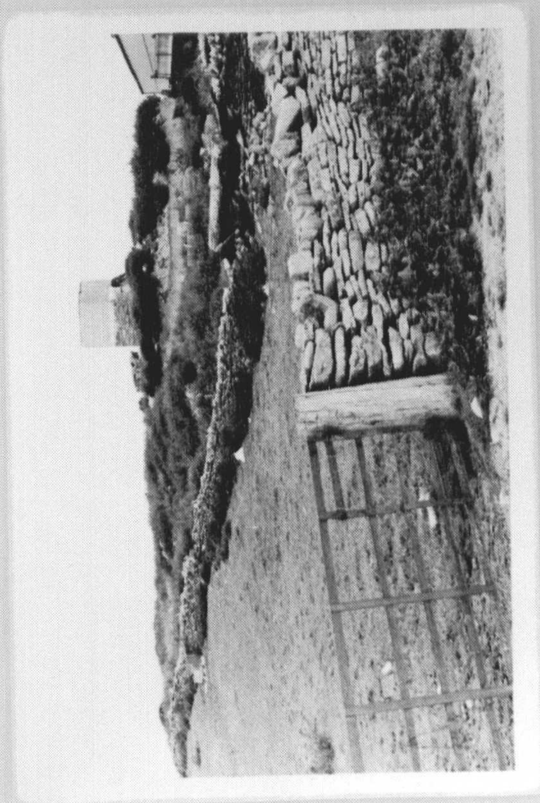
6:5:2 Selection and Sampling of Soils and Sediments in and around the Farm Mounds of Westbrough and Skelbrae

Selection of the two farm mounds at Westbrough and Skelbrae (Plates 6:4 and 6:5) to identify processes of farm mound formation was conditioned primarily by the availability of radiocarbon dating evidence for their lower layers. Langskail farm mound had to be ruled out of this detailed analysis because at the time of the major field work season there was a good possibility that this was to be made a protected site and therefore not to be touched.

A total of fourteen profiles were considered in relation to formation processes of the Westbrough and Skelbrae farm mounds, not all of which came from within these farm mounds (Table 6:5). Profiles in the farm mounds were dug at increasing intervals away from the original profiles exposed by D A Davidson (see Chapter 3). This was done in an effort to reveal the maximum stratigraphic variability within the farm mounds. The line taken on which the Westbrough profiles were dug followed the section which already exposed part of the mound, caused by excavation to provide foundations for a new cattle court (see Chapter 3). In addition to the original profile examined by D A Davidson,a further four profiles were examined along this line of the Westbrough farm mound (Fig 6:9). Three additional profiles were examined beyond the confines of this mound. One randomly selected profile was dug in each of the other early township land use areas identified by early cartographic evidence (see Fig 6:3). This gave control profiles from early arable land, meadowland and grazing land. The transect line along which profiles were examined in the Skelbrae farm mound ran from the highest point on this mound, where D A Davidson examined the first profile, down the farm mound slope in a south-westerly direction. A further three profiles were examined along this transect line in addition to the original D A Davidson profile (Fig 6:10). Two soil profiles from beyond the farm mound but on a continuation of the transect line were examined as control profiles. These profiles are named as Skelbrae Profile 5 and Skelbrae Profile 6.

The size of profile exposed in the farm mounds was normally 1m x 1.5m

PLATE 6:4 Westbrough farm mound, Sanday.



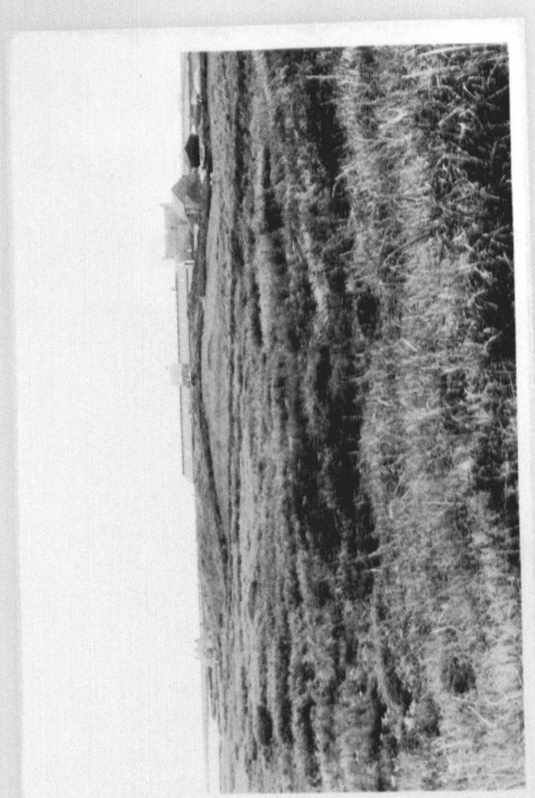
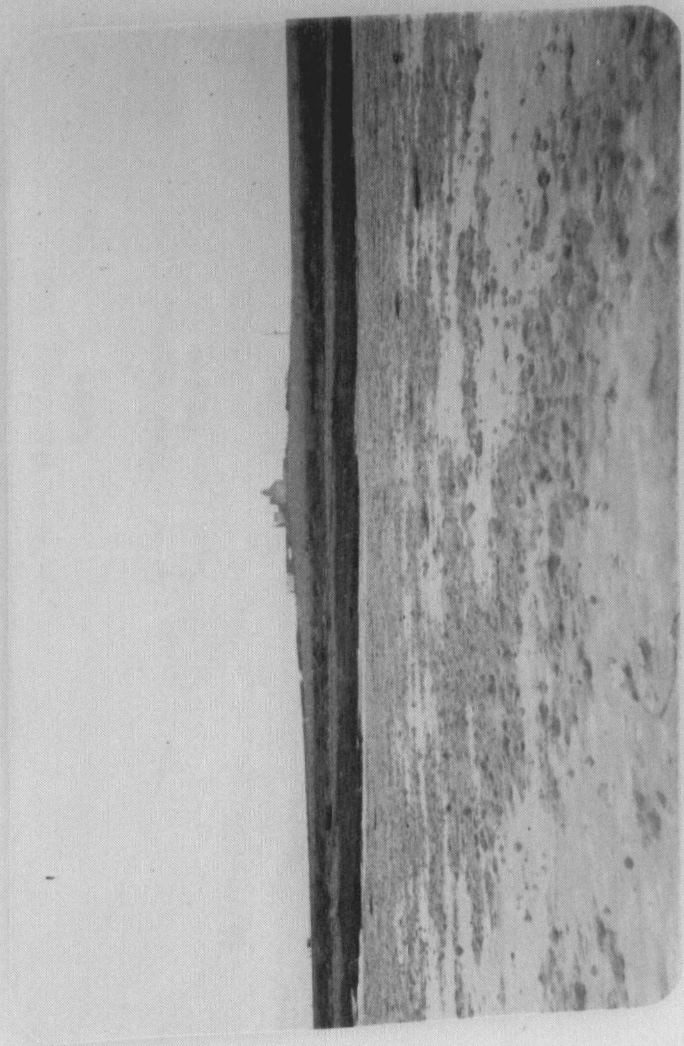


PLATE 6:5 Skelbrae farm mound, Sanday.



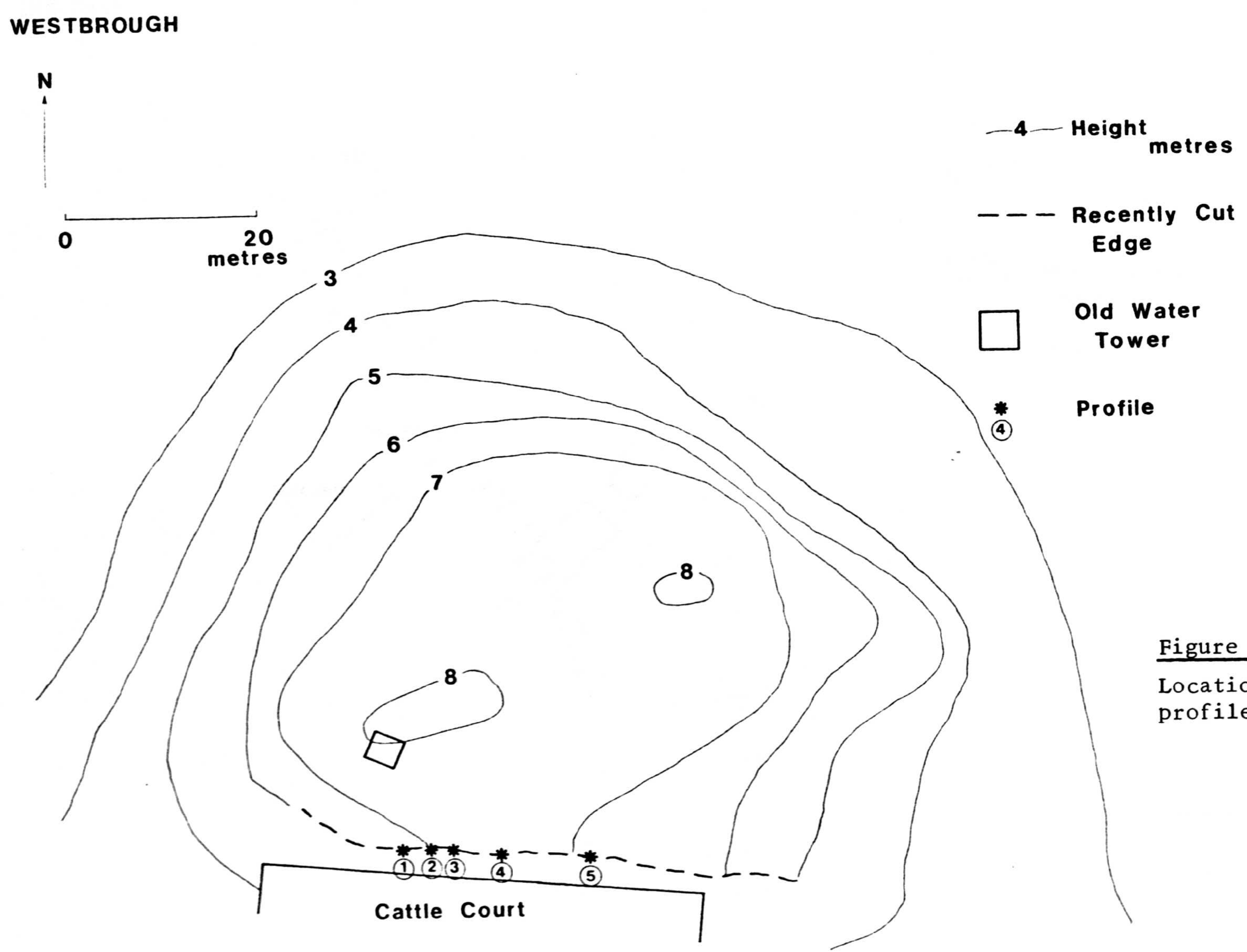


Figure 6:9

Location of examined profiles at Westbrough.

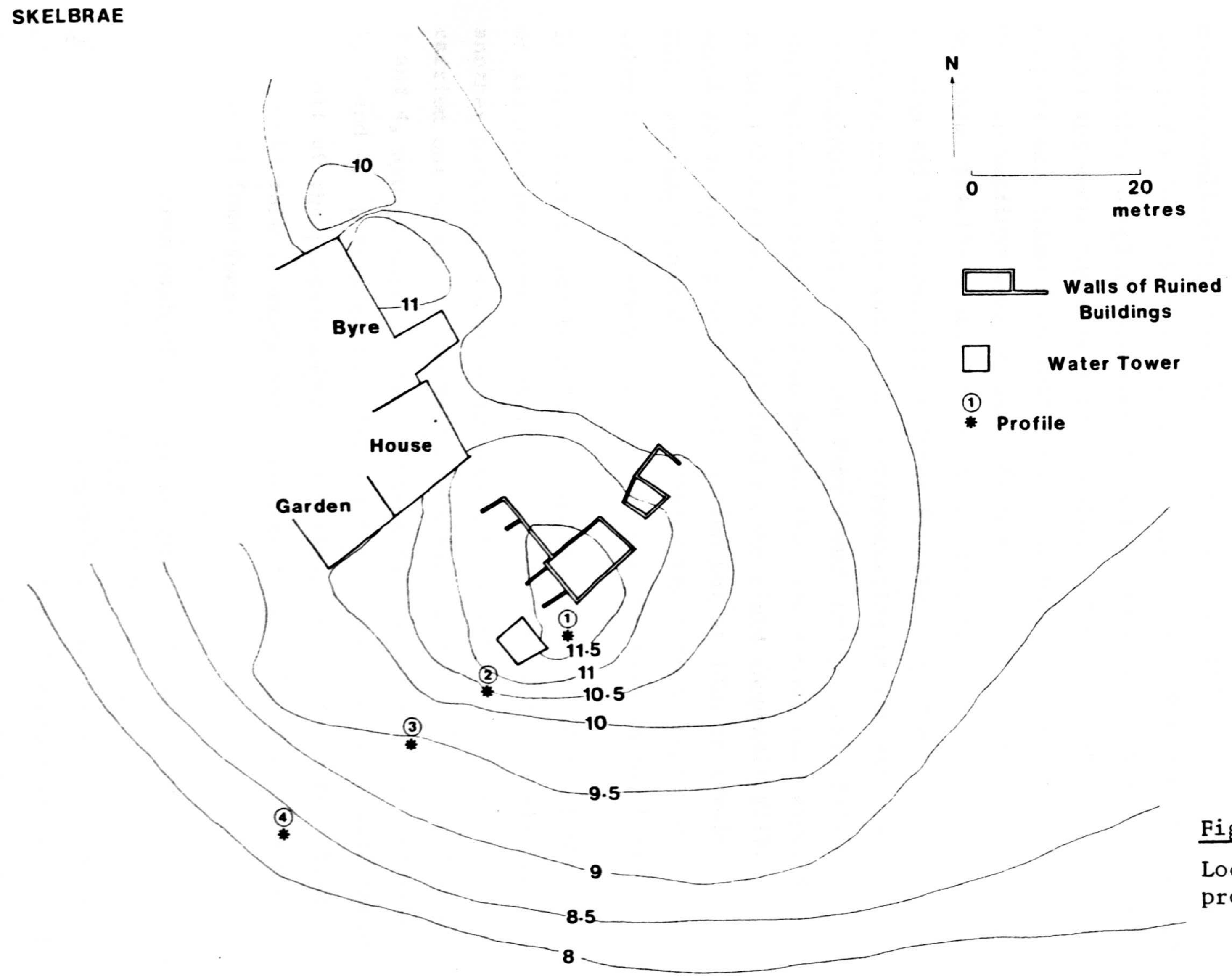


Figure 6:10

Location of examined profiles at Skelbrae.

depth. More depth was gained at Westbrough because of the already exposed section. Field descriptions of sedimentary horizons within the farm mounds were recorded in a slightly modified numeric form of the Soil Survey for England and Wales (1976) (Appendix V and VI). Field observations of the farm mounds were recorded in this way because this information was to be used in calculations of horizon similarity. Sampling of the exposed profiles in the farm mounds for laboratory analysis was based on the observed stratigraphic complexity. Samples were taken from each horizon identified in the field and where there were large columns of homogenous material samples were taken from that homogenous unit at 20cm intervals. Six thin sections were prepared; from Westbrough Profile 2 at 96-106cm, 174-184cm and 206-216cm and from Skelbrae Profile 1 at 78-88cm and 100-110cm and Skelbrae Profile 2 at 70-80cm. These thin sections gave reasonable representation of the variety in stratigraphy found in the two farm mounds under consideration. Soil profiles examined from beyond the farm mounds were exposed to the B/C horizon and described in the field (Appendix VII). Sampling of these profiles was carried out at 10cm intervals. This sampling interval within profiles meant that samples were taken from all of the pedogenic horizons observed in the field.

In the effort to identify farm mound function, the field properties of all examined profiles were considered. Total P_2O_5 analysis, another potential means of determing farm mound function, was carried out on two of the Westbrough farm mound profiles, Profiles 2 and 4, and on three of the Skelbrae farm mound profiles, Profiles 1, 3 and 4. Determination of total P_2O_5 levels was also undertaken for all of the profile samples from beyond the farm mound. Each of the six thin sections were examined to aid the identification of farm mound functions.

One profile from each of the Westbrough and Skelbrae farm mounds, Profile 2 and 1 respectively (Fig 6:11 & 6:12) were subject to particle size and $\delta^{13}C$ analysis in an effort to identify the materials of formation. Off site profiles examined for particle size distribution characteristics to identify material sources were the meadowland and early arable land profiles adjacent to the Westbrough farm mound and the

Figure 6:11 Sampling points from Westbrough Profile 2.

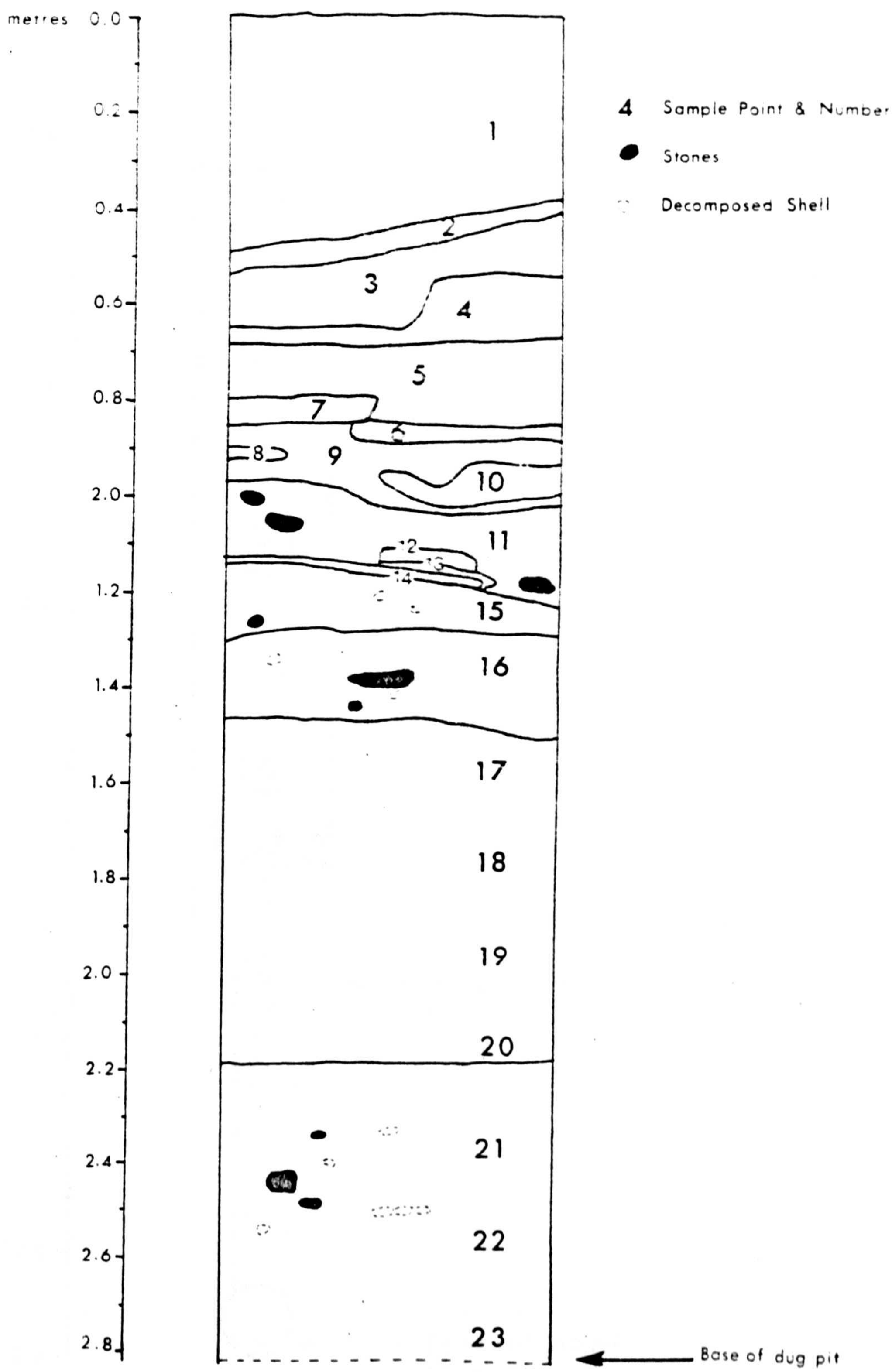
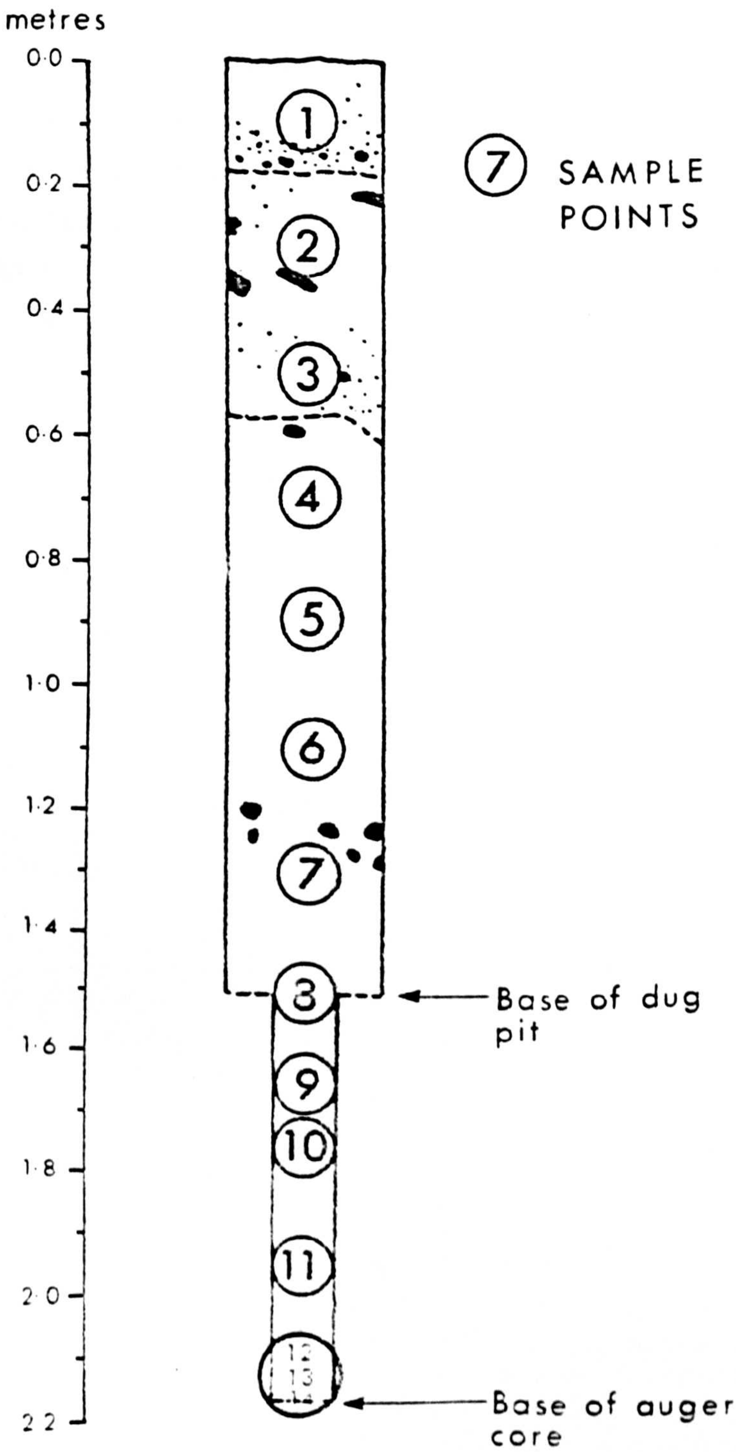


Figure 6:12 Sampling points from Skelbrae Profile 1. (after D.A. Davidson)



Skelbrae Profile 6 from nearby the Skelbrae farm mound. Additional materials considered in relation to the inorganic and organic materials of farm mound formation were the turf roofing material, turf/manure mixture, straw/manure mixture, peat ash, beach sand, wind blown sand, seaweed and Calluna/Nardus vegetation litter from the locations already given in the previous section.

The sampling strategy above does appear somewhat complicated but this was necessary so that both anthropogenic sediment types of deep top soil and farm mound could be considered in terms of their function, inorganic materials of formation and organic materials of formation. What these functions and materials of formation were is now elucidated in the following three chapters.

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ANTHROPOGENIC SEDIMENTATION IN ORKNEY :

THE FORMATION OF DEEP TOP SOILS AND FARM MOUNDS

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CHAPTER 7

PROCESSES OF FORMATION 2 : LAND USES ASSOCIATED WITH DEEP TOP SOILS AND FARM MOUNDS

7:1 Introduction and Objectives

In its broadest terms this chapter is concerned with testing the hypotheses set up in Chapter 6 that relate to the land uses associated with anthropogenic sediments in Orkney. Additionally, this chapter attempts to identify the intensity of those land uses. Two complementary sedimentary and pedological methodologies are used in this chapter to achieve an analysis of early land uses associated with deep top soils and farm mounds. These methodologies are soil/sediment morphology and soil/sediment phosphate chemistry. Both rely on the principle that different human activities upon the landscape result in distinctive imprints in the soil/sediment system. Examination of sediment morphology in the field and at the microscopic level seeks to identify characteristic depositional and post depositional fabric organisations that reflect distinctive land uses. Such an approach must however be seen within the context of fabric organisation caused by natural pedogenic and diagenic processes. The methods of soil/sediment phosphate analysis approach the same problem from a different angle. Analysis to establish the total levels of phosphate in anthropogenic soils/sediments represents, at its most basic, the total amount of phosphate contained in the original sedimentary material less that removed by activities such as cropping. It can be argued that different land uses result in varying inputs and outputs of phosphate to and from the soil/sediment system. Thus total phosphate values may indicate the land use and land use intensity to which man subjected a particular portion of landscape. Phosphate fractionation is an attempt to refine this approach by identifying relative amounts of different types of inorganic phosphates in a soil/sediment sample. Different percentages of the various fractions can be considered as the result of variation in land use. Again however it is necessary to take natural pedogenic and diagenic processes into account when attempting to consider the total phosphate balance and phosphate fraction values in terms of land use. Together, the procedures of soil/sediment morphology, field and microscopic, and phosphate chemistry, total analysis and fractioned values, potentially provide a powerful set of tools for elucidating the land use and land use intensity of the deep top soils and farm mounds in Orkney. The foundations for this assertion are presented in the following sections.

7:2 Morphology as a Means of Identifying Land Use and Land Use Intensity Associated with Anthropogenic Sediments

7:2:1 Field Morphology

Field morphology of anthropogenic sediments potentially offers the first estimation of land uses associated with anthropogenic sediments. The initial task of any field examination of soils/sediments is to identify distinct horizons or units. Without accurate identification of horizons,nothing can be said about their organisation and inter-relationships from which function can be inferred. Based on Munsell colour, texture and stoniness, identification of horizons in the field should present no real difficulty. These methods are standard and widely applied (Hodgson, 1978). It is how these sediments are organised that is of critical importance in identifying early land uses and so several case studies of how sediment organisation relates to usage are now briefly described. These studies have been selected to illustrate sediment organisations for land uses which have been hypothesised for the deep top soils and farm mounds (Chapter 6).

The first example are the wurts of northern Germany. These landscape features were constructed deliberately as a raised living platform in poorly drained areas. Stable refuse was carefully packed into layers forming the wurt core. This was then covered with a layer of carefully packed clay sods with the internal layers of these clay sods completely intact (Korber-Grohne, 1981). Thus the layering and careful packing of sedimentary materials, evident in the field, in a mound of unknown function could well be indicative of a raised living platform.

A second example is mound formation by house collapse, a phenomenon characterised by the tells of the Near East. Excavation of a tell at Sitagroi (Renfrew, 1971) revealed more than 10m of stratified deposits. These deposits exhibited distinct floor levels based on their compaction and thick homogenous layers which are the result of wall collapse (Lloyd, 1963). Thus movement of material to the tell was conditioned by the requirement for building material; the function of the mound over the ages was a dwelling area. Post depositional processes have since re-organised this material principally by wall collapse. Again however, the point to note is that homogenous layers interspersed by compacted stratigraphic units, considered to be floor areas, can be identified in the field. A broad indication of mound function can thus be obtained from field evidence alone. Further stratigraphic evidence of a dwelling function for the farm mounds would be furnished if post holes could be identified. In plan view these features are roughly circular and can be over 1m in diameter. They can be recognised because a different matrix from the surrounding sedimentary material generally fills them. This infilling matrix may have been packing material or material that has fallen into the hole. Watkins (1978-80) identifies numerous post holes at the Dalladies Iron Age settlement, Kincardine, Scotland, by their featureless dark soil, distinct from the surrounding matrix.

Finally, midden deposits are also recognised on the basis of field observation and are identified as such in many archaeological investigations (eg Bailey, 1975). The main sedimentary characteristics of such deposits is that they take the form of bands and lenses of varying materials, deposited at varying angles. Pieces of bone, shell and charcoal may be found in such midden material. It is obvious therefore that such deposits in an unknown field situation could be clearly distinguished from deliberate packing of material to form the wurt and the thick homogeneous layers of tell formation. All of the above discussion assumes that post depositional processes have not altered the original stratigraphy. It is essential therefore to identify changes in the original depositional stratigraphy and to be able to ascribe these changes to particular post depositional processes.

Post depositional disturbances caused by human activity may yield vital clues as to the use of an area, particularly where cultivation is thought to have been practised. The implements of early cultivation have been experimentally demonstrated to leave marks and traces in soils and sediments (Hansen, 1968-71). Understanding of the soil organisation caused by early agricultural implements is best developed for ploughs and ards. Plough marks can indicate the implement used, the direction of movement and the intensity of ploughing. Such marks, normally between 10-100mm thick, are frequently identified as darker streaks in lighter coloured sub-soil (Breeze, 1972-75; Noe, 1976-79; Madson, 1980). The contents of these marks are partly surface soil that has fallen back behind the plough share and partly of soil pushed in from below or the sides of the furrow (Neilsen, 1968-71). It may be possible therefore in anthropogenic sediments of varying coloration, to detect plough marks. It is not however necessary to have differing coloured soils for plough marks to be evident. Hansen's (1968-71) experimental work with early ploughs established that the lower part of the plough share made a pale zone of torn up soil within the top soil, resulting from the movement of particles horizontally and vertically during tillage. Similarly, Neilsen (1968-71) identified lighter streaks in surface "sandy mould" which he considered to represent ploughing activity. Good preservation of top soil plough marks and other arable features, eg ridges, wheel tracks, harrow marks and hoof imprints, probably require burial soon after their formation (Ramskow, 1981). Such conditions may well be provided by the deposition of material forming the deep top soils and farm mounds.

The effect of people or animals moving about on a mound, or indeed in an arable area, may have the effect of homogenising anthropogenic sediments. Based on artifact distribution,Mathews (1965) estimated that a zone of 30cm thick could be affected in this way. This zone of disturbance moves upwards as the deposit grows blurring the depositional characteristics. To complicate this issue, Hughes and Lampert (1977) demonstrated that different materials have different susceptibilities to this type of disturbance. However farm mounds and deep top soils in all probability fall into the category that would be affected by trampling. Homogenous horizons in the mounds may therefore represent trampling effects and the use of an area of the mound as a pathway.

Finally, interpretation of land uses from properties of sediment organisation can only be successful if natural post depositional processes do not change the sediments beyond recognition. Horizonation due to podzolisation processes have been identified in plaggen soils now under forest cover (de Bakker, 1979) as is evident by the eluvial horizon. As both the deep top soil units and farm mounds selected for this study lie in a podzolic environment, profile development might be expected to take place. Pedogenic horizons should however be readily seen in the field particularly if comparison is made with surrounding soils and are unlikely to cause problems when identifying anthropogenic sedimentary units and their organisation. Where problems in interpretation are likely to arise is when the sedimentary materials have been homogenized. Wood and Johnson (1978) identify nine pedoturbation processes relevant to archaeological context which will homogenize sediments. Of these processes perhaps the most relevant to the Orcadian situation is faunal turbation caused by earth worms. Stein (1983) identified two disrupting effects on sediment stratigraphy at Carlston Annis shell mound caused by earth worms, mixing of different sediments and destruction of sedimentary unit boundaries. Both if present in the Orcadian features would make it difficult to identify functions from sediment stratigraphy. Zones of sediments which are homogeneous must be examined closely for evidence of natural post depositional disturbances, in particular root activity and early worm activity, evident as channels and burrows in the stratigraphy.

It may be concluded that field observations on their own can provide a good indication of the general function of a deep top soil unit or farm mound provided preserving conditions have prevailed. The studies reviewed above provide a basis against which observations of sediment organisation in deep top soils and farm mounds can be evaluated. Clear differences in sediment organisation caused by different functions are evident where post depositional disturbance has not taken place. It may be possible to identify ploughing and trampling effects in stratigraphies - anthropogenic post depositional disturbances. Care will be required however to differentiate anthropogenic post depositional disturbances from pedoturbation effects.

7:2:2 Thin Section Micromorphology as a Means of Identifying Land Use and Land Uses Associated with Anthropogenic Sediments

In principle, thin section micromorphology, introduced to pedology by Kubiena (1938), represents an extension of the observations made in the field. Thin section micromorphology permits identification of anthropogenic sediment organisation below the resolution of the naked eye. A 30um slice of resin impregnated soil mounted on a glass slide is examined by means of a petrological microscope. The principles in using thin section micromorphology to elucidate functions in an area are precisely the same as those for field morphology. Identification of land use function is dependent upon being able to observe depositional characteristics and post depositional alterations caused by man within the context of inherited characteristics and natural pedogenic changes. Features observable in thin section which identify distinct sedimentary units and pedogenic processes are already well documented (Romans and Robertson, 1975; FitzPatrick, 1980; Mücher and Morozava, 1983) and so, with experience, should be readily recognised in anthropogenic sediments. What is less easy is the attributing of micromorphological features to anthropogenic activity. In his recent "state of the art" summary of micromorphology in archaeological research, Goldberg (1983) notes that the technique has rarely been used to identify site function. (Goldberg only reports Bar-Yosef, in press, a study of a Bedouin camp). Clearly controlled experimentation is desirable but in the absence of such micromorphological data, there is still some evidence to suggest that this technique is potentially of great value in elucidating site functions.

Intuitivly if depositional and post depositional anthropogenic processes can be recognised in the field,it seems possible that such processes will be observable in thin section. Numerous studies into the effects of contemporary land use activities, primarily agricultural, on soil micromorphological properties would tend to confirm this. Structural changes at the micro-morphological level can be observed when forest heath or grassland is converted to arable land (Jongerius, 1983). Moving implements also influence soil structure. Tractor wheels travelling over the soil body have been demonstrated to alter shape, orientation and size distribution of pores (Murphy et al 1977), while tillage operations produce considerable variability in aggregate size distributions as well as a major influence on fabric reorganisation (Pawluk, 1980). Treatment of soils with organic amendments has resulted in modified pore size distribution by increasing the number and the percentage area occupied by pore spare in the 50 - $<$ 500 μm size range (Pagliai et al, 1981). Of interest in this study was that pore size distribution modification was much the same for different organic amendments. The use of sewage sludge, compost and manure resulted in the same pore size distribution. As a final example,Jongerius (1970; 1983) reports differences in slaking characteristics, in percentages of pore space and in humic aggregates under different crop rotations.

Clearly a variety of different anthropogenic activities on and in the soil body readily alter its structure. This presents hope that historic and pre-historic anthropogenic activities will be recorded by soil structural characteristics. The readily altered nature of soil structure is however likely to present problems to the re-construction of anthropogenic activities as structure may simply be recording the most recent process to act upon the soil body. Still, where soils or sediments are buried, as is the case with deep top soils and farm mounds, structural characteristics associated with anthropogenic activity may be preserved. Land clearance and cultivation by late Neolithic or early Bronze Age man has been observed as distinct micromorphological features. Discrete contrasting areas of poorly and well organised plasma were identified in a buried palaeosol at Pitstone, Buckinghamshire, England (Valentine and Dalrymple, 1976). Micromorphological analysis of the late Roman/early Medieval dark earth from Gloucester, London and Norwich was used to verify hypotheses concerning the use to which these soils were put (Macphail, 1983). Based on organic material in thin section and the basic fabric, micromorphology supported the hypothesis of two types of dark earth, one being the result of refuse disposal, the other being deliberately imported for urban cultivation. Macphail also stresses the importance of fabric organisation caused by earth worm activity. Examination of Valentine and Dalrymple's (1976) study and Macphail's (1983) study show that juxtaposed fabrics are indicative of arable activity, a micromorphological property which could be of importance when considering farm mound function.

In conclusion, it can be stated that buried soils offer the best hope for the preservation of early anthropogenic activity. While micromorphology holds considerable promise for the identification of early land use,the lack of experimental evidence available at present is a serious drawback to using this technique. Nevertheless it was decided to proceed with this technique because it should at least be able to discriminate anthropogenic post depositional disturbance characteristics from natural post depositional features. Some degree of interpretation of anthropogenic features may be possible based on the work of Macphail (1983) and Valentine and Dalrymple (1976) and by considering the thin sections in relation to conclusions drawn from field morphology.

7:3 Soil/Sediment Phosphate Chemistry

7:3:1 Total Phosphate Analysis of Anthropogenic Soil/Sediments To Elucidate Land Use and Land Use Intensities

Of all the soil elements examined in archaeological and historical contexts phosphorus has had the longest history and the greatest range of applications. Hughes (1911) first identified enhanced soil phosphate levels associated with human activity in relation to the Egyptian pyramids (reported by Hamond, 1983). Some decades later between the 1930s and 1950s, Arrhenuis in Sweden and Lorsch in Germany analysed soils for available phosphorus to identify settlement location and so construct early population concentrations on a regional scale (Cook and Heizer, 1962; Eidt, 1984). Since these pioneering studies the use of soil phosphate analysis has had an increasing role to play in questions of historic and pre-historic man-environment relationships. This is thanks to the peculiar binding properties of phosphorus which results in its long-term retention in the soil. Added to this is the fact that various human activities frequently disrupt the biogeochemical cycle of phosphorus leading to loss or gain in the soil system. Recent applications of soil/ sediment phosphate analysis in early man-land relationship studies have included the identification and delimitation of sites of archaeological interest, the identification of features of within settlement areas, establishment of relative population densities at a site and assessing the broad dietary habits of a population (see for example Cook and Heizer, 1962; Conway, 1983; Hamond, 1983; Provan, 1971; Bakkevig, 1980; Eidt, 1977; 1984; Davidson, 1973; Griffiths, 1980; 1981; Sjoberg, 1976).

In considering phosphorus in the environment the most convenient framework is that of the P cycle (see for example Brady, 1974; Emsley and Hall, 1976). On a global scale the P cycle consists of a primary inorganic cycle and two secondary organic cycles, one terrestrial, the other marine (Emsley and Hall, 1976). The concern in this thesis is primarily with the terrestrial soil/ sediment part of this cycle and so attention is focused on this area. The level of discussion required on the behaviour of phosphorus within the terrestrial cycle is dependent on what type or amount of phosphorus is actually being measured. It is possible to measure several species or fractions of phosphorus in the soil. The two simplest methods, and those of which the Strathclyde University Geography Department Laboratory has experience is the determination of 'available' phosphorus and total phosphorus. Interpretations of land use function from plant available phosphorus are difficult to make for several reasons. These include the fact that different extractants remove different amounts of 'available' phosphorus and so it is not certain precisely what is being measured. A second problem is that the available phosphorus is more readily removed from the soil by leaching and plant uptake (Eidt, 1977). 'Available' phosphorus values are unlikely to give a good indication of land use functions and intensities. Determination of total phosphorus values has already been successfully undertaken to identify the anthropogenic nature of the deep top soils and farm mounds (see Chapter 3). Furthermore if total values are used it will be known that these represent the balance of the amounts of phosphorus contained in the original anthropogenic sedimentary material plus additional inputs less outputs.

It may be argued therefore that spatial variation in total phosphate levels potentially represent differences in land use functions. Such variations may arise because sediments of different phosphorus concentrations may be deposited on different land use areas. Also, different cropping activities will remove varying amounts of phosphorus from the soil resulting in a distinctive total phosphate value. Oats and barley, the two main crops grown in medieval Orkney, remove 4.4 and 6.0 kg/Ha respectively of elemental phosphate per year. In natural ecosystems the death and subsequent decay of plant and animal material returns phosphorus to the soil system and thus an equilibrium is maintained. Any attempt to interpret land use type and intensity from total phosphate values must take into account variations due to natural processes. Considerable variation in phosphorus content exists in the organic materials of which anthropogenic sediments are in part composed (Table 7:1).

Table 7:1

P_2O_5 Amounts in Some Contemporary Organic Materials

Source	P_2O_5 As a % of Material
Dairy cattle manure	0.12 (after Brady, 1974)
Feeder cattle manure	0.21 " " "
Pig manure	0.32 " " "
Sheep manure	0.31 " " "
Horse manure	0.20 " " "
Seaweed (average)	0.046 (after de Boer, 1981)
Seaweed (range)	0.0007 - 0.27 (after de Boer, 1981).

Variation in amounts of phosphorus in inorganic materials might also be expected in Orkney where sedimentary rocks form the basement geology. Input of phosphorus to the anthropogenic soil/sediment system via precipitation can however be considered as negligible except in areas where today there is intensive agricultural activity (Wadsworth and Webber, 1980). Loss of phosphate from the soil/sediment as a result of leaching is considered to be limited because of the exceptionally low degree of solubility of phosphorus in the soil (Eidt, 1984). Humification releases the organically bound phosphate which, in acid soils, is rapidly fixed through ligand exchange by iron and aluminium hydroxide or oxides. Under basic pH regimes calcium compounds fix the released phosphate (Russell, 1973). Over the c 1400 year time span with which this thesis deals it maybe expected that a large proportion of the phosphorus within the Orcadian anthropogenic sediments will be retained (Walker and Syers, 1976). Only with areal re-distribution of phosphate caused by soil erosion will the original total phosphate pattern be altered or destroyed (Shapley and Smith, 1983; Oldfield, 1983).

Several studies have demonstrated that it is possible to establish discrete functions in areas of human activity using total phosphate analysis of soils. Within a former Huron Indian village(dated to the 1600s) in Canada,the Benson site, organic and inorganic phosphorus levels gave indication of middens, post moulds, pits, paths and houses (Griffiths, 1980). Phosphorus (available and total) in conjunction with trend surface analysis was used successfully by Conway (1983) to establish several features of a Romano-British hut group in Wales. In different buildings of the group, walls, concentrations of occupation within huts, stall areas for cattle, byre drains and hearths were indicated by phosphorus values. Beyond the immediate areas of the huts, courtyards and middens were indicated. As a final example, a study by Konrad et al (1983) at a pre-historic Indian site beside Munsunga Lake, Maine, USA established that total phosphate analysis indicated different activity areas in settlements as old as 10,000 years.

Similar principles can be applied to land use beyond the immediate settlement area. Improvements of arable soils by the application of manure, humus, ashes, etc raises total soil phosphate levels. Areas where slash/burn agriculture is practised and in areas where crops are removed without land fertilization will serve to deplete phosphorus levels in soils (Eidt, 1984). Different farming practices may therefore be expected to exhibit distinctive phosphorus soil profiles. Considerably less work has been done to elucidate agricultural land uses from phosphorous analysis as compared with habitation sites. Some studies do however indicate that this method is appropriate to the problem of identifying the land use associated with deep top soils. Bakkevig(1980) at Sandra Farm,dating from the Iron Age, in the Suldal district of Norway, used phosphate spot test analysis (Eidt, 1977) to identify pre historic arable activity. Ralph (1982) demonstrated a 15-20% increase in amount of soil phosphate in a medieval droveway, a 60% increase in a sheep field and a small net gain in a tilled field which represented the balance between crop removal and manural additions.

Based on these examples it would appear that total phosphate analysis offers a real possibility to elucidate deep top soil and farm mound function and function intensity. This is provided that results are interpretated in terms of a simple input-output model of phosphorus behaviour in soils and sediments.

7:3:2 Phosphate Fractionation Analysis

Determination of total soil phosphate values will not always separate out different land use functions. On occasion there may be exceptionally high natural levels of phosphorus in soils. Also, and perhaps of more relevance to this present work, is the possibility that different intensities of a particular land use may result in total soil phosphate values being similar to another land use. Recently efforts have been made to overcome such problems by attempting to identify the composition of inorganic phosphorus compounds in anthropogenic soil/sediments. Basically three approaches are possible to obtain this information, equilibration methods (Black, 1957), the solubility product principle (Larsen, 1967; Russel, 1973) and fractionation by using several extractants consecutively (Chang and Jackson, 1957; 1958). Of these three procedures, only fractionation has, to the author's knowledge, been used in the context of early man-land relationships. Eidt and his co-workers in several publications have developed the techniques of Chang and Jackson producing a procedure which, it is claimed, extracts the inorganic phosphorus associated with settlement activity (Eidt, 1984; 1977; Eidt and Woods, 1974; Woods, 1977). By Eidt's procedure three principle types of inorganic phosphorus compounds are identified.

1. Easily extractable phosphate, consisting mainly of loosely bound Al-P and Fe-P and that resorbed by Ca CO_3 plus the minute amount of phosphate already in solution.

2. Tightly bound or occluded phosphate absorbed by diffusive penetration or by incorporation with aluminium and iron oxides and hydrous oxides.

3. Occluded calcium phosphate and apatite.

Proportions of phosphorus in these three fractions are thought to vary in a predictable way with land use. Such correlations can be explained, Eidt claims, by the different amounts of phosphorus removed from the soil by grazing, harvesting, etc or added to the soil by fertilization, waste disposal etc. These assertions are supported by analytical evidence from a wide variety of environments. Residential land use, planting ridges, burials, ceremonial sites and forest sites have been identified, and even distinction between fields with different crop combinations have been achieved by the phosphate fractionation procedure of Edit. Other workers have used phosphate fractionation procedures to identify differences between cultivated and uncultivated soils. Such studies have indicated that considerable amounts of inorganic labile phosphorus are removed during cultivation and crop removal (Hedley et al 1982; Tiessen, et al 1983). Although the procedures used in these experiments differed from those used by Eidt, they still serve to indicate that phosphate fractionation procedures are potentially useful in elucidating land use histories.

Phosphate fractionation has not been without its critics. Larsen(1967) commenting upon the Chang and Jackson (1957) fractionation technique stated that the method was arbitrary because the extraction reagents will inevitably cause a re-distribution of phosphate during the extraction. Compounds reported to be present may not have been so in the original soil material. In Larsen's opinion the most relevant means to identify the nature of phosphorus in soils is by the solubility product principle. White (1978) points out that Eidt's procedures fractionate soil phosphorus primarily into Al-P, Fe-P and Ca-P. As Al, Fe and Ca can vary considerably within the soil profile and under different pH conditions, interpretations of land use functions from fractionated values will be erronous. Some support for White's contention comes from Eidt's own data (Eidt, 1984). Data for phosphate fraction 1 show a significant Spearman Rank correlation with pH at the 95% level while phospate fraction 3 data correlate with pH at the 99% level. This supports the alternative hypothesis that there is a statistically significant relationship between pH level and phosphate values from fraction 1 and 3 of Eidt's fractionation method. Nevertheless, the fractionation procedure of Eidt's is gaining increasing acceptance amongst geographers and archaeologists. Selected samples were therefore examined for variation of fractionation values.

7:4 Materials and Methods

The materials and methods are described only briefly as full details are given elsewhere. The strategy in selection and sampling of anthropogenic sediments to elucidate their processes of formation has already been given in Chapter 6. It is worth repeating here that attention focuses upon the deep top soil units at West Howe (HY21 35) and the farm mounds of Westbrough (HY663 423) and Skelbrae (HY676 438). Selection of profiles was based upon pre-agricultural revolution maps which show the different land uses in early Orcadian townships. Profiles were dug in these different land use areas as outlined below.

In the effort to elucidate the function of the deep top soil units a total of nineteen profiles were considered. Six profiles were within the area mapped as a deep top soil, seven in non deep top arable land, two in the meadowland and one each in the farmyard zone, reclaimed hill land and undisturbed hill land. Eight profiles were considered in relation to the function of Westbrough farm mound, five within the mound itself and one each from meadowland, arable area and grazing land. Six profiles were considered in relation to Skelbrae farm mound function, four from the mound and two from beyond the mound area. Profiles are described in Appendices IV-VII.

Full details of the methods of analysis are given in Appendix VIII. It is sufficient to say here that field description of soils/land sediments was based on the Soil Survey field handbook (Soil Survey, 1976). Field properties considered to indicate the organisation within and between the horizons and the potential causes of that organisation, including anthropogenic, were structure, organisms, phosphate spot test value, mean horizon thickness, mean horizon orientation and horizon continuity. For the ninety-seven farm mound horizons, a similarity matrix was calculated using Gowers Coefficient of Similarity (Gower, 1972) and the results fed into a computer package programme for Cluster analysis (Wishart, 1979). Thin sections were described according to the system of FitzPatrick, (1980). Total phosphate analysis of soils/sediments was by the fusion macro-method outlined by Jackson (1958). Phosphate fraction analysis with minor adaptions followed the procedures of Eidt (Eidt and Woods, 1974; Eidt, 1984).

7:5 Results and Discussion : Deep Top Soils, West Howe, Marwick

This section is divided into three parts. Interpretation of deep top soil morphology in terms of land use is presented first, followed by interpretation of the phosphate chemistry results. These two strands of evidence are then brought together so that a coherent statement of deep top soil land use and land use intensity can be made.

7:5:1 Morphological Investigation

The opening approach was to set the deep top soils of Marwick in context and demonstrate how environmental constraints set limits upon 18th Century land use in the Marwick Basin. Examination of the four major types of 18th century land use in Marwick (Fig 6:1) in relation to topography (Fig 6:7), drainage conditions (Soil Survey for Scotland, 1981) and examined soil profiles permitted the following observations to be made. Hill land is restricted to the higher and/or steeper ground beyond the hill dyke. Profile "Control" provides a description of an unmodified hill land soil profile, while profile Howe 31 indicates a profile that has been cut over and subsequently reclaimed as is evident from the organic layer within the profile at c 22cm depth. Descriptions of these and other profiles examined in Marwick are given in Appendix IV. Within the confines of the hill dyke meadowland is found on the low-lying poorly drained alluvial and gley soils of Marwick. Mottling and gleying of sub-soil horizons characterise these areas (see Howe - peat-alluvium profile). Other 18th Century land uses are not exclusive to particular areas of the landscape but imperfectly drained soils of the Bilbster Series are dominated by grazing land and non-deep top soil arable land (Profiles Howe 26A, 26,23 and 34). Some deep top soil arable land is to be found in these imperfectly drained areas,(eg Muce profile) but more normally these are located in areas of the freely drained Bilbster Series (Profiles Howe 23A, 18, 18A, and 13). Non deep top soil arable land also occupies freely drained areas but normally at higher altitudes than the deep top soils (Profiles Howe 3A, 3, 27A and 27). It can be concluded therefore that environmental parameters, in particular drainage and altitude, set limits upon the early land use types of the Marwick Basin. From an arable viewpoint deep top soils occupy the most attractive location. This could mean that this area represents the earliest arable activity and most valued land, characteristics that are indicative of the tunmal in Orkney as described in Chapter 6. Set in context there is good reason to propose that deep top soils represent the tunmal zone of the Orcadian township.

Further evidence that areas of deep top soil represent the tunmal is the distinct break in slope that can be observed along part of the downslope edge of the West Howe deep top soil unit (Fig 7:1). It is entirely reasonable to postulate that this slope form has arisen by a process possibly analagous to one theory of lynchet formation. Cultivation can accelerate the movement of soil

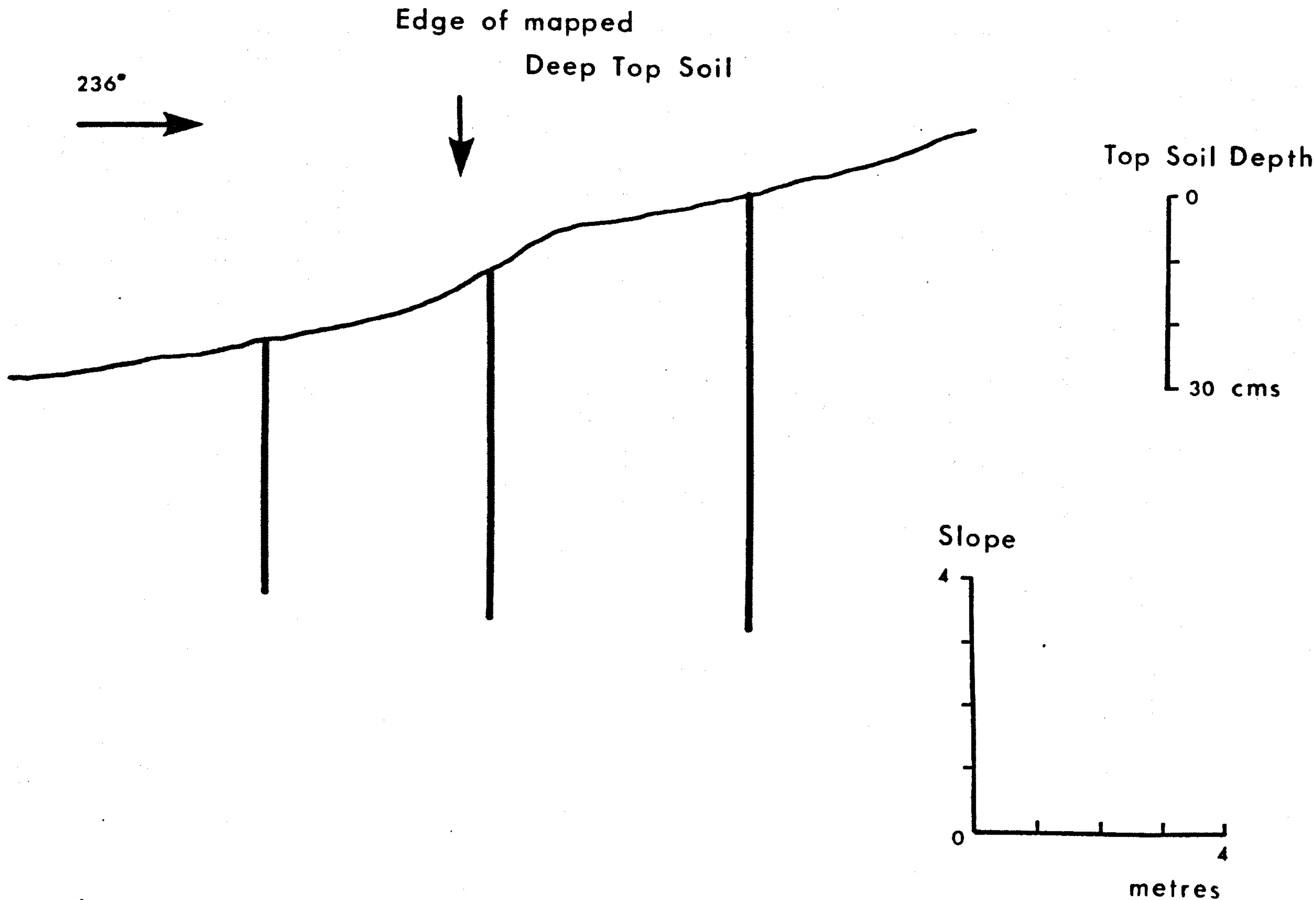


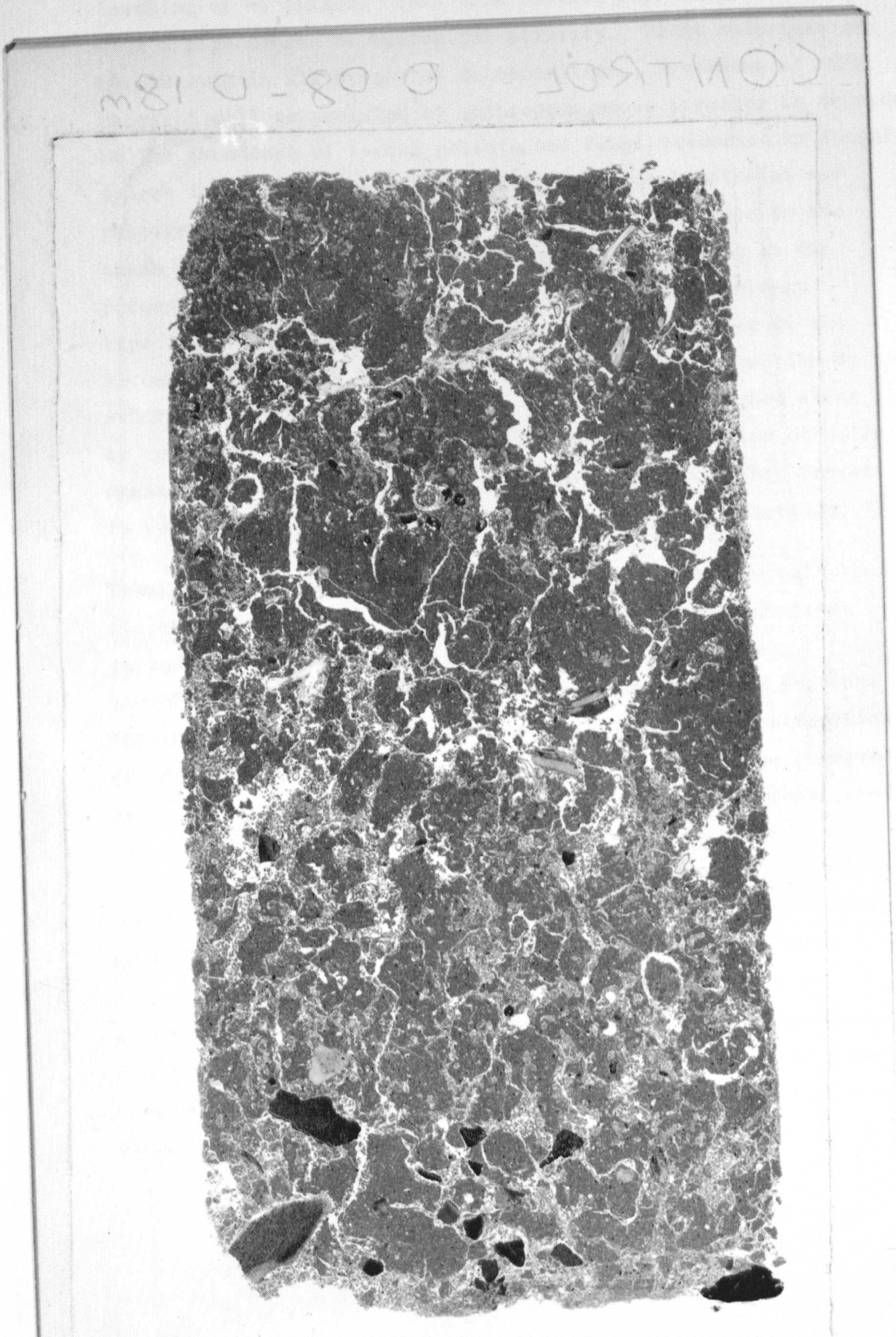
Figure 7:1 The observed break in slope along the edge of the mapped deep top soil.

material in the downslope direction, material which accumulates on the uphill side of permanent field boundaries or other obstruction MacNab, 1965). The most likely obstruction at this point in the landscape in Orkney would be the Auld Bow turf dyke which separated the tunmal from the rest of the township. It seems clear from field evidence alone that the areas of deep top soil represent the tunmal.

The above paragraphs provide evidence from the field that deep top soils can be considered as the tunmal area of the township. Within the deep top soil zone itself careful examination of profiles Howe 13, 18, 18A and 23A give no indication of varying arable practice except that the thickness of deep top soil tends to decrease with distance from the farm. Whether this reflects a variable function of the tunmal will be discussed later. All the field indications today are that the deep top soil at West Howe is a homogenous unit. Any horizon boundaries within the S horizon are clear and smooth and in any case the slight colour differences (10YR 3/2 to 10YR 3/3; 10YR 4/2 to 10YR 4/3; 10YR 4/4 to 10YR 3/3) are most likely due to differential drying out of the profile rather than any sedimentary difference. Other S horizon characteristics are virtually identical and thus post depositional processes may have served to remove any sedimentation structure there might have been. Such a homogenization process included, with the exception of the Howe 23A profile, the incorporation of the original A horizon into the deep top soil, suggesting piece-meal deposition of the sedimentary material.

Examination of six thin sections from the West Howe deep top soil unit was undertaken in an effort to further characterise the structure and organisation of these deep top soils and so identify depositional and post-depositional processes. Two thin sections came from each of the Howe 13, 18 and 23A profiles. These are considered in relation to a seventh thin section which is from the undisturbed hill land profile ("Control" profile). This site is probably as close to any of a profile formed by natural processes in Orkney. The Control thin section (Plate 7:1)

PLATE 7:1 Thin section from the undisturbed Hill land (control) profile. 8-18cm depth. (x2 magnification).

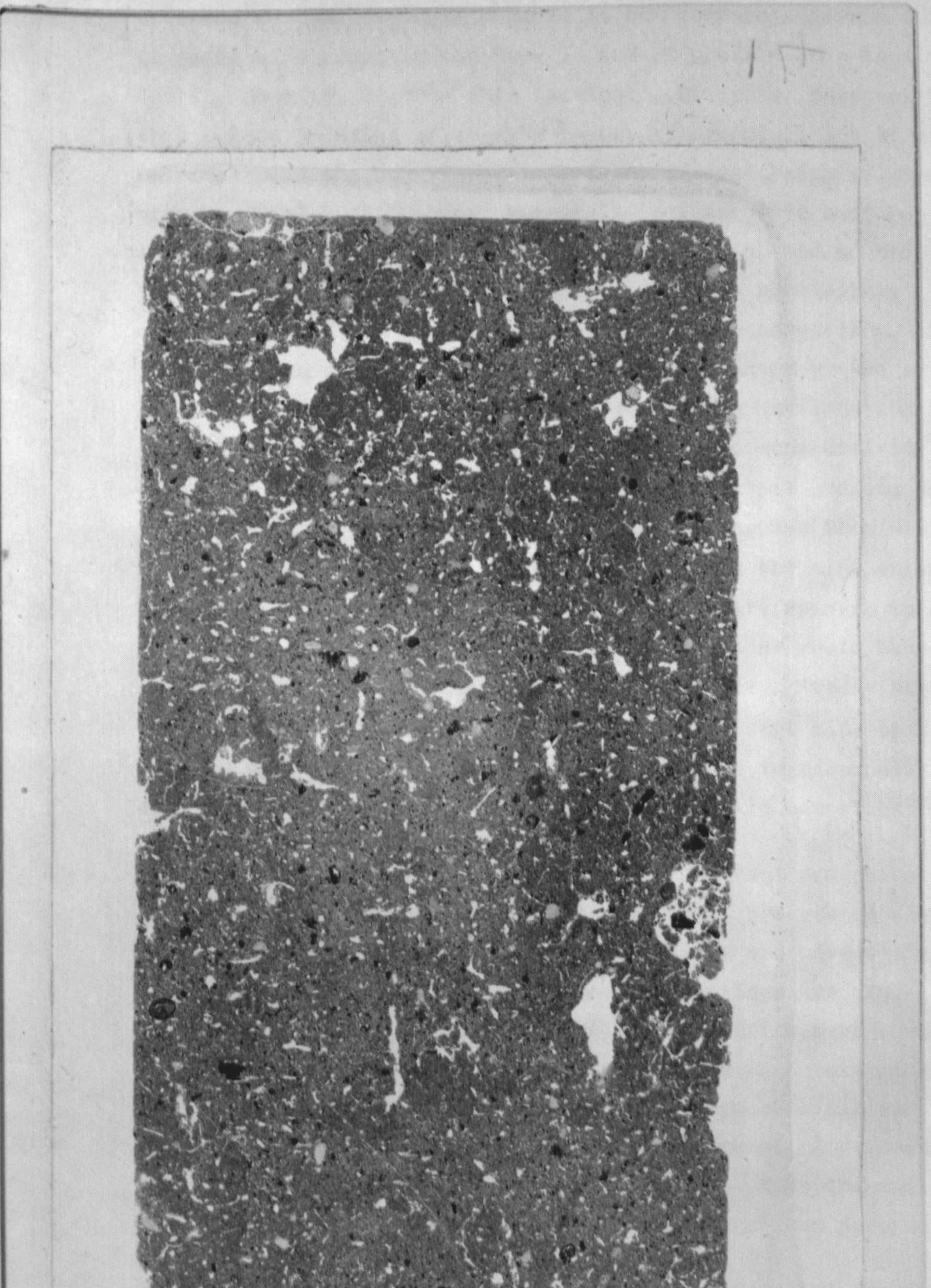


is described in Appendix IX. It is characterised by a subangular blocky and crumb structure with weakly to strongly accordant peds. Within these peds are very small crescentic to ovoid discrete pores. Frequent incomplete pores surround the peds. Two sets of processes dominate in this top soil as evidenced by micromorphological features, active biological activity and leaching of materials. This thin section represents a soil with a high degree of biological activity. Plant materials can be observed in all stages of decomposition. Breakdown of this material will be assisted by anthropods,whose presence is detected by the abundance of faecal pellets, and fungi, evidenced by fungal spores in thin section. Enchytraid worm faecal material and passages can also be detected and probably contribute to the crumb structure of this section. Wetting and drying is the process most likely responsible for the subangular blocky structure of the upper part of the section. Leaching is the second process that can be identified in this thin section by the evidence of bleached stone rims. Formation of bleached stone rims is considered to be associated with the transportation of colloidal organic matter which forms an iron humus complex. This process is found dominantly in podzolic soils (Romans and Robertson, 1975).

Examination of the six deep top soil thin sections reveals their close similarity to one another, and their sharp contrast to the undisturbed profile described above. It is therefore possible to consider the deep top soil thin sections together. Features which indicate post depositional alterations of the material by natural processes and by man can be observed. There is also some evidence remaining for the depositional process. The deep top soil thin sections are described in Appendix IX from which it can be seen that natural post depositional processes dominate (Plate 7:2).An alveolar structure is found throughout each section with discrete pores of an ovoid to crescentic shape. The most likely interpretation for the formation of this structure is to be found in the joint processes of compaction and decomposition. Compaction is primarily the result of the overburden and possibly some degree of trampling due to arable activity. This has the effect of welding peds and larger soil groupings together. Some

PLATE 7:2 Thin section from the West Howe deep top soil. Profile Howe 13, 40-50cm depth.

(x 2 magnification)


HOME 13

evidence for this welding process is the composite matrix colours of small size found in the Howe 13 and 23 profile thin sections and the Howe 18, 20-30cm thin section. Discrete pores within this welded material arise as a result of decomposition of organic materials and the subsequent release of gasses (Palagiai,et al, 1981; Brewer, 1964). All organic materials in these thin sections are strongly decomposed, unlike the Control profile, and so this alveolar structure is probably indicative of a once highly organic horizon now in an advanced stage of decomposition. No further fresh organic materials are being received by the areas of the deep top soil represented by these thin sections and this lack of input is reflected in the lack of mesofauma activity. Arthropod pellets are rare and are probably fossil judging by the fact that it was sometimes difficult to distinguish them within their surrounding matrix. A few fungal hyphae are also evidence of past biological activity. Earthworm activity appears to be absent. Presumably,prior to burial,these sections would have represented a zone of active biological activity. Today these buried sections have little of this process except microbial, causing the build-up and release of gases due to decomposition of the remaining already well decomposed organic materials.

While compaction and gas release are the dominant processes in these thin sections,another natural pedogenic process of significance is micro-erosion. Thin uniform silt coatings are observed to line many pores and channels. Sometimes such coatings are clay. These features do not appear to be illuvial (FitzPatrick,pers comm) and so it is proposed that micro-erosion of clods when this material was at the surface is responsible. Water from rainfall and the melting of snow and ice runs along the surface of clods downwards, thus eroding the soil clod (Jongerius, 1970). When the soil dries out this eroded material is deposited on channel and pore wall.

Evidence for the alteration of deep top soil material by direct human activity is limited. The use of the deep top soils as a planting medium is evidenced by an infilled root channel in the Howe 18, 20-30cm thin section, but more features of this sort are lacking. Ploughing activity has not, disappointingly, left its mark in the form of anisotropic lines. The original high organic content of the deep top soils would probably serve to mask any features of this nature, even if the light one-stilted plough was capable of producing them in the first place. Subtle colour differences within the thin sections (designated as zones in the thin section descriptions) are in part artifacts of thin section production. Such differences in colour represent slight differences in thin section thicknesses, verified by the varying brightness of quartz grains. Some of these zones do however represent slightly different materials used in the formation of the deep top soils. No distinct pattern or organisation for these colour differences exist, either within or between the thin sections. This randomness indicates a combination of unstructured deposition and mixing by ploughing. Because no pattern emerges in comparing the thin sections, it can be concluded that deposition and ploughing activity was similar throughout the deep top soil of West Howe.

Examination of thin sections confirms the field observation that the deep top soil unit at West Howe is the result of a set of similar physical processes throughout its formation. Natural post depositional regrouping characteristics dominate the thin section but it needs to be noted that processes leading to the alveolar structure of the deep top soil were initiated by human activity. Such initiating activities must have been similar throughout the deep top soil to result in the same structural type. Features which can be attributed directly to human activities, both depositional and post depositional, exhibit no spatial pattern within the deep top soil. There are good grounds therefore for considering the West Howe deep top soil as a homogenous unit at least in terms of post depositional activities.

7:5:2 Phosphate Investigations

Total phosphate analysis forms the backbone of this Section. As already pointed out in Section 7:3:1 total phosphate in a soil/sediment sample represents a balance of the inherited amounts of phosphorous plus additional inputs, less outputs. Based on this principle it has been demonstrated in numerous research papers that spatial variations in this balance can be indicative of varying land use functions. Here total phosphate analysis is used in an effort to distinguish between tunmal and townsland arable land and, further, to identify any variation of land use within the deep top soil units at West Howe. Total phosphate results in Table 7:2 were expressed in mg/100g and mg/cm^{-3} to allow for any variation in material density of the samples. However, a product moment correlation coefficient of +0.9841 indicates that there was no statistically significant difference between the two different expressions of the results at the 99.9% significance level. It was decided therefore to use only results expressed in mg/100g. Phosphate fractionation was introduced in an effort to identify distinctions in land use particularly where total phosphate values are similar in different parts of the landscape. This technique was however of limited usefulness because of the high correlation between the various phosphate fraction percentages and pH, as will be demonstrated later. Table 7:2 presents the results of total phosphate analysis of soils/sediments within the Marwick drainage basin, focussing on West Howe. From these results critical comments can be made upon deep top soil land use.

Before discussing the question of deep top soil land use as indicated by total phosphate analysis,certain preliminaries are necessary to set the West Howe deep top soil unit within the context of phosphate patterns across the landscape. Firstly it is necessary to demonstrate that certain levels of total phosphate values are distinct to what is thought to be early (pre-agricultural revolution) arable land. Secondly, it is necessary to identify any evidence of phosphate movement within and through the soil/sediment body attributable to natural processes. The data must be scrutinised for evidence of downward translocation, upward movement because of plant demand, erosion or earthworm activity. Only when these preliminaries are undertaken can meaningful statements be made about the land uses associated with the deep top soils.

TABLE 7:2

TOTAL P_2O_5 VALUES FROM SOILS AND SEDIMENTS IN MARWICK

PROFILE NO	18TH CENTURY LAND USE	HORIZON	SAMPLE DEPTH(cm)	TOTAL P_2O_5 (mg/100g)	DENSITY (g/cm-3)	TOTAL P_2O_5 (mg/cm-3)
CONTROL	HILL - LAND	A1	10	197	0.73	1.4381
		A2	20	176	0.73	1.2848
		A2	30	111	0.87	0.9657
		B2	40	93	1.20	1.116
		B2	50	95	1.21	1.149
		B2	60	80	1.16	0.928
H31	HILL - LAND (Reclaimed)	S1	10	141	0.88	1.2408
		B2 (organic)	20	231	1.20	2.772
		B2	30	90	1.20	1.08
		BX	40	83	1.20	0.996
PEAT / ALLUVIUM	MEADOWLAND	A1	20	165	0.73	1.2045
		B2g	40	126	0.73	0.9198
		B2g	60	131	2.29	2.9999
		C (waterlogged)	80	152	2.29	3.4808
H34	GRAZING LAND	S1	10	255	1.02	2.601
		S1	20	218	1.04	2.2672
		B2	30	52	1.18	0.6136
		B2	40	63	1.11	0.6993
GLEY SOIL	MEADOWLAND	S1	20	165	ND	ND
		B_2g	40	126	ND	ND

DEEP TOP SOIL ARABLE AREAS (i) WEST HOWE, MARWICK

PROFILE NO	18TH CENTURY LAND USE	HORIZON	SAMPLE DEPTH(cm)	TOTAL P_2O_5 (mg/100g)	DENSITY (g/cm-3)	TOTAL P_2O_5 (mg/cm-3)
H23A	ARABLE	S1	10	470	1.17	5.499
		S2	20	354	1.20	4.248
		S2	30	324	1.18	3.8232
		A1	40	92	1.29	1.1868
		B2	50	80	1.27	1.016
H18	ARABLE	S1	10	626	1.13	7.0738
		S1	20	423	1.12	4.7376
		S2	30	474	1.13	5.3562
		S2	40	401	1.11	4.4511
		S2	50	393	1.14	4.4892
		B2X	60	195	1.27	2.4765
		B2X	70	132	1.38	1.8216
H18A	ARABLE	S1	10	637	1.07	6.8159
		S2	20	430	1.13	4.859
		S2	30	479	1.15	5.5085
		S2	40	520	1.12	5.824
		S2	50	363	1.11	4.0293
		S2	60	326	1.10	3.586
		S2	70	326	1.14	3.7164
		B2	80	249	1.21	3.0129
		B2	90	196	1.19	2.3324
H13	ARABLE	S1	10	768	1 09	8 3712
		S2	20	430	1.12	4.816
		S2	30	558	1.11	6.1938
		S2	40	552	1.09	5.6898
		S2	50	441	1.09	4.8069
		S2	60	429	1.09	4.6761
		S2	70	394	1.18	4.6492
		B2	80	197	1.20	2.364

DEEP TOP SOIL ARABLE AREAS (ii) MUCE AND NETHERSKAIL, MARWICK

PROFILE NO	18TH CENTURY LAND USE	HORIZON	SAMPLE DEPTH(cm)	TOTAL P_2O_5 (mg/100g)	DENSITY (g/cm-3)	TOTAL P_2O_5 (mg/cm-3)
MU	ARABLE	S1	15	750	1.04	7.80
		S2	30	796	0.99	7.8804
		S2	50	1148	0.99	11.3652
		B2g	70	451	1.31	5.9081
NS	ARABLE	S1	20	1166	1.05	12.243
		S2	40	747	1.09	8.1423
		S2	60	841	1.12	9.4192
		B2	80	359	1.40	5.026

FARMYARD SEDIMENTS

PROFILE NO	18th CENTURY LAND USE	HORIZON	SAMPLE DEPTH(cm)	TOTAL P_2O_5 (mg/100g)	DENSITY (g/cm-3)	TOTAL P_2O_5 (mg/cm-3)
HOWE FARMYARD		-	20	661	0.94	6.2134
		-	40	958	0.88	8.4303
		-	60	1466	0.85	12.461
		-	80	1159	0.86	9.9674
		-	100	1677	0.89	14.9253
		-	120	1587	0.90	14.283
		-	140	1484	0.94	14.9496

NON DEEP TOP SOIL ARABLE AREAS OF MARWICK

PROFILE NO	18TH CENTURY LAND USE	HORIZON	SAMPLE DEPTH(cm)	TOTAL P_2O_5 (mg/100g)	DENSITY (g/cm-3)	TOTAL P_2O_5 (mg/cm-3)
H26	ARABLE	S1	10	525	1.04	5.46
		S1	20	439	1.07	4.6973
		B2	30	191	1.09	2.0819
H26A	ARABLE	S1	10	529	1.07	5.6603
		S2	20	441	1.12	4.9392
		B2X	30	135	1.13	1.5255
H23	ARABLE	S1	10	583	1.07	6.2381
		S1	20	651	1.10	7.161
		B2X	30	310	1.21	3.751
		B2X	40	338	1.33	4.4954
H3	ARABLE	S1	10	241	1.09	2.6269
		S1	20	220	1.11	2.442
		B2	30	121	1.16	1.4036
H3A	ARABLE	S1	10	179	1.10	1.969
		S1	20	150	1.09	1.635
		B2	30	95	1.15	1.0925
H27	ARABLE	S1	10	210	1.11	2.331
		B2	20	179	1.14	2.0406
H27A	ARABLE	S1	10	245	1.12	2.744
		B2	20	219	1.16	2.5404

From Table 7:2 it is possible to identify distinct groupings of total phosphate values in S and A horizons which relate to different early land uses. Whichever way these values are expressed, the S horizons of deep top soils form a group with those arable non deep top soils which lie downslope from the West Howe deep top soil unit (Profiles Howe 23, 26 and 26A) together with those samples at 20cm and 40cm in the farmyard. The range of this group is between 324 and 1166 mg/100g P_2O_5. Hill land (111 to 197 mg/100g P_2O_5), meadowland (one sample at 165 mg/100g P_2O_5), grazing land (218 to 255 mg/100g P_2O_5) and arable land lying upslope from the West Howe deep top soil unit (150 to 245 mg/100g P_2O_5) are all below the range for the above mentioned deep top soil/non deep top soil arable grouping. Below the 40cm level,in the farmyard the total phosphate range is higher with values from 1159mg/100g P_2O_5 to 1677mg/100g P_2O_5. Were it not for the arable land lying upslope from the West How deep top soil unit,it would be possible to conclude that early arable activity results in an almost mutually exclusive range of total phosphate value in Marwick. The range of total phosphate values for profiles Howe 3, 3A, 27 and 27A in the S horizon are similar to the grazing land range of values. It seems possible therefore that this arable land identified by the 1760s township map of Marwick represents an area which was sporadic in its cultivation. Historical evidence indicates that on occasion grazing land was cultivated and then allowed to revert (See Chapter 6). It is proposed therefore that total phosphate values from the area upslope from the West Howe deep top soil unit represent a variable land use of this type. Thus total phosphate values from the deep top soils and arable land lying downslope from the West Howe deep top soil unit represent areas of permanent arable activity. It is upon these latter areas that our attention will focus.

The second preliminary to be undertaken before detailed comment is made upon deep top soil function relates to the movement of phosphate within and through the soil/sediment body. Translocation and erosion would appear to be the most important processes that will have spatially altered total phosphate values in the arable soils. The other two major processes thought to control post depositional re-organisation of phosphate are considered to have a negligible effect. There is little or no evidence for earth worm activity in the thin sections of deep top soils (see previous section) and because there is evidence for downward translocation of phosphate into the B horizons, upward movement by plant activity appears to be insufficient to act as a counter-balance. Evidence for the downward translocation of phosporus from these arable soils comes from examining the total phosphate levels in the B horizons of early arable and non arable Bilbster Series soils. Figure 7:2 shows three sets of B horizon total phosphate values. The upper set is data from the early permanent arable land in Marwick. This set can be compared with B horizon total phosphate values from other non arable land use areas of Marwick and with other Bilbster Series soils throughout Orkney to obtain some indication of downward translocation of phosphate in early permanent arable land soils. It is worth noting that the third set of data comes from Bilbster Series soils which today are cultivated. Simply by observing Figure 7:2 it is clear that the early permanent arable land soils have a greater total phosphate content in their B horizons. This observation is confirmed by the Mann-Whitney U Test which gives a statistically significant difference to the 99.9% level when comparing early permanent arable land values with the other two data sets. The conclusion is therefore that there has been significant downward translocation of phosphate in the early arable land soils. Comparing deep top soil B horizon values with non deep top soil arable land values gave no significant difference when statistically examined with the Mann-Whitney U Test and the significant level set at 95%. Compared with the Soil Survey data, the mean increase in B horizon total phosphate levels is from 110.97 to 227.92mg/100gP_2O_5, an increase of c x 2.06. Similar figures are obtained when compared with the other, non arable, functional areas in Marwick. Here the mean increase in B horizon total phosphate levels is from 96.6 to 227.92mg/100gP_2O_5, an increase by a factor of some 2.36. Given that the range of phosphate values in the early arable land S horizons around West Howe is from 324 to 768mg/100g P_2O_5, a range of 444, a downward translocation effect in terms of losses and/or gains of c110mg/100g P_2O_5 would have a significant blurring

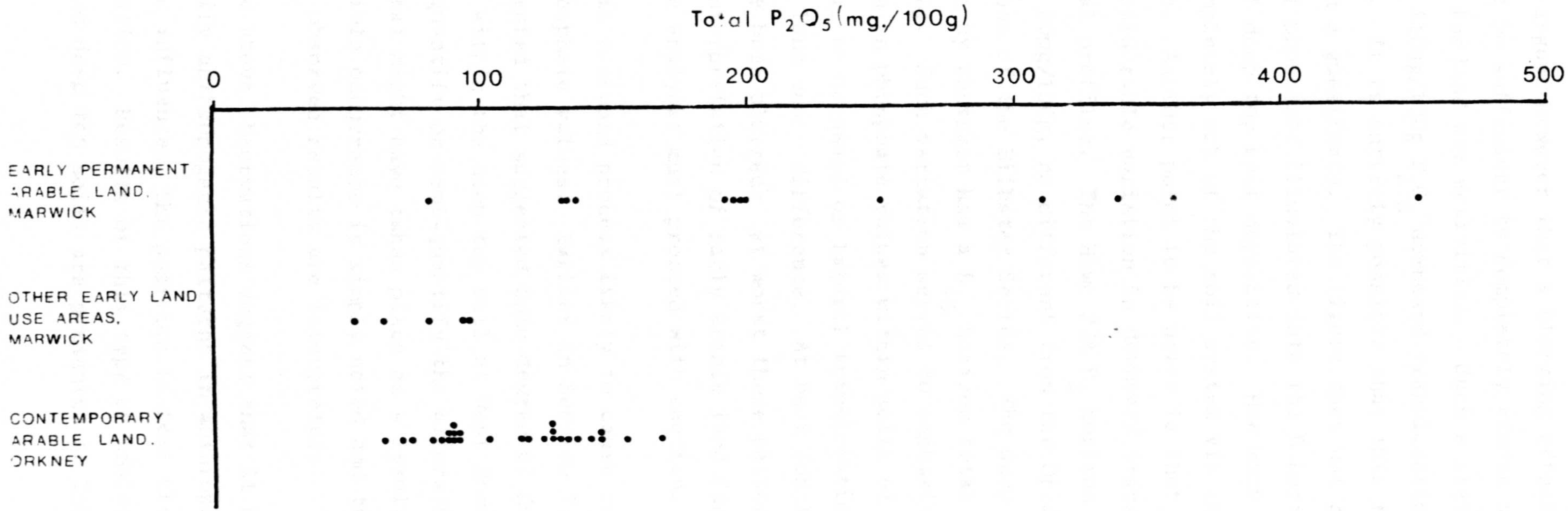


Figure 7:2 Total phosphate levels from B Horizon profiles of the Bilbster Soil Series and deep top soils.

effect on any patterns of phosphate value attributable to land use. It maybe argued however that a blurring effect of this magnitude would not be sufficient to completely remove or alter total phosphate evidence for land use activities. Such a statement is dependent on the c 110mg/100g P_2O_5 downward translocation figure being accurate. It is entirely possible that this figure is little more than a guestimate. The figure does not represent the total amount of phosphate illuviated into the B horizon during the period of deep top soil deposition. How much phosphate has moved completely out of the soil system via the B horizon is not known. Another point to be noted is that there would appear to be considerable variation in downward translocation within individual profiles. The Howe 23A B_2 horizon has a total P_2O_5 value of 80mg/100g, no different from the Orcadian background B_2 horizons of the Bilbster Series. The deep top soil profile from Muce by contrast has a B_{2g} horizon total phosphate value of 451mg/100g. Such variation serves to emphasise that spatial variation in phosphate values within soils of early arable activity may be due to downward or lateral translocation effects rather than any land use difference. At best functional patterns will have been blurred; at worst these patterns will have been lost. Interpretation of early arable land function through phosphate analysis must proceed with caution.

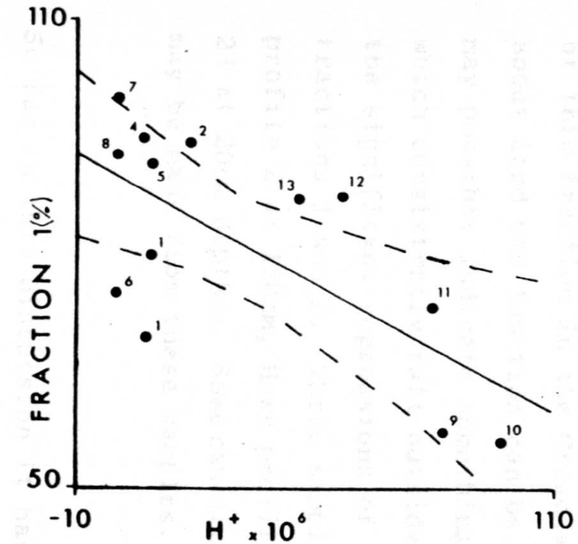
Erosion is a second process likely to cause redistribution of total phosphate values. Earlier in Section 7:5:1 field evidence was presented that suggested some degree of downslope material movement within the deep top soil at West Howe. Little can be done to quantify or semi-quantify the alteration in phosphate values that might have taken place as a result of erosion. Its possible occurrence is simply noted and taken into account when the observed results are interpreted.

While the above observations suggest that it may be possible to identify anthropogenic patterns in anthropogenic soils despite pedogenic influences, the position is less clear for phosphate fractionation. Results of this type of analysis for both farm mounds and deep top soils are presented in Table 7:3. Considering

TABLE 7:3

PHOSPHATE FRACTIONATION VALUES FROM FARM MOUNDS, SANDAY AND DEEP TOP SOILS, MARWICK

Sample & Depth No(cm)	Land use based on morpholo-:gical analysis	Total P_2O_5 mg/100g	Total fract-:ion Values mg/100g	Residual %	Fract-:ion I	Fract-:ion II	Fract-:ion III	pH
WB2/270	Midden(?)	1166	129.33	88.91	79.66	16.39	3.94	6.13
WB2/210	Midden(?)	1756	1217.44	30.67	94.26	3.37	2.37	5.90
WB2/150	Capping Material(?)	345	156.35	45.32	69.37	28.44	2.19	6.20
WB2/73	Midden(?)	726	375.77	48.24	94.50	3.32	2.12	6.33
WB-A/20	Arable Land	759	466.56	38.53	91.54	6.02	2.44	6.05
SK1/90	Midden(?)	653	216.77	66.80	74.95	23.34	1.72	7.62
SK1/150	Capping Material(?)	116	30.08	74.07	99.79	0	0.21	7.37
SK1/220	Midden(?)	1053	454.16	56.88	92.79	5.70	1.51	7.56
SK-M/10	Meadowland	373	246.56	33.90	57.50	41.29	1.20	5.19
CO 20	Undisturbed Hill land	176	21.84	87.59	45.24	54.40	3.48	4.27
H18A10	Arable Tunmal	637	376.86	40.84	56.06	41.85	2.08	5.03
H18A20	Arable Tunmal	430	252.84	41.20	73.29	25.46	1.25	5.22
H18A60	Arable Tunmal	326	187.68	42.43	87.34	12.42	0.20	5.48
H23 20	Arable Townsland	651	216.92	66.68	86.88	10.78	2.33	5.60



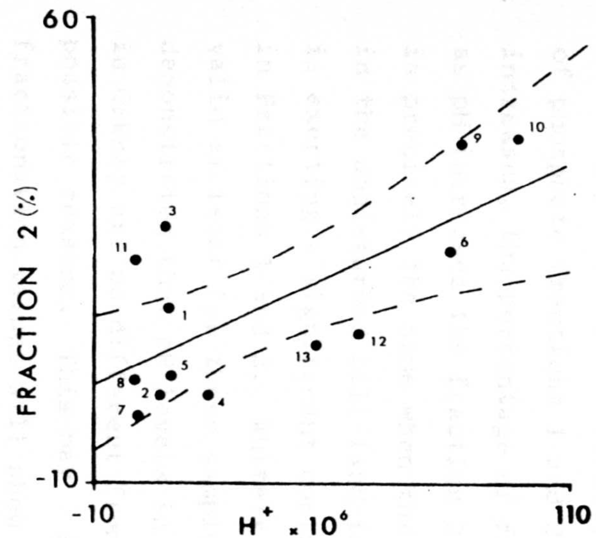
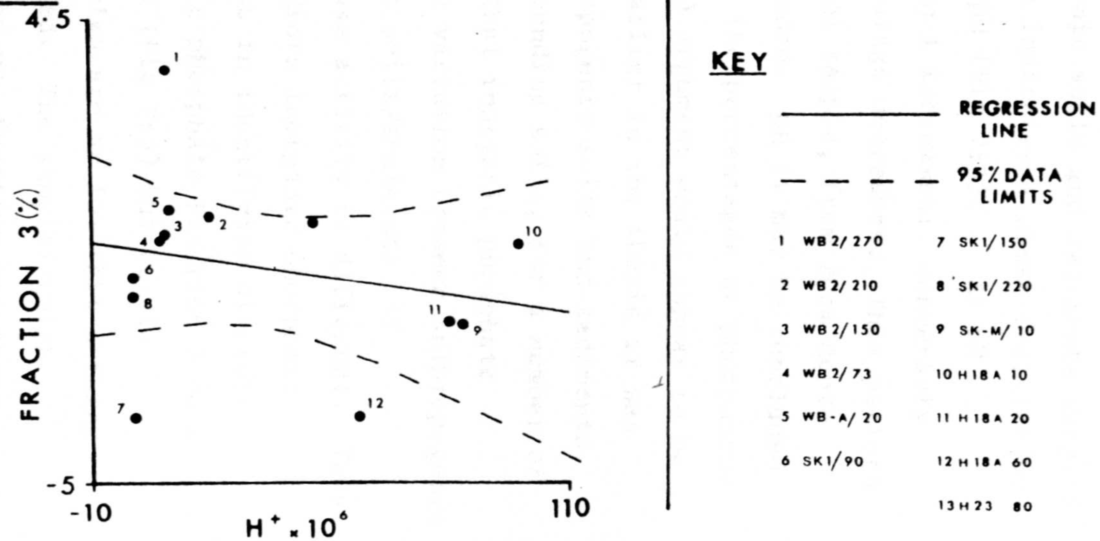


Figure 7:3 The Relationships of Inorganic Phosphate Fractions with pH.

Fraction 1 Regression line B = -0·271 C = 90.086
r = -0.680 (sig. to 95% level).

Fraction 2 Regression line B = 0.277 C = 7.888
r = 0.699 (sig. to 99% level).

Fraction 3 Regression line B = -6.394 C = 2.018
r = -0.231 (not significant).

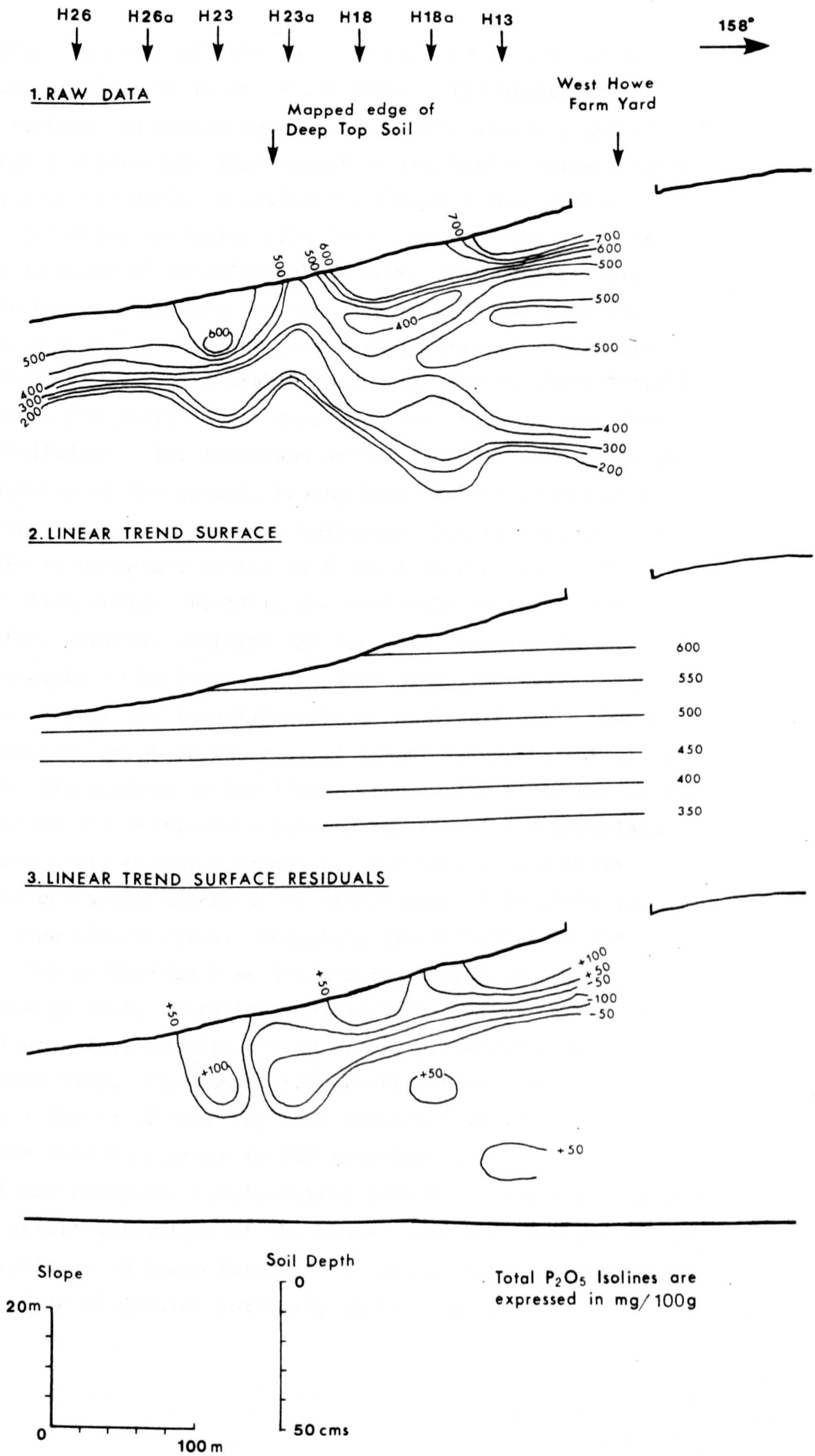


the thirteen samples from anthropogenic soils and sediments subject to inorganic phosphate fractionation indicates a clear correlation of phosphate fractions 1 and 2 with pH (Fig 7:3). As pH increases, the percentage of fraction 1 increases; conversely as pH increases the fraction 2 percentage decreases. This pattern is precisely the same when the control sample, from 20cm depth in the undisturbed hill land is included. pH it may be concluded is exerting a significant control on the percentages of phosphorus in Fractions 1 and 2. White's (1978) argument would appear to be valid at least for these samples. Earlier in the thesis it was demonstrated that pH levels in anthropogenic soils and sediments in Orkney are no different from surrounding soils, for a number of possible reasons. This may imply that inorganic phosphate fractionation values will show little variation between anthropogenic soils/sediments and non anthropogenic soils/sediments if pH is the same and even if the land use activity is different. Thus for Orkney it may be concluded that Eidts inorganic phosphate fractionation is of limited usefulness in identifying discrete areas of land use activity. Inorganic phosphate Fraction 3 does not demonstrate a correlation with pH (Fig 7:3) but levels of this fraction in the Orcadian samples are so low that nothing about land use function can be inferred. The samples which may possibly indicate something of land use function are those which consistently fall outside the 95% data limits for the significant regressions of pH against inorganic phosphate fractions 1 and 2. Three samples fall into this category, Westbrough profile 2 at 150cm, Howe profile 18A at 60cm and Howe profile 23 at 20cm depths. Some cautious conclusions of land use function may be made from these samples.

So far in this discussion it has been observed that early permanent arable land soils have virtually a mutually exclusive range of total phosphate values within the Marwick drainage basin. Relative to the background soils, soils of the early permanent arable area have a greater total phosphate content. Variation of phosphate levels within these arable soils may therefore reflect differences in the detailed function of the arable area provided downward translocation and erosion processes have not destroyed such a pattern. The task therefore is to identify discrete areas and trends within the early permanent arable land area and ascribe to them the function they served within the organisation of the Marwick township. Focussing attention on the deep top soils, the patterns of land use so identified represent the cause of anthropogenic sedimentary material movements. A synthesis of these two elements of the anthropogenic sedimentation process, land use and sedimentary materials used is undertaken in Chapter 9 together with consideration of the temporal aspects of deep top soil evolution. For the moment it is sufficient to identify discrete areas and trends of activity, a task accomplished by mapping and contouring the spatial pattern of total phosphate within the early permanent arable area. As a further refinement, trend surface analysis was undertaken and computed values and residuals plotted of the significant trends.

The conclusion of the previous section on morphological investigations was that the deep top soils formed the tunmal with the townsland arable land lying beyond. Figure 7:4 represents the plotted and contoured total phosphate values of S horizons in early permanent arable land and from this map certain features begin to emerge. Ignoring for the moment the sub-soil values which form close contours running virtually parallel through the length of the area examined and the patterns of variation within the deep top soil, itself, the most important feature to note is the change in contour pattern occurring close to the edge of the mapped deep top soil unit. This change occurs in the 450mg/100g P_2O_5 contour and on either side of this change, phosphate levels increase. Nowhere else in the area examined is such a feature to be seen and thus there is good reason to believe that this change represents the interface of the tunmal and townsland arable land. Such an obserservation and interpretation confirms the conclusions of the previous section that deep top soils represent the tunmal with the remaining arable land representing the townsland. Within this townsland area a zone of greater phosphate concentration is identified close to the tunmal/townsland interface. It is possible to argue for two distinct arable zones within the townsland area.

Figure 7:4 The distribution of total phosphate values from the West Howe transect.



The other point of significance is that the levels of phosphate in the townsland zone decrease with depth.

Trend surface analysis of this data established that a linear surface was significant to the 99.9% level. The higher orders of trend surface considered (quadratic, cubic, quartic, quintic) do not give a significant improvement on the linear surface fitted to the data (Table 7:4). Plotting the linear trend surface indicates two characteristics (Fig 7:4). One is that there is a general decrease of total phosphate level with depth. This characteristic extends from the deep top soil tunmal into the townsland, the implications of such a characteristic therefore apply to both areas of the arable land. The second characteristic is that total phosphate levels decrease down the slope away from the farm buildings. The townsland arable land can thus be viewed as an extension of the tunmal, having lower levels of phosphate being further away from the farm buildings, but also exhibiting the decline in phosphate levels with depth evident throughout the arable land soils. Plotting the residuals of the linear trend surface analysis confirms the two zones of varying arable activity thought to be found in the townsland (Fig 7:4). Immediately beside the tunmal/townsland boundary, Profile Howe 23 residual values are above the general linear trend, while Profiles Howe 26 and 26A conform to the linear trend. The above discussion has emphasised the distinction between the tunmal and townsland parts of the early Orcadian township. Two sets of phosphate fraction values which appear to be independent of pH serve to highlight some similarities. Phosphate fractionation of the sample at 60cm in Profile Howe 18A and the sample at 20cm in Profile Howe 23 yield virtually identical percentage phosphate fractionation values despite having widely different total phosphate levels (Table 7:5). The sample from Profile Howe 18A represents the earliest phases of deep top soil formation while the sample from Profile Howe 23 represents the townsland area of the township. Based on these phosphate fractionation results it would appear that the early arable activities of the tunmal were very similar to those of the townsland. A lower intensity of arable practice preceded arable practice of greater intensity in the tunmal.

TABLE 7:4

ANALYSIS OF VARIANCE FOR THE LINEAR AND QUADRATIC SURFACES OF TOTAL P_2O_5 (mg/100g) IN EARLY PERMANENT ARABLE LAND "S" HORIZONS

Source of Variation	Degrees of Freedom	% RSS	Mean Square	F Ratio	Significance
Total, 28 sample points	27				
Due to linear surface with 3 constraints	2	46.602	23.301	10.909	99.9%
Due to residuals over linear surface	25	53.398	2.136		
Due to added quadratic components	3	8.182	2.727	1.327	Not significant
Due to residuals over quadratic surface	22	45.216	2.055		

As the quadratic components do not give a surface of increased significance, neither will other higher orders.

Table 7:5

Phosphate Fractionation Values from Tunmal and Townsland Soils in Marwick

Sample No and Depth (cm)	Early Land Use	Total P_2O_5mg/ 100g	Total inorganic mg/100g	Fraction (1) (%)	Fraction (2) (%)	Fraction (3) (%)
Howe 18A/ 60cm	Tunmal	326	187.86	87.34	12.42	0.20
Howe 18A/ 10cm	Tunmal	637	376.86	56.06	41.85	2.08
Howe 23/ 20cm	Townsland	651	216.92	86.88	10.78	2.33

Attention now turns to the deep top soil itself or the tunmal as we may now call it. Plotting of the raw data and contouring reveals the general decline in total phosphate levels with depth and away from the farm (Fig 7: 5). There are however two anomolies in the central portion of this deep top soil as well as there being considerable variation in the distance between contours. As with the analysis of tunmal and townsland together, trend surface analysis of deep top soil S horizon data establishes that a linear surface was significant to the 99.9% level and that higher order trends did not significantly improve this linear surface (Table 7:6). Plotting of the linear trend computed values identified the two controls on the spatial pattern of total phosphate values (Fig 7:5). The general trend is that total phosphate values decrease with depth (or time) and away from the farm buildings, summarized by a direction of slope value of 196°. If decreasing phosphate values were only related to distance from the farm the direction of slope would have been 270°. Similarly if decreasing phosphate values were related only to depth in the profile the direction of slope would have been 166°. Depth, or time, thus explains c 71% of the trend, the remaining 29% being explained by distance away from the farm. The time factor is therefore the most important constraint on total phosphate values within the deep top soil of West Howe. In interpretating

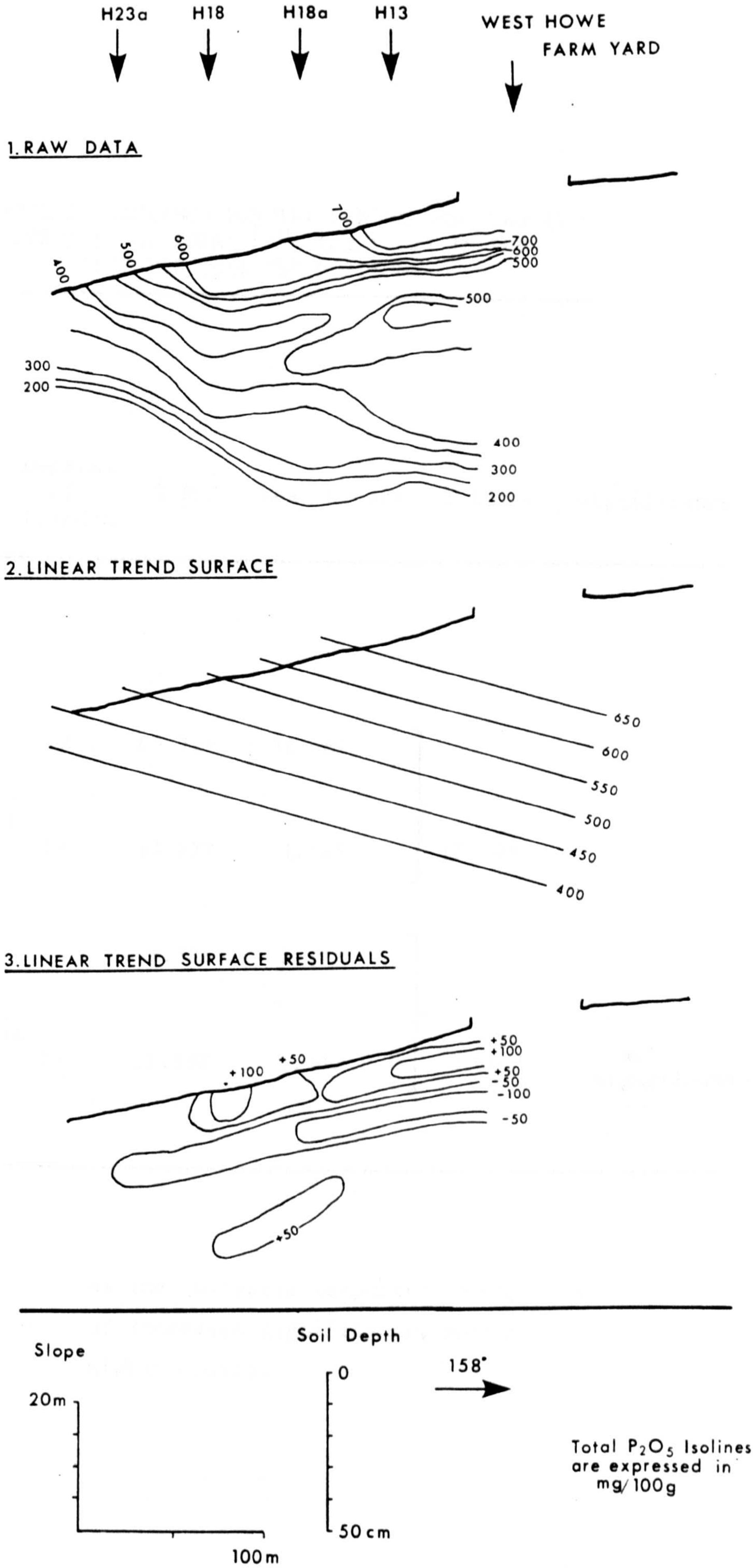


Figure 7:5 The distribution of total phosphate values in the West Howe deep top soil.

TABLE 7:6

ANALYSIS OF VARIANCE FOR THE LINEAR AND QUADRATIC SURFACES OF TOTAL P_2O_5 (mg/100g) IN THE DEEP TOP SOIL "S" HORIZONS

Source of Variation	Degrees of Freedom	% RSS	Mean Square	F Ratio	Significance
Total, 22 sample points					
Due to linear surface with 3 constraints	2	65.323	32.661		
Due to residuals over linear surface	19	34.677	1.825	17.895	99.9%
Due to added quadratic component	3	3.525	1.175		
Due to residuals over quadratic surface	16	31.152	1.947	0.6035	Not significant

As the quadratic components do not give a surface of increased significance, neither will other higher orders.

these results it is necessary to remind ourselves that total phosphate values represent a balance between the inputs of phosphate and the outputs. The anthropogenic phosphate patterns observed in this deep top soil thus represents the balance between the phosphate content of the organic fertilizers used and the outputs due to cropping activity. Clearly this balance varies within the deep top soil unit at West Howe. Based on two assumptions it is possible to argue that intensity of cultivation was greater closer to the farm and during the later period of deep top soil evolution, ie where the total phosphate values are greatest. The first assumption is that it is unlikely that arable activity would decrease towards the farm building, which would mean less phosphate removal. The second assumption is that the material of the deep top soil is not simply the toft waste being deposited with the least effort. This is a valid argument when one considers the very high farmyard phosphate values; toft wastes would more likely be deposited here than in the fields. It seems therefore that there was a deliberate policy of fertilising the land closer to the farm than the land further from the farm. It is presumed that this was to allow a greater intensity of cultivation. By the same argument cultivation intensity became greater as the deep top soil developed.

Plotting the residual values identifies the deviation from the general trend just outlined above. From Figure 7:5 it is possible to distinguish three major zones. Zone 1 is found predominantly in the lower area of the deep top soil unit and shows little or no deviation from the general trend. There is one area, Zone 1A, which shows a slight increase in total phosphate values relative to the general trend. Lying above Zone 1 is Zone 2 which runs through the entire middle to upper portion of the deep top soil unit. This zone is characterised by total phosphate values below the general linear trend with the deviation becoming greater the closer to the farm buildings. The upper 10-15cm of this deep top soil unit, Zone 3, is a zone of total phosphate values above the general linear trend values. Within this area are two peaks, concentrations of phosphate amounts. Further down the slope the values revert to lying within the general trend. It is important to elucidate what these four discrete zones mean in terms of land use because, thinking back to the gravity model of anthropogenic sedimentation, these variations potentially represent slight differences in the reason for movement of anthropogenic sediments. Unfortunately, because phosphate fractionation is related to soil pH rather than land use function in these Orcadian soils, this technique could not be used to assist in interpretating how the tunmal was organised in time and space. Reliance had to be placed on total phosphate values only. Based on the assumption that a greater total phosphate value represents greater arable activity the deviations from the general trend represent fluctuations in the intensity of arable practice. Zone 1 conforms to the general linear trend of increasing activity with time and proximity to the farm, despite the slight fluctuation represented by Zone 1A. Zone 2 represents a phase of deep top soil evolution when, relative the general trend, there was a uniform decline in arable activity across the tunmal. The upper part of the deep top soil is characterised by some degree of diversification in the intensity of arable activity. This latter phase of deep top soil evolution is characterised by three discrete areas, probably representing three separate fields. The two fields closest to the farm, Zones 3A and 3B, were cultivated to a greater intensity than might be expected from the general trend,suggesting that there was an increased requirement for food during this period of deep top soil formation and so the fertility of the land was raised further. Zone 4 fits into the general linear trend outlined above.

7:5:3 Conclusions

Both morphological and phosphate chemistry investigations demonstrate the distinctiveness and uniqueness of the deep top soil within the Marwick township. Both methodologies point to the deep top soil representing the cultivated tunmal area of the early township landscape. This represents the area of continuous and intensive arable activty. Although anthropogenic total phosphate patterns have been blurred by the process of downward translocation it is still possible to discern such patterns within the deep top soil unit at West Howe. Trend surface analysis identified that the intensity of arable practice within the tunmal increased with proximity to the farm buildings and as the deep top soil evolved. Plotting of the residual values of trend surface analysis identified deviations from this general trend. By this procedure a period when arable activity declined uniformly across the tunmal is identified. More recently diversification of arable activity is evidenced by the presence of three distinct fields which are contemporary with each other. The two fields closest to the farm buildings have a greater level of phosphate content than might have been expected from the general linear trend. It is suggested therefore that the latter period of deep top soil evolution is characterised by a sharp break to a new, higher, level of intensive arable practice.

There is an understandable reluctance to apply these observations beyond the West Howe deep top soil unit. It seems reasonably certain however that elsewhere in Orkney, where they are found, deep top soils represent the tunmal area of the pre-agricultural revolution township. That is, during the late Norse and Medieval period, areas where deep top soils were evolving were among the most intensively cultivated parts of Orkney. Furthermore this was the land that was held in a semi-permanent way by the adjacent farm. Although the deep top soil at West Howe indicates that the intensity of arable practice increases with the more recent deposits, this cannot be taken as a general rule. Total phosphate values from other deep top soil units in Marwick show one profile, that at Muce, as having a decline in arable activity with the more recent deposits (Table 7:7).

Table 7:7

Total Phosphate Values from Netherskail and Muce Deep Top Soils, Marwick

Netherskail

Horizon	Depth(cm)	Total P_2O_5 mg/100g
S_1	20	1116
S_2	40	747
S_2	60	841
B_2	80	359

Muce

Horizon	Depth(cm)	Total P_2O_5 mg/100g
S_1	15	750
S_2	30	796
S_2	50	1148
B_{2g}	70	451

Each deep top soil unit will have its own distinctive formation history, tied to the history of the adjacent farm(s). Fluctuations in population level at a particular farm, periodic phases of abandonment and periods of little or no arable activity at a particular farmstead would all serve to give a distinctive evolutionary history for each individual deep top soil unit.

7:6 Results and Discussion : The Farm Mounds of Westbrough and Skelbrae

This section describes and interpretes the results of sediment morphology and sediment phosphate investigations upon the farm mounds. Like the previous section each type of investigation is considered separately before the two are brought together. Conclusions can then be drawn about what factors were responsible for the movement of material resulting in farm mound formation.

7:6:1 Morphological Investigations

The first attempt at elucidating farm mound function was by the method of

it was established that the Orcadian farm mounds are very distinctive in their sediment characteristics. Detailed morphological analysis was therefore restricted to the farm mounds themselves. Appendices V and VI list the field sediment characteristics of the farm mounds at Westbrough and Skelbrae couched in the numeric form of Soil Survey(1976). These appendices are divided into two broad parts: The upper section contains sediment properties that indicate the nature of the material involved in the formation of farm mounds. It is on the basis of these properties that distinct horizons are identified. The lower part of this appendix contains properties indicative of how the horizons are organised and some of the possible causes of horizon organisation (eg plant root occurrence). How sediment horizons are organised, it has already been argued, may yield clues as to the use a particular anthropogenic sedimentary body was put. Grouping of similar horizons may therefore represent similar usage.

The first impression obtained in considering the field evidence is the evident layering in most profiles of the farm mounds. Horizonation is more obvious at Westbrough than Skelbrae but nevertheless the impression is of numerous cycles of deposition with comparatively little post depositional disturbance (Figs 7:6 and 7:7). Such characteristics would seem to be consistant with the hypothesis that the bulk of the mound represents the midden area of the toft. There are however anomolies, notably the comparatively homogenous Skelbrae Profile 1 and the thick homogenous layers found in the lower section of the Westbrough farm mound. Whether these anomolies also represent a midden function remains to be seen.

Taking the eleven properties of organisation for each horizon, calculating a similarity matrix by Gowers equation and clustering that matrix by the Furthest Neighbour procedure yielded Tables 7:8 and 7:9. Furthest Neighbour analysis using a minimum and maximum cluster of 2 and 8 respectively gave the best separation of the data. The clustering procedures of Single Linkage suffered from chaining effects as did the average Linkage procedure, although to a lesser extent. The dendrogram structure for each method was however similar indicating a heirarchal structure of sediment horizons did exist. Sediment horizons grouped at the 0.800 coefficient level are tabulated in Table 7:8. Grouping at this level identifies six categories of horizon but the first point that should be noted is the general similarity of the horizons. Clustering only begins at the 0.470 coefficient level and of the groups formed at the 0.800 level 53.6% of the horizons are within Group 1. Of the six groups identified at the 0.800 level, Groups 3 and 4 can be considered as the top horizons of the farm mounds. Group 3 horizons dominate at Westbrough and are characterised mainly by their thickness of horizon. At Westbrough these horizons are known to have been formed by recent dumping of material and thus the comparatively great thickness represents a greater magnitude of deposition than occurred during the main period of mound formation. Group 4 type horizons dominate the upper horizons at Skelbrae. This group can also be considered as surface sediments as indicated by the occurrence of roots. Horizons 10 and 11 in Skelbrae Profile 2 which are not at the present

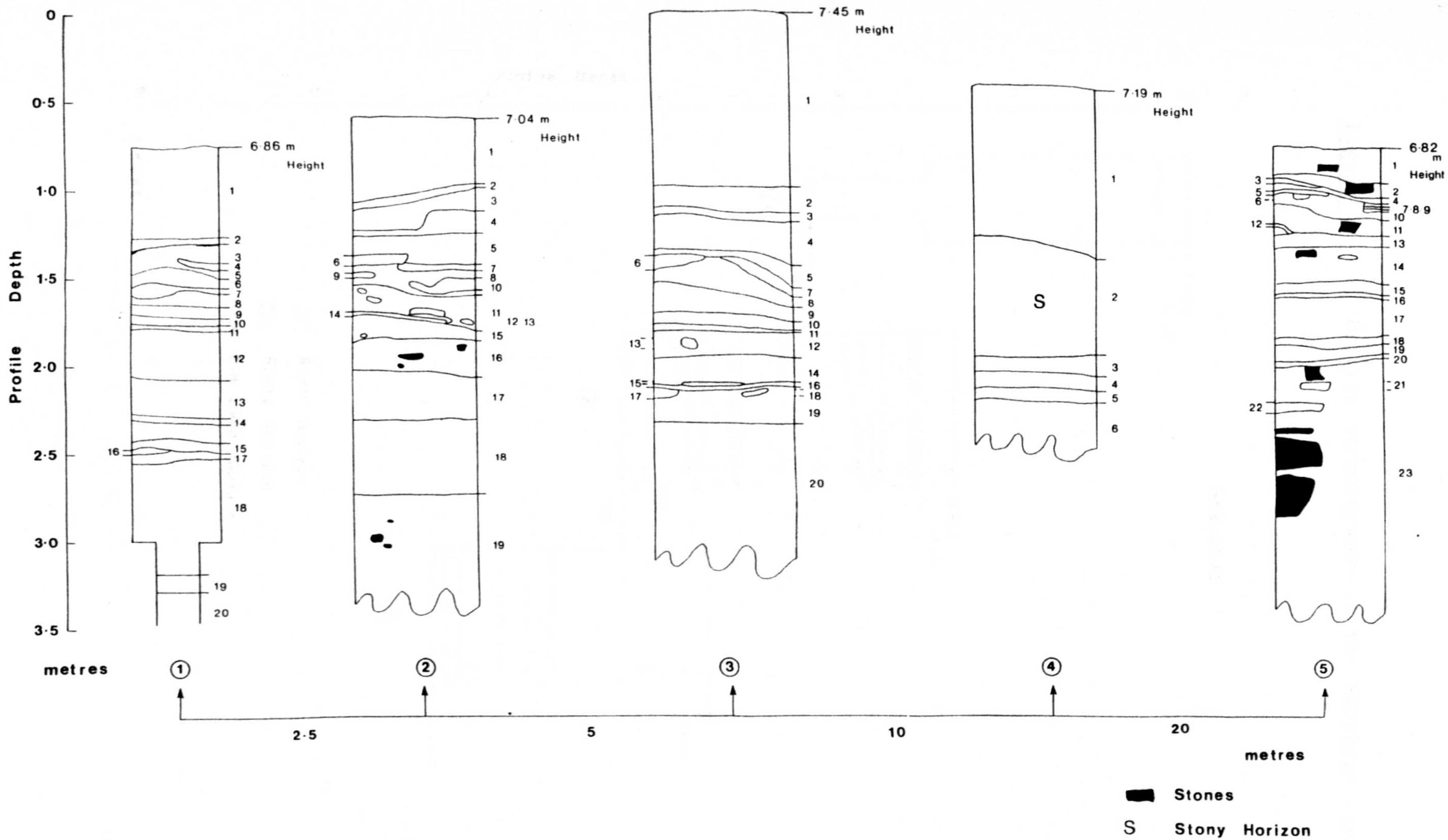


Figure 7:6 Profile stratigraphy of the Westbrough farm mound.

Figure 7:7 Profile stratigraphy of the Skelbrae farm mound.

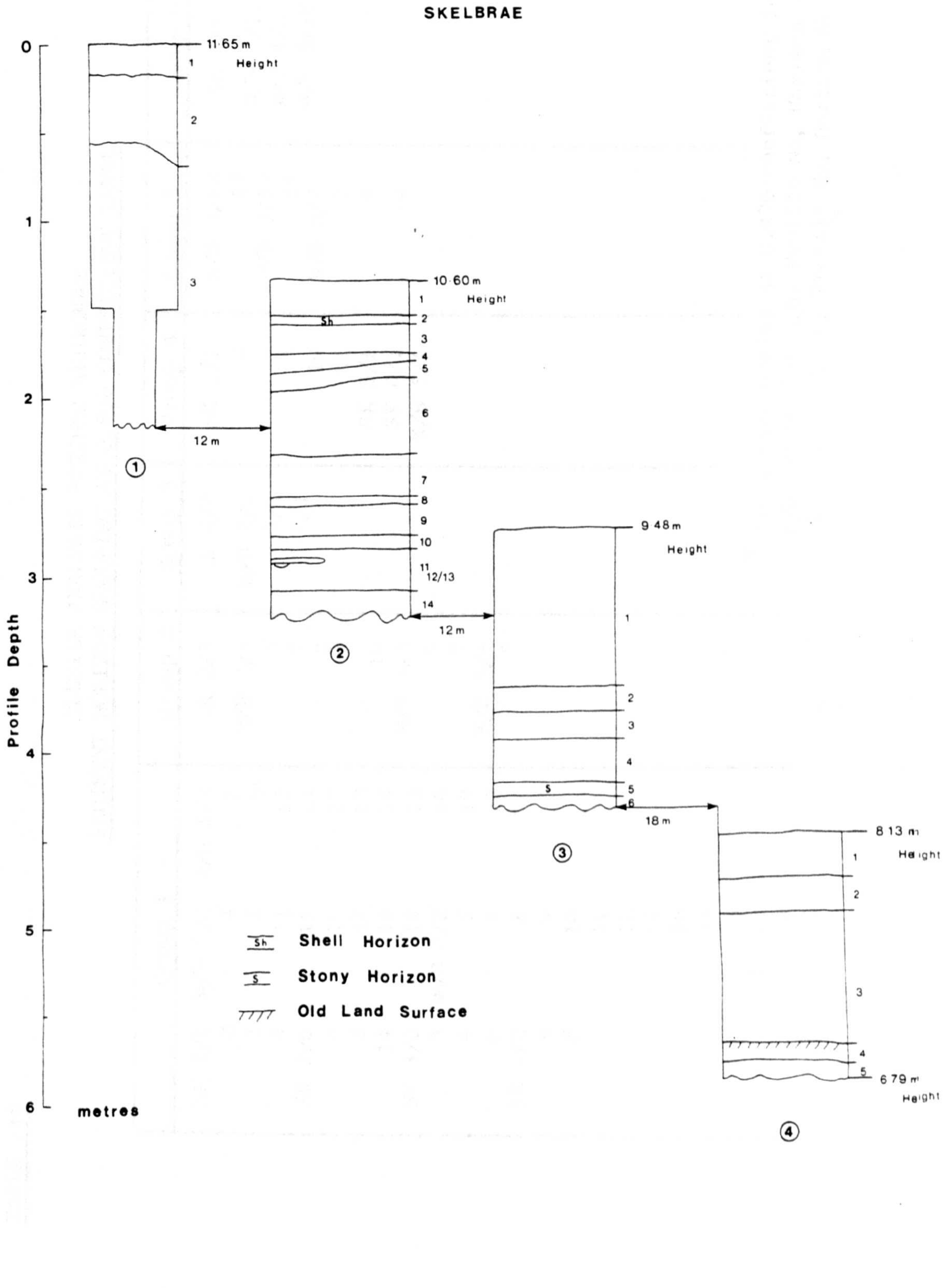


TABLE 7:8

CLUSTER ANALYSIS FURTHER NEIGHBOUR
SEDIMENT HORIZON GROUPING AT 0.800 COEFFICIENT LEVEL

Group 1			Group 2	Group 3	Group 4	Group 5	Group 6
SK 1/1	W/B 2/2	W/B 5/2	SK 2/5	SK 4/3	SK 2/1	W/B 2/12	SK 3/5
2	4	3	W/B 2/3	W/B 2/1	2	13	W/B 2/14
3	5	6	6	3/1	3	W/B 3/15	W/B 4/2
4	11	10	7	4/1	4	18	W/B 5/18
SK 2/6	15	11	8		10	W/B 5/7	
8	16	12	9		11	8	
9	17	13	10		SK 3/1	9	
14	18	14	W/B 3/5		SK 4/1	12	
SK 3/2	19	15	6		W/B 5/1		
3	W/B 3/2	16	7				
4	3	19	W/B 5/4				
6	4	23	5				
SK 4/2	8						
4	9						
5	10						
	11						
	12						
	14						
	16						
	19						
	20						
	W/B 4/3						
	4						
	5						
	6						

* Clustering begins at 0.470 coefficient level.
W/B 2/5·Westbrough, Profile No, Horizon No.
SK 2/5,·Skelbrae, Profile No, Horizon No.

TABLE 7:9

CLUSTER ANALYSIS FURTHEST NEIGHBOUR
GROUP 1 SEDIMENT HORIZON GROUP,
SUBGROUPED AT 0.900 COEFFICIENT LEVEL

Group 1A	Group 1B		Group 1C
SK 1/1	SK 1/1	W/B 3/2	W/B 3/8
3	SK 2/6	3	W/B 5/2
4	7	9	3
SK 4/5	8	10	10
W/B 2/18	9	12	
W/B 3/4	14	14	
11	SK 3/2	16	
W/B 4/4	3	19	
W/B 5/11	4	20	
13	6	W/B 4/3	
14	SK 4/2	5	
16	4	6	
17	W/B 2/2	W/B 5/15	
19	4	21	
	5	23	
	11		
	15		
	16		
	17		
	19		

*
W/B 2/5=Westbrough, Profile No, Horizon No.
SK 2/5,=Skelbrae, Profile No, Horizon No.

day surface can therefore be considered as representing a period of non deposition of sufficient duration for the horizons to acquire surface characteristics. The third observation that can be made from the cluster analysis at the 0.800 coefficient level is that Groups 2, 5 and 6 pick out a range of continuous or discontinuous horizons of varying orientation. These groups are found only in the Westbrough farm mound with the exception of Profile 3, horizon 5, in Skelbrae. This latter horizon represents an anomaly, like Westbrough Profile 4, horizon 2, and Profile 5, horizon 18, as these represent stone or shell layers within the mound. These horizons can be considered as narrow bands of waste materials dumped upon the mound and remaining relatively undisturbed since their deposition.

Taking the 0.900 coefficient level as a cut-off point to consider the internal heirarchy of Group 1 gave the grouping of Table 7:9. At Skelbrae, the distinctiveness of Profile 1 compared to the other profiles is apparent. Given the banded organisation of Skelbrae Profiles 2, 3 and 4 it seems clear that they represent a midden. The distinctiveness of Profile 1 suggests some other function as yet unknown but which maybe elucidated by thin section micromorphology. Table 7:9 serves to emphasise the organisational similarity that exists within the Westbrough mound suggesting a broadly similar mound function throughout its period of formation. Given the evidence of depositional cycles in the upper part of this mound,it is proposed that the broad function of the mound was that of a midden. Major differences are because of surface processes and recent dumping. Different groupings simply represent slight variations in deposition or post depositional processes but such differences are all within a general midden function.

Based on field evidence alone,of the profiles examined, all the indications are that the farm mounds represent the midden zone of the toft. While this maybe true as a general statement micromorphology and sediment phosphate analysis suggest some degree of variability in mound function. A total of six thin sections from farm mound profiles were examined. Each thin section contains distinctive micromorphological characteristics and so each is considered separately. Description of each thin section is given in Appendix IX.

Westbrough Profile 2 : 96-106cm (Plate 7:3)

This thin section is from the upper horizons of the farm mound at Westbrough in an area thought to be midden deposit. Although in the field only three distinct horizons were observed where this thin section was taken, eight discreet "micro" horizons of varying materials can be seen in thin section. These eight areas are organised in a laminar fashion suggesting eight distinct phases of "micro" disposition. Zones 1 - 5 and Zone 8 have an alveolar, welded structure suggesting that the main post depositional processes are gas release due to decomposition and compaction. Further evidence for these processes is Zone 6 which has a massive compacted structure and the fact that throughout the thin section organic materials are strongly to very strongly decomposed. Some degree of mesofauma activity is evident. Occasional passages are filled with what is considered to be faecal material; other passages have their sides plastered with dark amorphous organic material (Zone 4). These post depositional processes have not been intense enough to destroy the original stratigraphy and so it may be inferred that the accumulation rate at this stage of mound formation was relatively rapid. There is no evidence to suggest any anthropogenic disturbance of trampling or ploughing; the material in this thin section has been tipped onto the mound and left. It maybe concluded therefore that this thin section bears all the characteristics of a midden deposit.

Westbrough Profile 2 : 174-184cm (Plate 7:4)

Coming from the upper part of horizon 18, this thin section is composed mainly of moderately to strongly decomposed organic material. Four discrete zones can be discerned based on structure and colour. The boundaries between these areas are diffuse except with the "midden" like material which occupies the top left corner of the section. Apart from this there is no evidence for the distinctive undisturbed midden type zonation of the thin section described above. The alveolar and massive

PLATE 7:3 Thin section from Westbrough Profile 2, 96-106cm.

(x 2 magnification)

PLATE 7:4 Thin section from Westbrough Profile 2, 174-184cm.
(x 2 magnification)

structures bear witness to the processes of decomposition and compaction being of importance in this thin section, but other post depositional processes are also evident. An infilled route channel suggests that there was a lull in deposition of sufficient duration to allow the growth of plants on what was then the mound surface. Evidence of some rare arthropod faecal pellets and the whorled rainfall impact pattern in the central part of the section is further evidence of an active surface at this point in the mound. The question therefore has to be posed as to whether this surface represents simply a standstill phase in the midden deposition, whether it represents the open farmyard or whether this was some sort of garden plot. Phosphate analysis should help with this problem but for the moment it is sufficient to note that the juxtapositioning of the different matrix is similar to that of the arable deep top soils (See Section 7:5:1). Gardening activity is perhaps the most likely explanation of this pattern.

Westbrough Profile 2 : 206-216cm (Plate 7:5)

The final thin section from Westbrough also comes from the peaty horizon 18 of Profile 2 and is entirely organic. Slight differences in density, pore characteristics and colour indicate four discrete areas within this thin section. Within this section there is no evidence of any characteristic of surface horizon or of any midden type banding as was found in the previous thin sections. It seems likely that this material was deposited as one unit, slight colour differences being part of the original peaty material. Whether this single unit was deposited to create the planting surface for the garden plot described above or was simply the waste of some other toft function dumped on the midden, is not clear. Structural characteristics observed reflect the original spongy organic characteristic as well as the alveolar structure of compaction and decomposition.

Skelbrae Profile 2 : 70-80cm (Plate 7:6)

Like the thin section from Westbrough profile 2 at 96-106cm, this thin section has several discrete zones organised in a laminar fashion. Apart from Zone 3 which is an organic micro horizon

PLATE 7:5 Thin section from Westbrough Profile 2, 206-216cm

(x 2 magnification)

PLATE 7:6 Thin section from Skelbrae Profile 2, 70-80cm.

(x 2 magnification)

the structure throughout is alveolar and welded. The ubiquitous anthropogenic sediment processes or decomposition and compaction are therefore again operating. Mesofauna activity is represented by rare earthworm passages, sometimes filled with faecal material. However as with the Westbrough Profile 2, 96-106cm thin section, post depositional disturbances have been insufficient to alter the depositional stratigraphy. There has been no process of surface alteration either anthropogenic or non anthropogenic. It may be concluded therefore that this thin section represents midden deposition which was comparatively rapid.

Skelbrae Profile 1 : 78-88cm and 100-110cm (Plates 7:7 and 7:8)

These two thin sections are considered together because of their close similarity. Each of these thin sections can be considered as uniform, showing no evidence of any micro-depositional structure. It may be therefore that this material was deposited in one major event. Alternatively it may be that post depositional disturbance has completely erased any evidence of discrete horizon. A third possibility is that any discrete horizonation has been masked by the uniformity of the sediments. Boundaries of depositional phases would not therefore be apparent. The processes of decomposition and compaction are again evident from the alveolar structure found throughout these two sections. Evidence of other post depositional processes is however limited, whether anthropogenic or non-anthropogenic. Deposition was therefore one major event, or incremental with similar materials disguising any horizonation. Such observations are similar to those of the thin section from Westbrough Profile 2, 206-216cm. Does this thin section represent an area that was deliberately raised for some purpose or is it simply a uniform waste material dumped on the midden? It is hoped that phosphate analysis may help in the solving of this question.

Examination of thin sections from farm mounds has been useful in that it has indicated that farm mounds may have had a wider role within the toft than simply just a midden. There is clear micro-morphological evidence to support the conclusion based on field morphology that the mounds are in part middens. However, there are

PLATE 7:7 Thin section from Skelbrae Profile 1, 78-88cm.

(x 2 magnification)

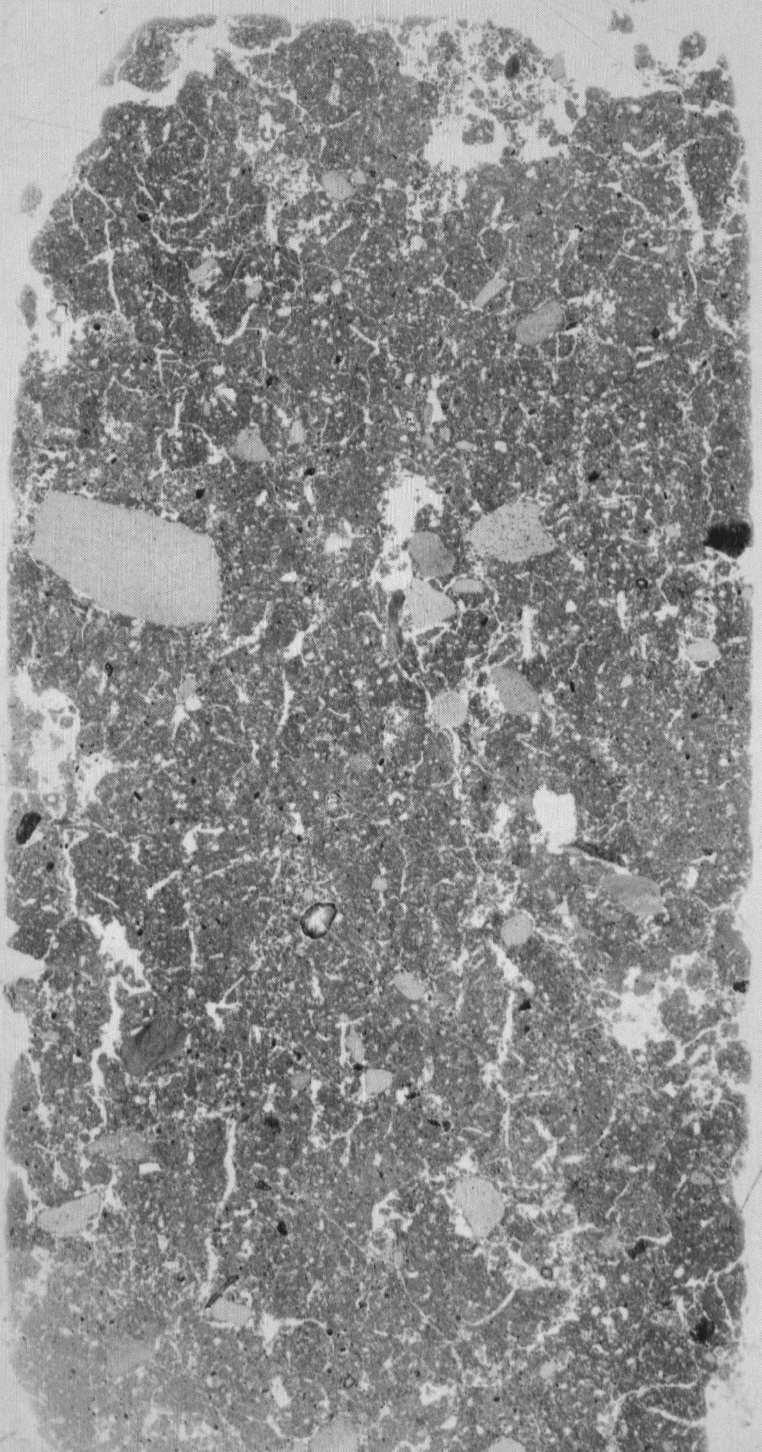
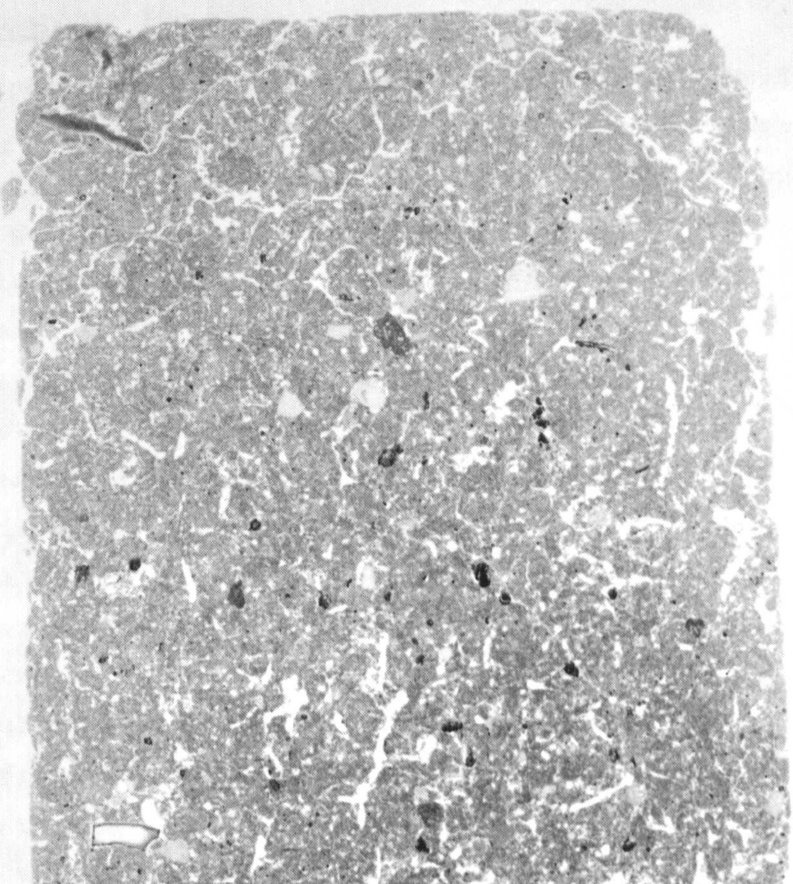


PLATE 7:8 Thin section from Skelbrae Profile 1, 100-110cm.

(x 2 magnification)



hints that the Westbrough and Skelbrae farm mounds had other functions. Raised platforms perhaps for gardening activity is one real possibility of an additional mound function.

7:6:2 Phosphate Investigations

Total phosphate values of two profiles from the Westbrough farm mound and of three profiles from the mound at Skelbrae are presented in Table 7:10 & 7:11. This data is augmented by total phosphate determinations from beyond these farm mounds but within their vicinity. Before any interpretation of farm mound function could be made it was necessary to decide which expression of the total phosphate results should be used, mg/100g or mg/cm^{-3}. A product moment correlation coefficient of 0.97 for the Westbrough data set and 0.94 for the Skelbrae data set supported to the 0.01 significance level that there was no statistically significant difference between the two different expressions of the results. It was decided therefore only to use the results expressed in mg/100g. Differences in material density make little difference to the interpretation of mound function from total phosphate analysis. Any such interpretation has to be carried out in light of several natural pedogenic processes which may alter or blur the levels of phosphorous caused by human activity. Earthworm activity, we have concluded from the thin section micromorphology, is limited. Similarly upward movement of phosphorous by plant induced gradients since the end of farm mound formation is limited. At Westbrough there is a distinct decline in phosphate levels with depth (Table 7:8). Skelbrae farm mound does perhaps exhibit some degree of upward movement in Profiles 1 and 4 (Table 7:11). Erosion, or perhaps more accurately slumping of material within and from the mound during its period of evolution, is one process that is difficult to get any semi-quantitative indication of today.

TABLE 7:10

PHOSPHATE VALUES FROM WESTBROUGH FARM MOUND AND SURROUNDING AREA

SITE AND PROFILE NO	HORIZON	SAMPLE DEPTH(cm)	TOTAL P_2O_5 (mg/100g)	OVEN DRY DENSITY (g/cm-3)	TOTAL P_2O_5 (mg/cm-3)
FARM MOUND WESTBROUGH 2	1	17	556	1.03	5.7268
	2	30	644	0.92	5.9248
	3	39	892	0.99	8.8308
	4	52	753	0.88	6.6264
	5	67	841	0.95	7.9895
	6	76	908	0.87	7.8996
	7	73	726	0.88	6.3888
	8	82	1031	0.85	8.7635
	9	83	1101	0.76	8.3676
	10	87	906	0.92	8.3352
	11	97	807	0.88	7.1016
	12	106	514	ND	ND
	13	108	1000	0.85	8.500
	14	110	576	0.70	4.032
	15	115	582	0.90	5.238
	16	130	1296	0.91	11.7936
	17	150	345	0.68	2.346
	18	170	723	0.61	4.4103
	18	190	439	0.64	2.8096
	18	210	1756	0.85	14.926
	19	230	1804	0.83	14.9732
	19	250	1120	0.85	9.52
	19	270	1166	0.85	9.911

SITE AND PROFILE NO	HORIZON	SAMPLE DEPTH(cm)	TOTAL P_2O_5 (mg/100g)	OVEN DRY DENSITY (g/cm-3)	TOTAL P_2O_5 (mg/cm-3)
FARM MOUND WESTBROUGH 4	1	50	779	ND	ND
	1	70	959	ND	ND
	2	127	890	ND	ND
	3	162	1067	ND	ND
	4	168	909	ND	ND
	5	178	1019	ND	ND
	6	192	854	ND	ND
WESTBROUGH MEADOWLAND	A2	10	136	1.00	1.36
	A2	20	83	0.63	0.5229
	A2	30	84	0.55	0.462
	A2	40	42	0.63	0.2646
	A2	50	6	0.68	0.0408
	A3	60	6	0.86	0.0516
	B2g	70	269	1.32	3.5508
	Cg	80	80	1.43	1.144
WESTBROUGH EARLY ARABLE LAND	S1	10	805	1.13	9.0965
	S1	20	759	1.16	8.8044
	S1	30	759	1.18	8.9562
	B2/C	40	429	ND	ND
WESTBROUGH GRAZING LAND	A2	10	561	ND	ND
	A2	20	577	ND	ND
	A2	30	555	ND	ND
	A2	40	667	ND	ND
	B2	50	341	ND	ND

TABLE 7:11

PHOSPHATE VALUES FROM SKELBRAE FARM MOUND AND SURROUNDING AREA

Size and Profile No	Horizon	Sample Depth (cm)	Total P_2O_5 (mg/100g)	Oven Dry Density (g/cm^{-3})	Total P_2O_5 mg/cm^{-3}
FARM MOUND SKELBRAE 1		10	678	1.10	7.458
		30	491	1.03	5.0573
(From D A Davidson)		50	447	1.01	4.5147
		70	517	1.05	5.4285
		90	653	0.99	6.4647
		110	628	ND	ND
		130	257	1.08	2.7756
		150	116	1.07	1.2412
		165	807	0.87	7.0209
		175	841	ND	ND
		195	1116	1.31	14.6196
		210	1076	ND	ND
		215	1053	1.31	13.7943
	(?) B_2	220	412	1.33	5.4796
FARM MOUND SKELBRAE 3		35	809		
		75	803		
		88	766		
		102	792	-- ND --	
		116	591		
		122	821		
FARM MOUND SKELBRAE 4		10	924		
		35	755		
		50	772		
		70	882	-- ND --	
		90	1165		
	(?) S_1	115	695		
	B_2	125	401		
FARM MOUND BASE SKELBRAE 5	S	10	457		
	S	20	296	-- ND --	
	S	30	350		
	B_2	40	57		
MEADOWLAND SKELBRAE 6	S	10	373		
	B_2	20	204	-- ND --	
	B_2	30	204		

Certainly of the profile pits inspected in these farm mounds there is little field evidence of erosion. Any layering characteristics are distinctly anthropogenic. It is as well however to acknowledge that such a process may have occurred and thus interpret total phosphate values with caution. Downward translocation is perhaps the most dominant process modifying anthropogenic total phosphate patterns. The B_2 pedogenic horizon underlying the farm mound at Skelbrae has a total phosphate values of c 400mg/100g. Total phosphate values of B horizons from two sites of the same soil series beyond the Skelbrae farm mound are 57 and 204 for Profile 5 and 6 respectively. This suggests an average increase of c 300mg/100g in total phosphate attributable to downward translocation. The range in total phosphate values within the Skelbrae farm mound excluding sub-soils is 1000mg/100g and so a c 300mg/100g downward translocation effect will means the blurring of the anthropogenic phosphate pattern but not its obliteration. There is the possibility that much of the phosphorus has been removed from the mound, through and beyond the underlying B horizon. Such a scenario seems unlikely because of the stability of phosphorus in the soil/sediment system as outlined earlier. It should also be stated that the increase of c 300mg/100g P_2O_5 in the sub-soil beneath the Skelbrae farm mound may represent the accumulated phosphate from a thick overlying sediment body. In view of the total amount of phosphorus within this sediment body, an accumulation of c 300mg/100g P_2O_5 in the sub-soil is comparatively negligible. If it is assumed that within the Westbrough farm mound there was a similar degree of limited phosphate downward translocation, then it is possible to state that the pattern of total phosphate values found in the farm mounds are mainly the result of anthropogenic activity. Some blurring of the anthropogenic pattern may have occurred because of downward translocation of phosphate, but this notwithstanding it will be possible to identify anthropogenic patterns.

Less emphasis needs to be placed on the phosphate fractionation results in view of the discussion in Section 7:5:2.
Only one of the samples subject to phosphate fractionation from farm mounds consistently falls outside the 95% data levels.

for the significant regressions of pH against inorganic phosphate fractions. This sample is from Westbrough Profile 2 at 150cm. It may be possible from this sample to draw some cautious conclusion of farm mound function.

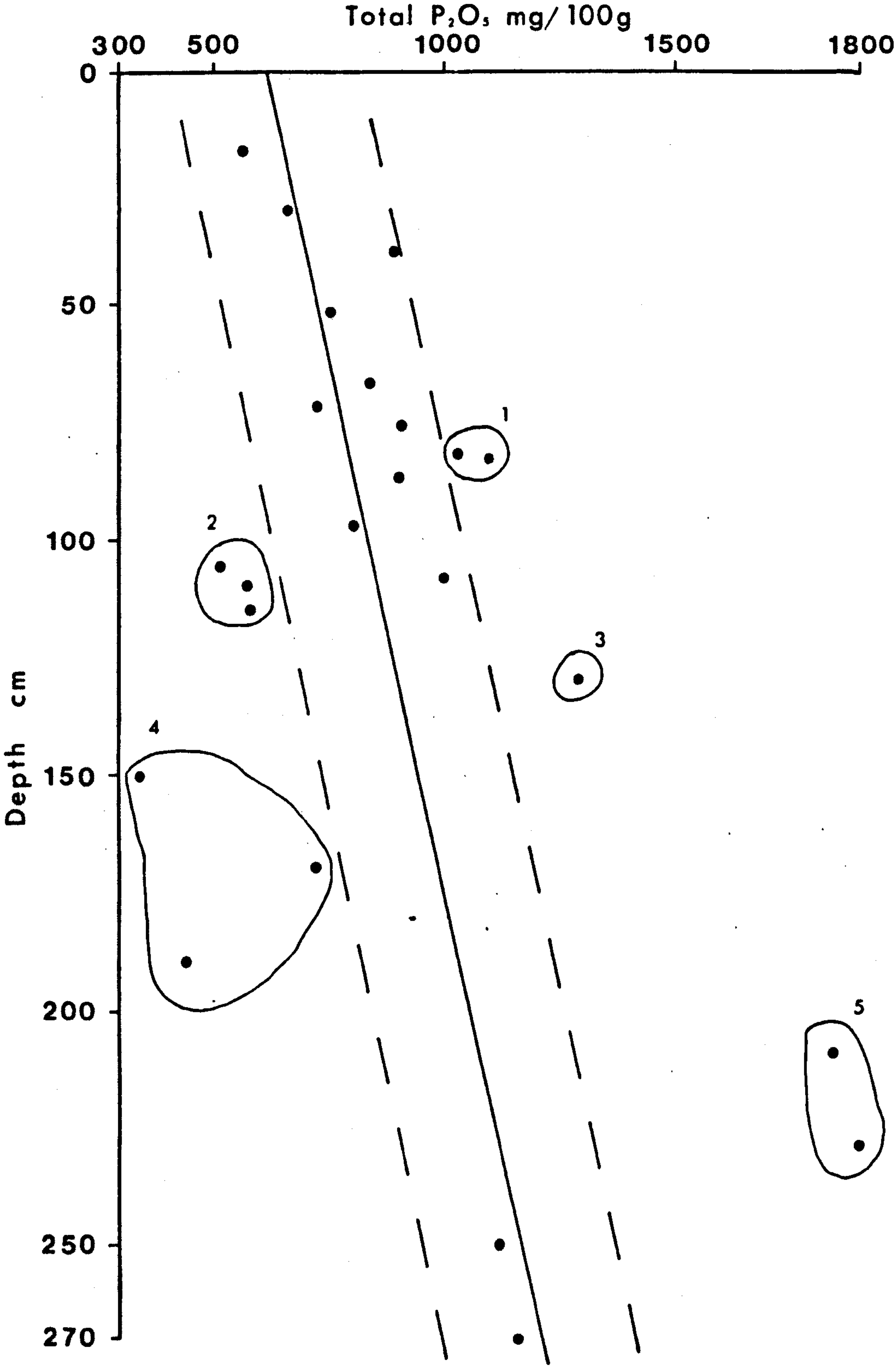
Knowing that total phosphate values within the farm mounds have been relatively little altered by natural post depositional processes means that these values represent mainly an anthropogenic pattern. To assist the interpretation of this pattern polynomial regressions were calculated for depth, which is a surrogate for time, against total phosphate (mg/100g). Each regression was tested incrementally for significance but only the regression of greatest significance was used. The two total phosphate profiles from Westbrough are now discussed, followed by three from Skelbrae.

Westbrough Profile 2

The depth and total phosphate values of Table 7:8 were regressed. Of the four polynomial regressions carried out on this data,linear regression provided the best order. The result was significant to the 95% confidence level, supporting the alternative hypothesis that there is a significant statistical relationship between depth (or time) and total phosphate value. As depth increases, total phosphate value increases (Fig 7: 8). Interpretation of this regression line in terms of function and function intensity must explain both the general linear trend and the significant deviations from this trend. Morphological evidence has already confirmed the general function of this farm mound as a midden and this conclusion aids the interpretation of the phosphate profile.

Four groups of anomalies lie beyond the 95% data limits of the regression line (Fig 7: 8). Groups 1, 2 and 3, which occur both above and below the trend line, can justifiably be interpreted as fluctuations in the use of the mound as a midden. Each of these three groups occur in the upper part of the farm mound where there is a distinctive midden stratification. Group 4, represents horizon 18, the peaty horizon, and the overlying horizon 17. The three samples of this zone indicate a lower level of total phosphate that might be expected from the general trend.

Figure 7:8 Regression of total phosphate values with depth in the Westbrough 2 profile.



Morphological investigations identified horizon 18 as anomalous in terms of sediment organisation while micromorphological examination indicated that this part of the farm mound was a surface horizon for some considerable period of time. Two of the total phosphate values from this anomalous group, at 150cm and 190cm depth, are more akin to background levels of total phosphate found outwith the confines of the farm mound. The results therefore suggest that this material is not toft waste but rather is material introduced to the mound as a capping to the underlying midden material, thus creating a living surface for the farmstead occupants. In this part of the mound the micromorphological evidence is for some sort of gardening activity, a hypothesis supported by the phosphate fractionation percentages from 150cm depth. These fractionated percentages which lie outwith a significant relationship with pH, show a similar distribution to those in the arable deep top soils (See Table 7:3). A gardening function for this part of the mound would explain the higher levels of phosphate at 170cm depth. This total phosphate value would here represent fertilization of the garden plot prior to a further capping of the mound at 150cm depth.

The anomalous total phosphate values of Group 5 are the highest levels encountered in this thesis. Such levels could only be achieved in a midden and so it seems that the capping material is overlying midden. The anomaly simply represents a fluctuation in the ability of the toft to generate waste material. Based on Figure 7:8 two phases of this deposition are apparent, total phosphate levels becoming lower beneath the anomaly. Recalling the radiocarbon dating of this farm mound (Chapter 5) reminds us that this lower part of the mound was probably deposited as one major event. Underlying the anthropogenic mound is waterlogged soil and it is tempting to suggest therefore that this mound was originally deliberately raised as a settlement platform. Midden material was deposited and capped to create this surface. It is difficult to understand why the early Orcadians of Westbrough should have undertaken such a task in view of the fact that freely drained land surrounds much of the Westbrough farm site. Total phosphate values from the lower part of the mound suggest exceptionally high population levels and thus it may have been necessary to reclaim as much land as was possible. Alternatively it may be that the early mound capping is a different generation's activity. Midden material deposited on useless waterlogged soils by an early generation were capped and utilised as a living platform by a later generation.

As the bulk of the mound is a midden the need of the toft site to rid itself of it waste materials is clearly a factor of significance in the formation of the farm mound. Generation of waste material is directly related to population density. Thus the total phosphate values from the midden part of the farm mound provide a relative indication of population density at Westbrough. It is possible to estimate numbers of population from total phosphate values provided the area of settlement and rate of sediment accumulation is known, (Cook and Heizer, 1965). In view of the uncertain rate of accumulation an unknown original size and configuration of the Westbrough mound it was decided that any attempt to obtain an absolute level of population would be at best a guestimate. The linear regression of total phosphate with depth in Westbrough Profile 2 provides us therefore with a qualitative index of population density at Westbrough. The general trend is for a declining population level from the mound origin to its cessation (see Chapter 5). The lower part of the mound represents a period of exceptionally high population density, particularly if much of this material was deposited over an instantaneous or exceptionally short period of time. Population declined steadily over the second midden phase in the upper part of the farm mound. If a steady rate of accumulation is assumed the population of Westbrough declined by approximately 30% over the second period of midden deposition. What this figure means in absolute terms will only be discovered with further dating evidence. It can only be noted for the moment that mound evolution continued with a declining level of population.

Westbrough Profile 4

Total phosphate values for Westbrough Profile 4 were obtained from the upper part of the farm mound. A large stone slab at 200cm depth prevented samples being obtained from a greater depth. For the total phosphate values obtained there is no significant relationship with depth (Fig 7:9). The range of total phosphate values is 779 to 1067mg/100g. The sediments of this profile are distinctive for this mound as there is no obvious stratigraphic sequence. It seems most likely therefore that here there has been some degree of mixing of the sediments. The result is the homogenization of any original phosphate pattern. If the stone slab is contemporaneous with the capping material of Profile 2 then here is further evidence for the use of this mound as a living platform. The most likely explanation for the stone slab is that is formed a pathway across the early mound. Even after deposition of midden material as horizons 3, 4 and 5 this part of the mound was probably still used as a pathway, giving the homogenized characteristics of the total phosphate values. Horizons 1 and 2 were probably each deposited as one event, horizon 1 a recent addition, horizon 2 at an unknown point in time. The observations in this horizon therefore support the general conclusions of farm mound function based on Profile 2. The use of the farm mound as a living platform was superceded by midden deposition.

Skelbrae Profile 1

Examination of Figure 7:10 indicates that there are striking similarities between Skelbrae Profile 1 and Westbrough Profile 2. Simply plotting the total phosphate values with depth indicates the presence of three anomalous values at 130, 150 and 220cm depth. No polynomial regression gave a significant fit to the data when all fourteen values are included. Removal of these three anomalies from the data set results in a linear regression significant to the 99% level. Without the anomalies, the alternative hypothesis is supported, ie that there is a statistically significant relationship between total phosphate levels and depth(time).

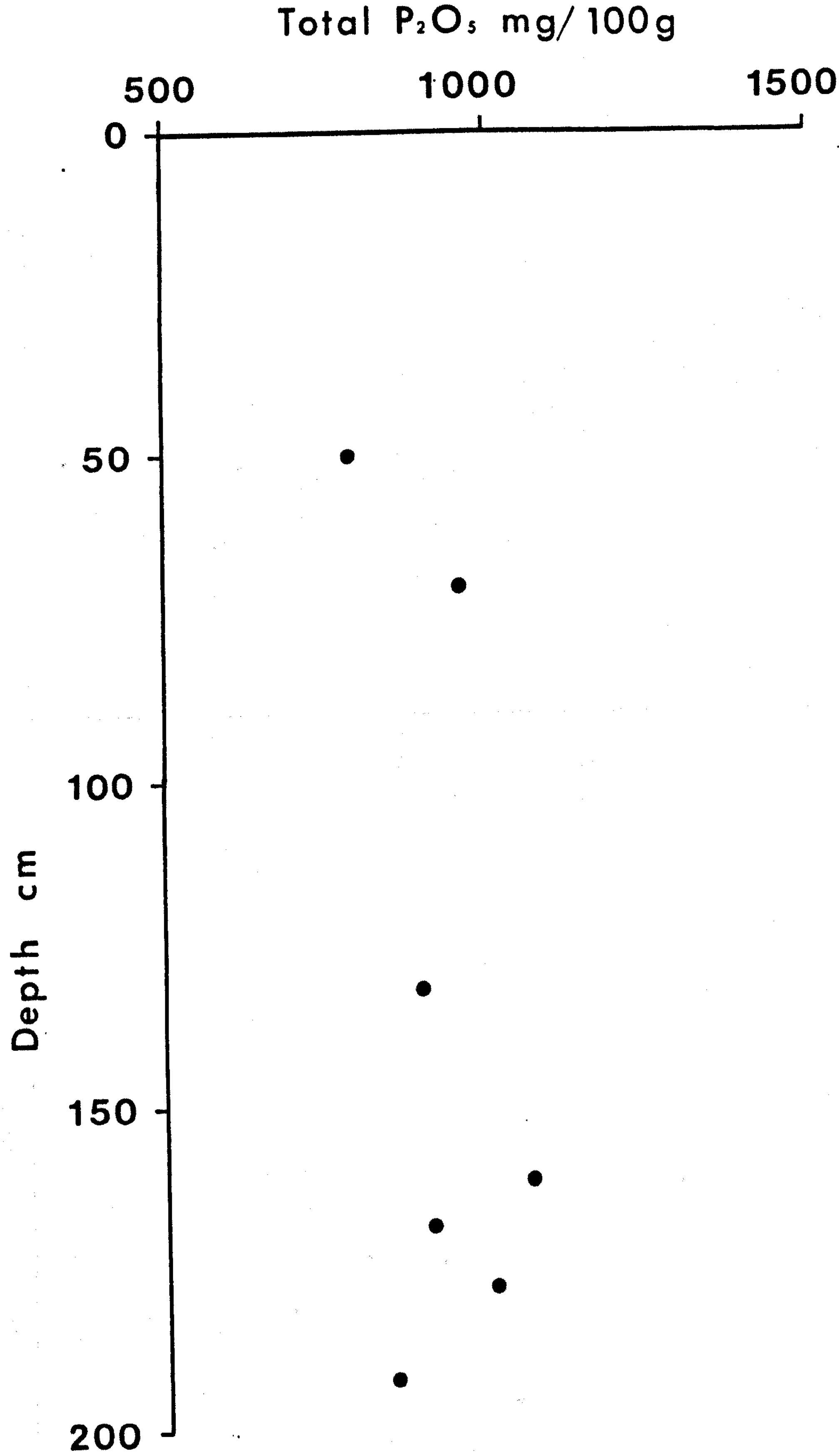
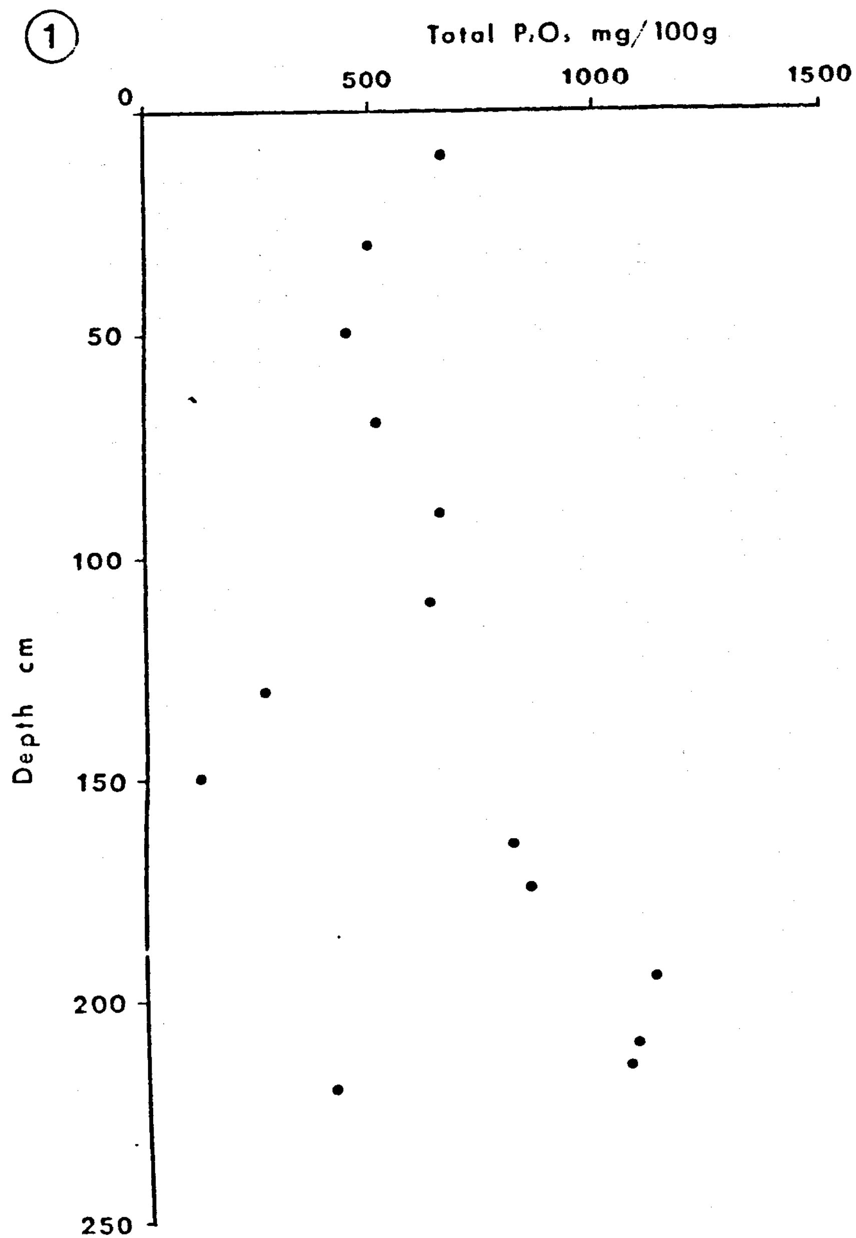
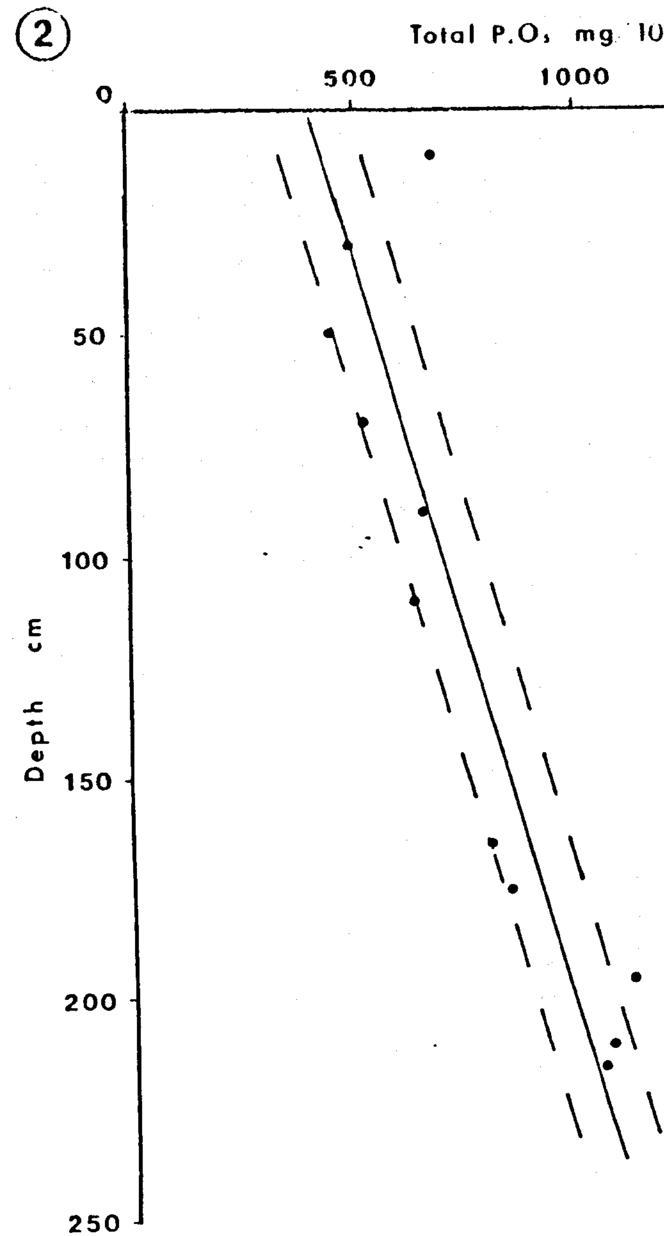


Figure 7:9 A plot of total phosphate levels with depth in the Westbrough 4 profile.

Figure 7:10:1 Skelbrae Profile 1 total phosphate levels with depth;



7:10:2 Regression of total phosphate levels with depth. Anomalies have been removed.



As depth increases, total phosphate level increases (Fig 7:10) as at Westbrough Profile 2.

Interpretation of these results gives a similar functional history for Skelbrae as for that at Westbrough. The anomaly at 220cm depth represents the pre-mound surface soil and so is discounted from the discussion. Low total phosphate levels at 130 and 150cm depth resemble levels found beyond the area of the farm mound. Like Westbrough it is possible to propose that these values indicate the capping of an early midden,which is high in total phosphate, to create a raised living platform. What activities were associated with this platform cannot be elucidated from the available data. Subsequent to this raised living platform the mound seems to have reverted to its original use as a midden, receiving the waste materials generated by the toft. Assuming that there is a direct relationship between total phosphate in a midden and the site population density,it is clear that there was a steady decrease in population as the farm mound at Skelbrae evolved. Population density decreased by about 50% over this period.

Unlike Westbrough where waterlogged soils underlie the mound, the Skelbrae farm mound rests on the freely to imperfectly drained podzolic Bilbster Series soil. There seems little need therefore for the deliberate raising of a living platform. It seems most likely that the early midden material gradually accumulated over several generations prior to its capping. Whether there was any great period of time between the end of early midden deposition and its capping is uncertain. There is however no break in the total phosphate/depth gradient between the lower and upper middens of the farm mounds. This suggests that the site was in continuous use as a settlement.

Skelbrae Profiles 3 and 4

Total phosphate analysis of sediments from these two profiles serve to indicate that the anthropogenic phosphate patterns observed in Skelbrae Profile 1 cannot be applied universally over all of the mound. Skelbrae Profile 3 demonstrated no significant relationship between total phosphate levels and depth (Fig 7:11). Neither is there any evidence of mound capping. The first question to be resolved therefore is whether the phosphate pattern found in this profile is anthropogenic or is the result of some natural post depositional process. Given the obvious stratigraphy of the profile it would appear that the phosphate levels represent an anthropogenic pattern. What is clear therefore is that different parts of the Skelbrae farm mound evolved differently. The levels of phosphate found in this profile are similar to those lying between c 160 and 180cm depth of Skelbrae Profile 1, immediately below the capping. Thus it is possible that these two parts of the mound are contemporaneous,with the rate of accumulation at Profile 3 greater than that at Profile 1 during this period. According to this reconstruction of events, little or no material will have been deposited at Profile 3 after the capping event. Such a conclusion seems entirely reasonable in view of the declining population thought to occur throughout the formation of this mound (Fig 7:10).

A similar interpretation of the phosphate pattern in Profile 4 can also be given (Fig 7:12). Once the total phosphate values from 115 and 125cm depth, the pre mound land surface, are taken out of consideration the samples left have levels of phosphate representative of the pre capping phase of Profile 1. Furthermore linear regression demonstrates the decline in total phosphate levels as the mound grew, similar to that in Profile 1 for the lower parts of this profile.

From the above results the picture emerging is that while there is evidence for three distinct phases of functional evolution in Profile 1, there is only evidence for one phase at Profiles 3 and 4. Growth of the mound at Profiles 3 and 4 only occurred during the initial stages of mound development, representing early midden deposition. There is no evidence of any capping or post capping midden deposition as found at Profile 1. It should also be noted that the thickness of the early midden material is greater at Profiles 3 and 4 than at Profile 1. It is possible to suggest therefore that the early focus of mound growth was at what is today the lower slopes of the farm mound. With the capping of the early

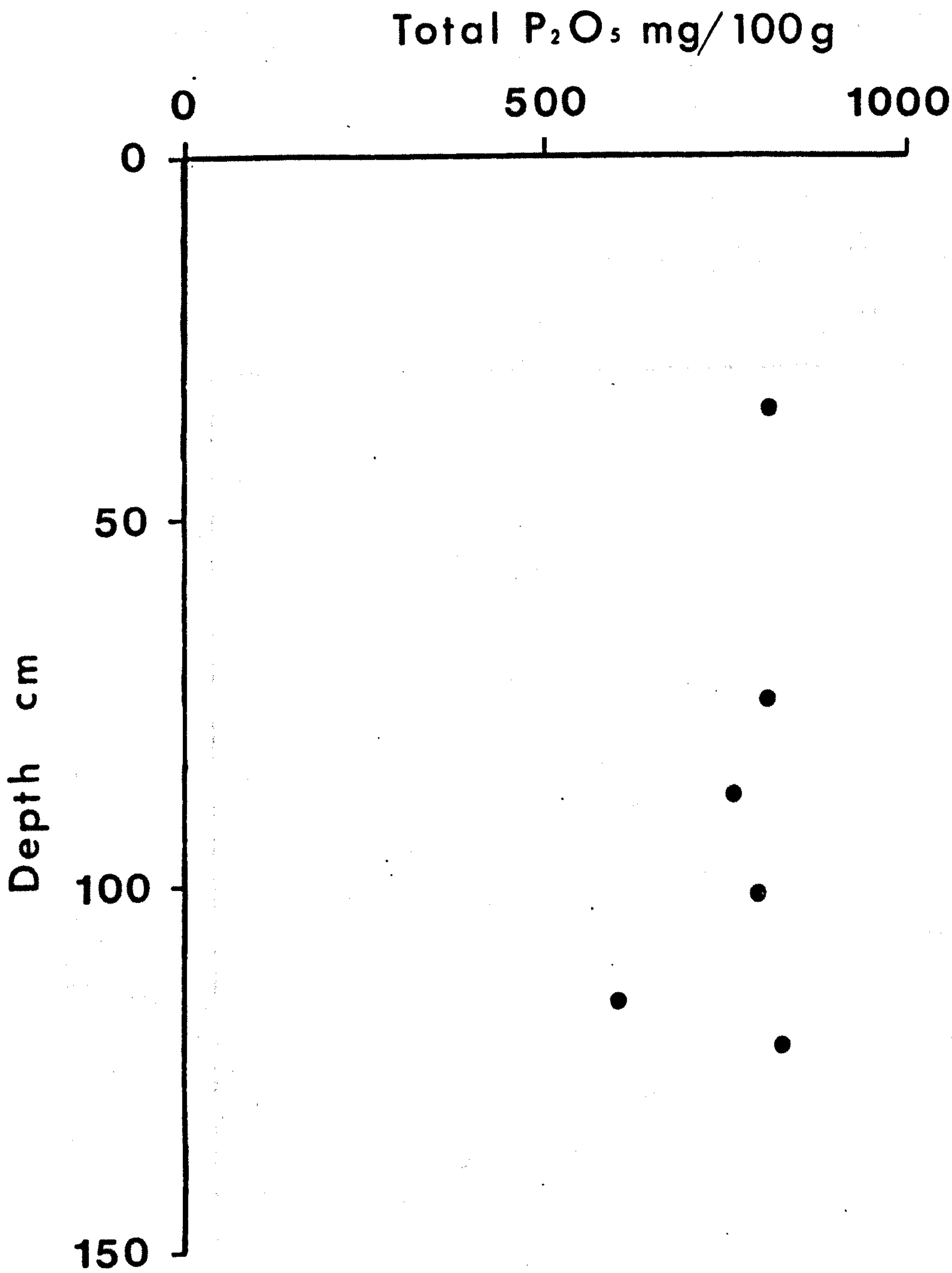
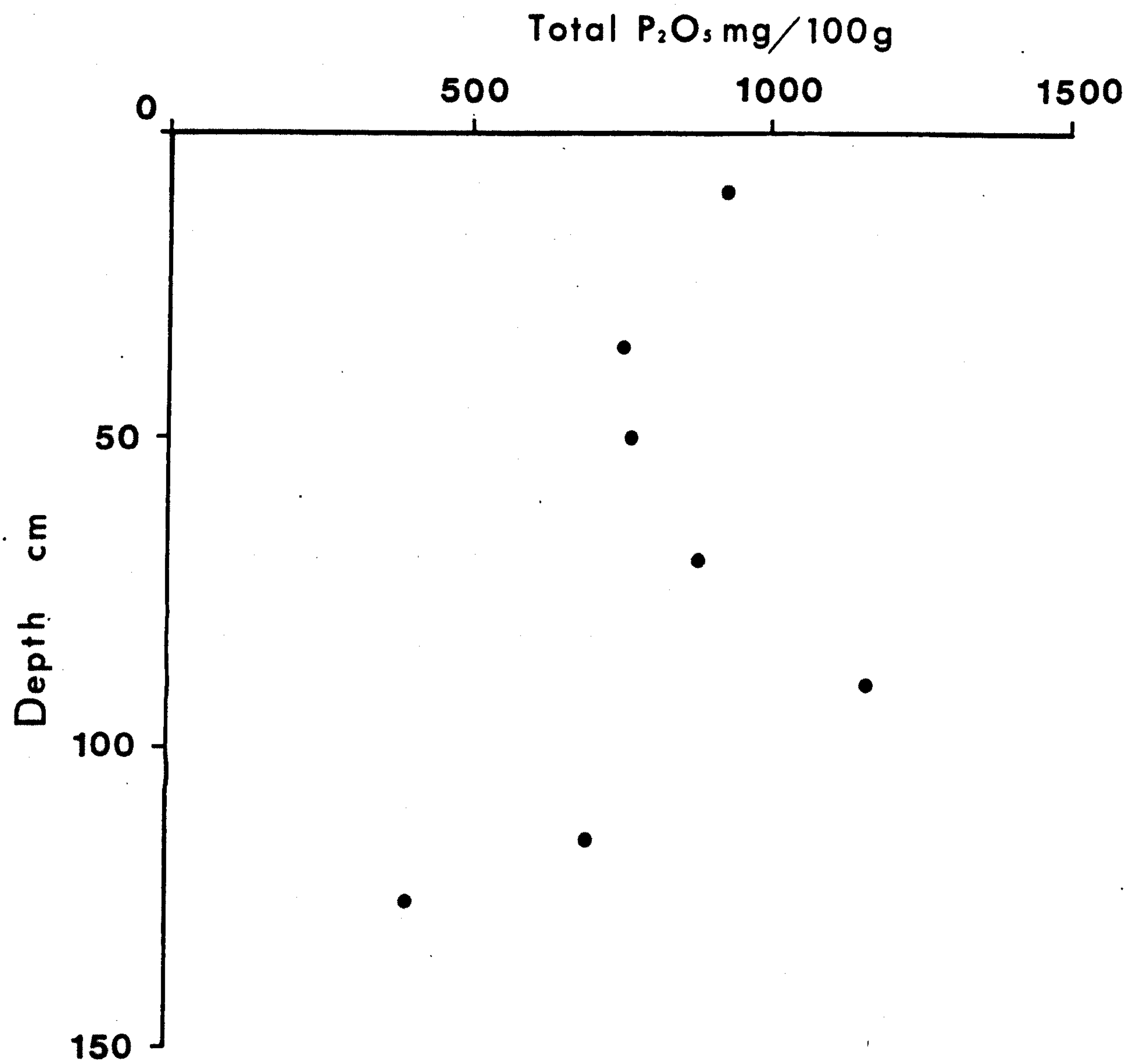


Figure 7:11 Total phosphate levels with depth in Skelbrae profile 3.

Figure 7:12 Total phosphate levels with depth at Skelbrae Profile 4.



midden, the focus of growth shifted to around the area of Profile 1.

7:6:3 Conclusions

Bringing together the morphological observations with the results of phosphate analysis permits a coherent statement to be made on farm mound function. Profile 2 at Westbrough and Profile 1 at Skelbrae form the major basis for these statements. The first conclusion to be drawn from the observations is that natural post depositional processes are limited in their disturbance of anthropogenic morphology and phosphate patterns. One major exception to this rule is the control pH exerts on percentage phosphate fractionation values obtained by Eidt's method. As pH levels in anthropogenic soils and sediments are no different from soils of a different genesis it may be concluded that phosphate fraction values are dominantly controlled by natural pedogenic processes. This apart, the processes of compaction, decomposition, leaching, bioturbation, upward movement of nutrients by plants and erosion may serve to blurr the anthropogenic patterns, but not to obliterate them. It is possible therefore to use morphology and total phosphate analysis to elucidate the function of the farm mounds.

At Westbrough four distinct phases of farm mound function can be identified. The lower part of the mound, below 210cm depth from the surface, represents the mound as a midden during a period of high population density. There is some evidence to suggest that much of this material was deposited as one major event and thus the question arises as to whether material was deliberately deposited to create a raised platform. Some support for this comes from the fact that underlying this mound are poorly drained soils. It may be that during this period of high population density it was necessary to reclaim as much land as possible. Use of settlement wastes represented the most convenient means of reclaiming waterlogged areas, a procedure analagous to the terpen sites of north Germany and the Netherlands. The second phase of farm mound function at Westbrough is represented by what is termed a capping of the early midden. This capping material, some 60cm in thickness, is considered to have been deposited to form a living platform. At this particular part of the mound there is evidence for some degree of cultivation and fertilization. It is proposed that a garden plot was located at this part of the mound. At Profile 4 this living surface is represented by a stone slab, which probably was a pathway across the mound. Diversity of activity upon this living surface is thus evident. How long this mound continued as a living surface is not clear but subsequent to this, the mound reverted to its original use as a midden. During the second midden period, deposition was gradual and continuous although the population was dwindling. Throughout the period of mound evolution it is estimated that, based on total phosphate levels, the population density dimished by around 36% from its original high level. The final phase in the functional use of the Westbrough farm mound is the recent deposition (or perhaps more accurately re-deposition) of material on top of the mound when excavation for a new cattle court was undertaken. A general picture emerges therefore of the mound being that part of the settlement site where the wastes of that site accumulated. There is however a phase in this farm mound's evolution when it was used as a living surface.

Examination of the Skelbrae farm mound Profile 1 reveals a similar pattern to that found at Westbrough. The lower part of Skelbrae Profile 1 is a midden, characterised by the highest levels of phosphate found in the profile. As at Westbrough, this early midden is capped and it is assumed that this too represents a living surface. The mound then reverted to its use as a midden, serving as a 'waste bucket' to the Skelbrae settlement whose population was dwindling as the mound evolved. In other parts of this mound there is only evidence for the early midden. There is no evidence for any capping process or a later midden. This suggests that the focus of mound development has shifted with time. Despite this it is possible to state that a pattern of mound function beginning to emerge. There is a sequence of early midden, capping of that midden to form a living surface and then revertion to a midden. These therefore represent the land use types of the landscape that cause movement and deposition of sedimentary materials resulting in the formation of at least two farm mounds on Sanday.

CHAPTER 8

PROCESSES OF FORMATION 3 : THE MATERIALS OF DEEP TOP SOIL AND FARM MOUND FORMATION

8:1 Introduction

The historical literature on Orkney has identified the types of materials potentially used in the formation of deep top soils and farm mounds. It is now necessary to identify the materials actually used. For this to be possible it was required that anthropogenic soil/sediment properties were selected which differentiated between the different suspected sources of anthropogenic sedimentary material in the Orcadian environment. Such properties are also required to have been preserved, or at least modified in a predictable and identifiable way, during transportation and under the post-depositional conditions found within the deep top soils and farm mounds. A further two criteria used in the selection of soil/sediment properties for this task of material identification were that the analysis for the selected soil/sediment properties was technologically feasible with the facilities available and that the techniques were appropriate to the scale of investigation. After consideration of several possible methodologies, particle size analysis was chosen to give a first approximation of the inorganic materials of formation from selected anthropogenic sediments. Stable carbon isotope analysis was selected to identify the organic materials of formation from the same sediments. These two methods best satisfied the criteria for selection outlined above.

8:2 Identifying Inorganic Materials of Formation

Before particle size analysis was selected as the technique best able to identify the inorganic materials of the Orcadian anthropogenic sediments, several other techniques were considered. For one reason or another these alternatives had to be rejected. Thus magnetic susceptibility measurements of sediments (Graham, 1976; Mullins, 1977; Thompson et al, 1980) while holding considerable potential for this research could not be undertaken because of the unavailability of appropriate equipment. Examination of quartz grain morphology by SEM may also have assisted in tracing sources of anthropogenic sediments. However because of the number of samples to be processed this technique was considered too time consuming. Ratios of elements have the potential to indicate zones of different weathering in the landscape and thus different anthropogenic sediment source areas (Goudie, 1981). Again however this technique was not appropriate, this time because it was thought that element ratios within the anthropogenic sediment would have been considerably altered by organic amendments (see Chapter 3).

Examination of sediment mineralogy was one set of methods explored to a greater extent than the techniques mentioned in the above sentences. Suites of clay, heavy and light minerals in sediments have been used to identify sediment sources (McGreal,1981; Yatsu and Shimoda, 1981). Preliminary work by Wilson at the Macaulay Institute for Soil Research (Wilson pers comm) has however indicated that the different rock types in Orkney (the soil parent material) cannot be differentiated on the basis of mineralogy. Identification of sediment sources by examining mineral weathering characteristics was also likely to prove difficult or impossible. Little mineralogical change could be discerned in the "control"profile (HY 245 255) examined by the Author (using the methods of Avery and Bascomb, 1974), an observation supported by Naidu (unpublished) who examined a Bilbster Series soil from North Bigging (HY 303 201).

Examining the field texture characteristics of the West Howe deep top soil indicates a generally silty nature which contrasts with the silty clay loam of surrounding top soils in Marwick (AppendixIV). Furthermore examination of the Howe 31 (hill-land) profile indicates that it has been truncated, possibly by man, and subsequently reclaimed judging by the buried organic layer resting on and incorporated into the B_2 horizon. Examination of field texture characteristics in the Westbrough and Skelbrae farm mounds reveals fluctuations within the exposed profiles. Particle size analysis would seem therefore to be of potential in elucidating the sources of anthropogenic sediments in Orkney. This method was technologically feasible in the University of Strathclyde, Department of Geography laboratories and it was possible to process the sizeable number of samples required. Theoretically particle size characteristics of any sediment reflect the inherent properties of that sediment, the transport-depositional system and the energy of the sedimentary process although the exact cause/effect relationships between particle size characteristics and physical processes are still not adequately explained (Gladfelter, 1977). In the following two sections attempt is made to identify the inherited particle size characteristics of the anthropogenic sediments and the origins of that inheritance. What the particle size characteristics are of the suspected anthropogenic sedimentary material and the behaviour of particle size properties under pedogenic and diagenic conditions is now explored. Full details of laboratory procedures for particle size analysis together with equations for calculating particle size values are given in Appendix X .

8:2:1 Particle Size Analysis of Suspected Inorganic Anthropogenic Sediment Materials

Suspected inorganic anthropogenic sediment materials can be divided into two broad categories. The first and largest category are what may be termed the primary materials. These are considered to represent the original source materials prior to any anthropogenic activity. Within this category are beach sands and calcareous wind blown sand together with material from soil profiles surrounding the anthropogenic sedimentary units at West Howe, Westbrough and Skelbrae. The second category of material analysed are materials the original characteristics of which have been modified in some way by the activities of the Toft prior to deposition as anthropogenic sediments. Within this category of secondary materials are peat ash, turf roofing material and midden material. Both these sets of materials are considered against a reference soil profile, the unmodified hill land, Bilbster Series profile, termed the "control". Discussion of the suspected inorganic anthropogenic sedimentary materials particle size characteristics is based upon mean, sorting, skewness and kurtosis values. Results are tabulated in Table 8:1- 8:3.

TABLE 8 : 1

PARTICLE SIZE DISTRIBUTIONS FROM MARWICK : NON DEEP TOP SOIL AREAS

PROFILE NAME & NUMBER	HORIZON	SAMPLE DEPTH (cm)	MEAN	SORTING	SKEWNESS	KURTOSIS
Howe 23	S_1	10	6.92	2.74	0.13	0.93
	S_1	20	6.66	2.54	0.13	1.09
	B_2x	30	6.54	2.79	0.03	1.13
	B_2x	40	6.40	2.41	0.09	1.12
Howe 26	S_1	10	6.82	2.85	0.12	0.93
	S_1	20	6.76	2.96	0.06	1.10
	B_2	30				
Howe 34	S_1	10	6.32	2.56	0.38	1.20
	S_1	20	6.50	2.91	0.07	1.15
	B_2	30	5.68	3.09	0.26	1.20
	B_2	40	5.80	3.56	-0.09	0.89
Howe 31	S_1	10	6.58	2.78	0.31	0.92
	B_2 organic	20	5.28	2.79	-0.05	1.41
	B_2	30	5.19	2.95	-0.04	1.20
	B_x	40	5.12	3.12	-0.03	1.02
Control Site	A_1	10	7.22	2.70	0.15	0.76
	A_2	20	6.81	2.91	0.09	0.98
	A_2	30	6.22	3.05	-0.06	1.24
	B_2	40	5.76	2.53	-0.23	1.17
	B_2	50	5.38	3.22	-0.21	1.00
	B_2	60	5.82	3.09	-0.25	1.18
Peat-Alluvium	S_1	20	8.98	1.99	0.26	0.95
	B_2g	40	8.10	2.10	0.10	0.74
	B_2g	60	7.62	2.15	0.10	0.80
	C (waterlogged)	80	5.70	1.99	0.35	0.97
Gley Soil	S_1	20	5.82	2.64	0.24	1.53
	B_2g	40	6.02	2.52	0.24	1.22

TABLE 8:2

PARTICLE SIZE DISTRIBUTIONS FROM SOILS SURROUNDING THE WESTBROUGH AND SKELBRAE FARM MOUNDS

PROFILE NAME & NUMBER	HORIZON	SAMPLE DEPTH (CM)	MEAN	SORTING	SKEWNESS	KURTOSIS
Westbrough Meadowland	A_2	10	6.60	2.42	0.72	0.64
	A_2	20	6.50	2.43	0.66	0.73
	A_2	30	6.72	2.48	0.32	0.78
	A_2	40	6.02	2.53	0.54	0.97
	A_2	50	5.66	2.33	0.50	0.95
	A_3	60	5.24	2.67	0.48	0.98
	B_2g	70	6.06	3.03	0.19	1.07
	C_g	80	5.20	3.04	0.14	0.83
Westbrough Early Arable land	S_1	10	6.16	3.02	0.16	0.91
	S_1	20	6.24	3.03	0.13	0.85
	S_1	30	5.86	3.24	0.12	0.64
	B_2/C	40	4.94	3.28	0.08	0.90
Skelbrae Grazing Land	S_1	10	6.08	2.99	0.14	0.92
	S_1	20	6.18	3.35	0.04	0.86
	B_2/C	30	5.88	3.12	-0.28	0.94

TABLE 8:3

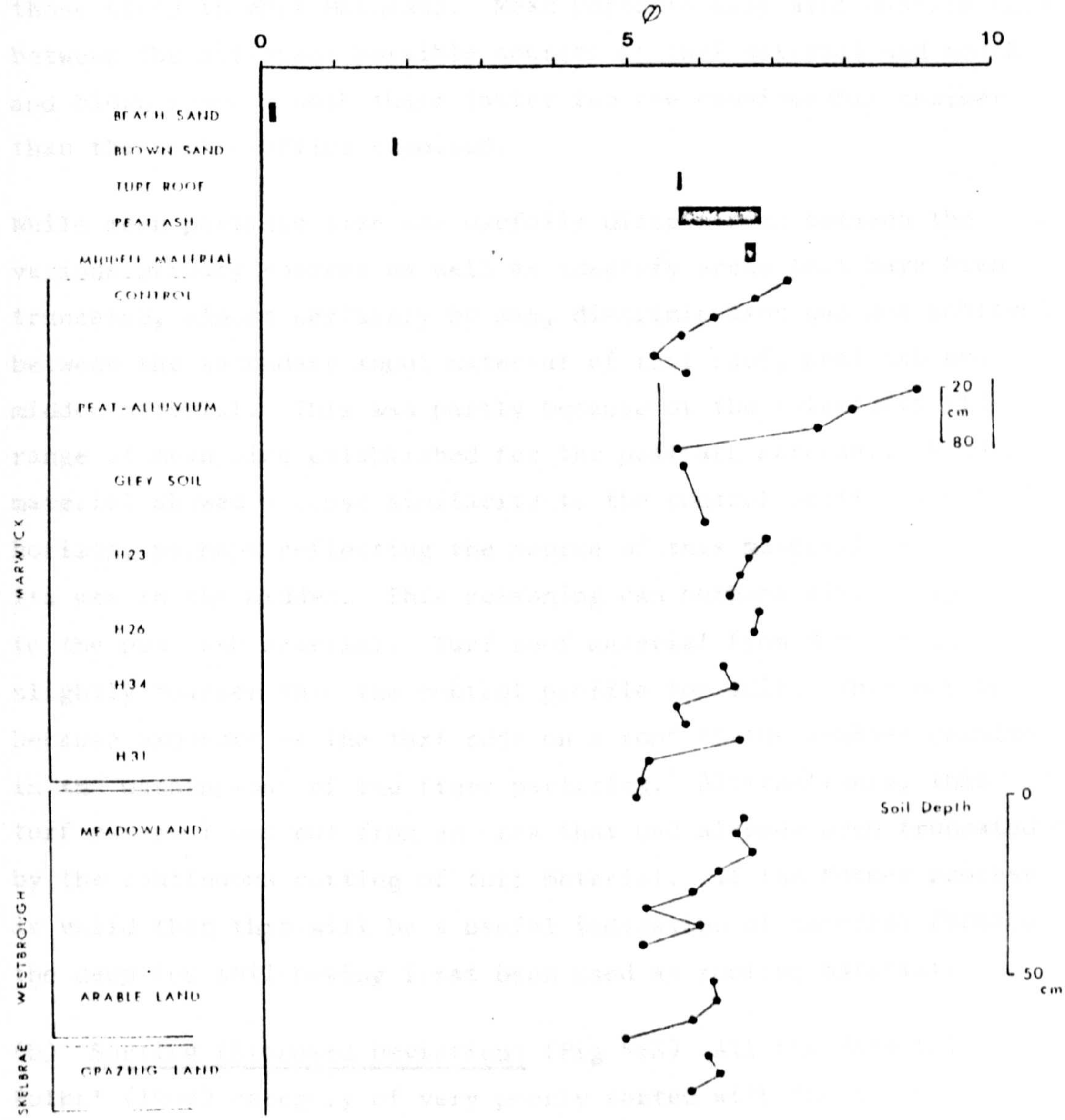
PARTICLE SIZE DISTRIBUTIONS OF POTENTIAL INPUT MATERIAL

MATERIAL	SOURCE	MEAN	SORTING	SKEWNESS	KURTOSIS
Beach sand	Marwick	0.12	0.17	1.00	0.82
Beach sand	Marwick	0.12	0.17	0.99	0.83
Beach sand	Marwick	0.13	0.17	1.00	0.82
Windblown sand	Linklet Bay North Ronald-:say	1.88	0.57	0.01	1.05
"	" "	1.89	0.58	-0.01	1.01
"	" "	1.89	0.59	-0.01	1.03
Turfroof	Marwick	5.78	2.83	-0.09	1.41
"	" "	5.71	2.85	0.08	1.38
"	" "	5.73	2.81	0.08	1.39
Peat ash	Birsay	5.76	2.09	-0.41	0.99
"	"	6.86	2.01	-0.46	1.80
Byre turf/ Manure	Cruesbreck, North Ronaldsay	6.74	3.12	0.05	0.87
"	" "	6.62	3.09	0.04	0.84

(a) Mean (Fig 8:1). This characteristic of a samples particle size distribution can be defined as its average size. The control profile exhibits a steady decline in mean into the B/C horizon from 7.22ϕ to 5.38ϕ at 50cm. Mean size increases slightly below this level. In Marwick the three Bilbster Series soil profiles from the early non deep top soil arable land demonstrate a similar pattern to the control profile although the range of mean particle size within these profiles is less. This perhaps reflects some degree of mixing by ploughing. Profiles from the grazing and hill lands have distinct discontinuities in their mean particle size profile patterns with a sharp break from the uppermost parts of the profile to a coarser lower zone. Given the obvious evidence that the hill land profile (Howe 31) had been truncated and then reclaimed (See Appendix IV) it is valid to suggest that both the hill land profile and the grazing land profile have been truncated by man to provide turf which possibly went to form the deep top soil. These areas were later reclaimed with some material as yet unidentified. Further comparison of these two profiles reveals that the hill land profile was probably coarser than the grazing land profile, thus giving a possible textural distinction with which to trace sources of the deep top soil material. Although only two samples were available from the gley soil (Thurso Series) in Marwick, they indicate a reversal of the pattern seen in the podzols, with the finest material found in the subsoil. These results also indicate that this gley soil is coarser in texture than the control profile. Whether this is a reflection of the gleying process or whether this profile too has been truncated to provide turf material is not certain. The alluvial deposits in Marwick demonstrate a comparatively wide range of mean particle size. Upper parts of the examined profile (down to 60cm depth) are finer than any other profile examined in Marwick. Mean values from this part of the alluvial profile are greater than 7.6ϕ, with mean size becoming coarser with depth.

Mean particle size of the profile exposed in the Saltings to the north of the Westbrough farm mound fluctuate down the profile but the general trend is towards a coarser mean particle size with depth. Compared with the upper horizons of the Bilbster Series profile

Figure 8:1 Mean particle size of suspected input materials and soils surrounding anthropogenic sediments.

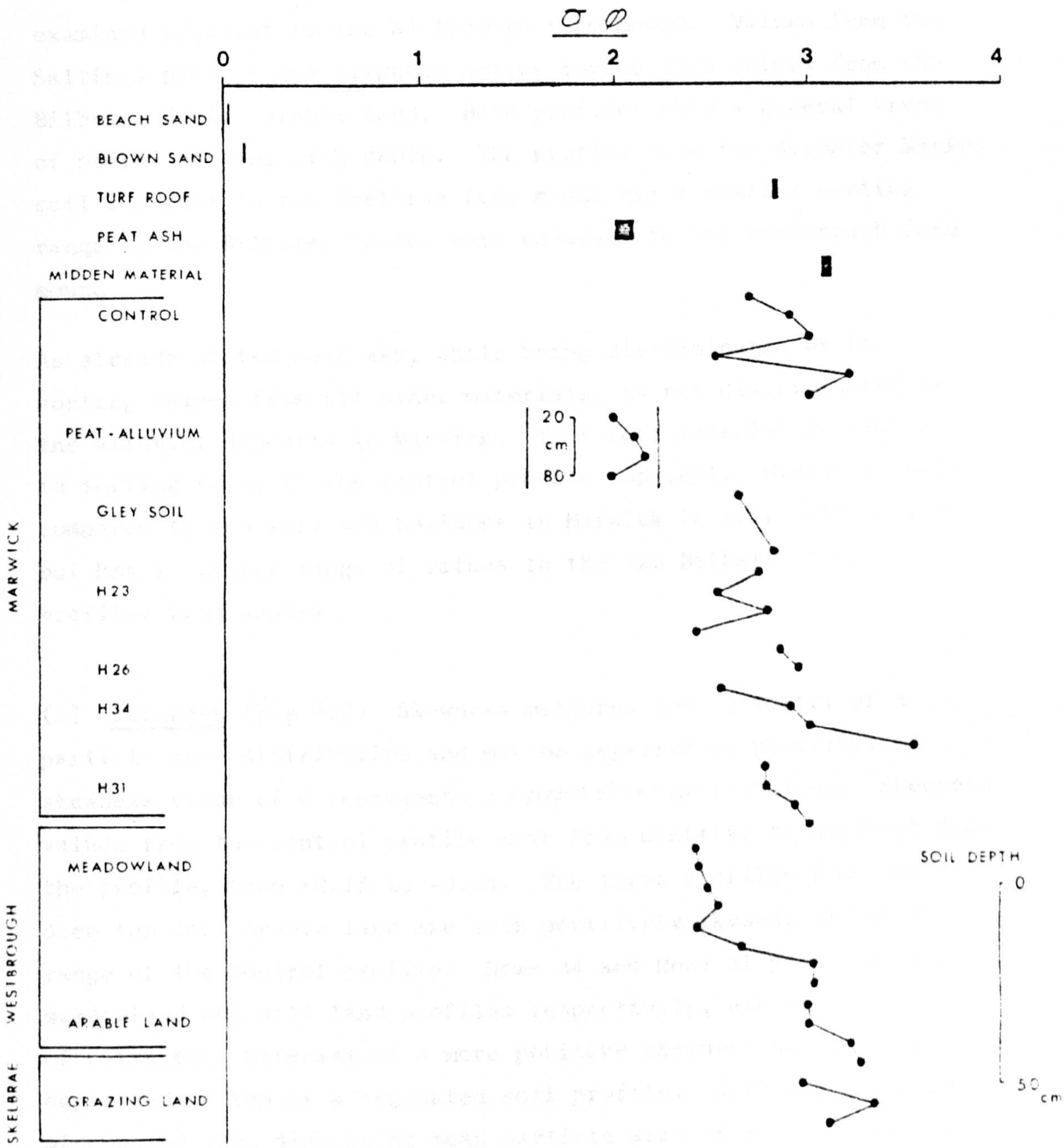


lying to the west of the farm mound the upper levels of the Saltings profile have a finer particle size. Given the relative coarseness of the Bilbster Series soil, there may have been some truncation, an observation that can also be noted for the Bilbster Series soil lying adjacent the Skelbrae farm mound. An alternative explanation for this relative coarseness is that the soil parent materials of the Bilbster Series in Sanday are inherently slightly coarser than those found in West Mainland. Mean particle size also discriminates between the different possible sources of turf material and beach and blown sands. Both these latter two are considerably coarser than the soil profiles examined.

While mean particle size can usefully discriminate between the various primary sources as well as identify areas that have been truncated, almost certainly by man, discrimination was not achieved between the secondary input material of turf roof, peat ash and midden material. This was partly because of the relatively wide range of mean size established for the peat ash material. Midden material showed a close similarity to the control profile top soil horizon, perhaps reflecting the source of this material prior to its use in the midden. This reasoning can perhaps also be applied to the peat ash material. Turf roof material from Marwick is slightly coarser than the control profile top soil. This may be because exposure of the turf sods on a roof to the weather results in the washing-out of the finer particles. Alternatively, this turf material was cut from an area that had already been truncated by the continuous cutting of turf material. If the former process is valid then this will be a useful indication of material forming the deep top soil having first been used as roofing material.

(b) <u>Sorting (Standard Deviation)</u> (Fig 8:2) All the data fall within Folks' (1966) category of very poorly sorted with the exception of the beach sands and blown sands which are very well sorted. Within the control profile top soil sorting becomes poorer with depth but there is a sharp break to a slightly better degree of sorting into the B horizons. All other soils in Marwick demonstrate a fluctuating sorting pattern down the profile; no pattern emerges. Furthermore all, with the exception of the alluvial profile, are similar in

Figure 8:2 Particle size sorting values of suspected input materials and soils surrounding anthropogenic sediments.



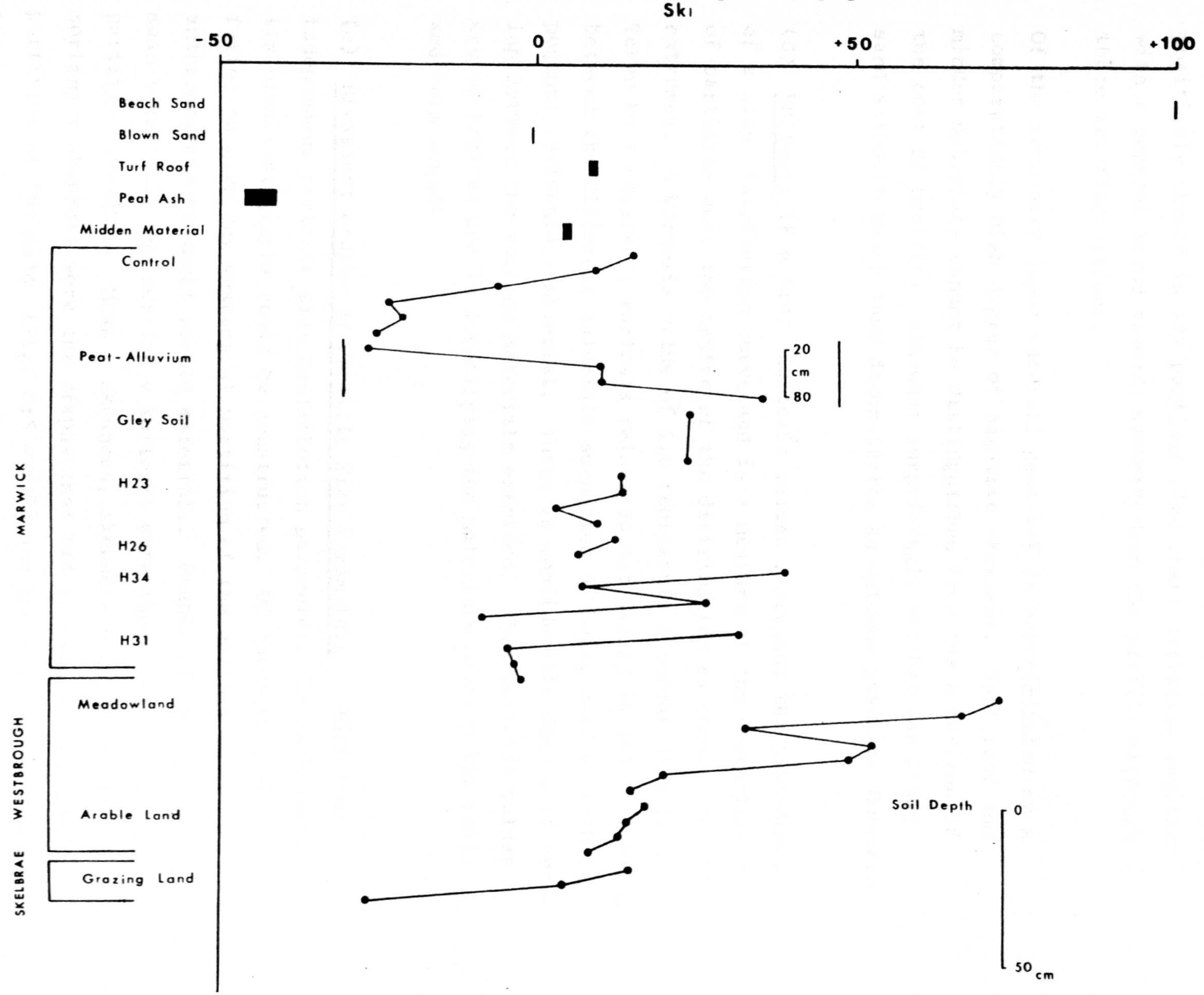
their sorting range to the control profile. This therefore limits the value of sorting as a discriminator of different sources of inorganic materials for deep top soils. The alluvial deposit is however discriminated from the other soils in Marwick by being slightly better sorted (c2.0-2.17) but unfortunately has a similar range to peat ash material.

Sorting does provide a distinction between the two soil profiles examined adjacent to the Westbrough farm mound. Values from the Saltings profile are slightly better sorted than values from the Bilbster Series arable land. Both profiles show a general trend of poorer sorting with depth. The profile from the Bilbster Series soil adjacent to the Skelbrae farm mound has a similar sorting range to the Bilbster Series soil adjacent to the Westbrough farm mound.

As already stated peat ash, while being discriminated by its sorting values from all other materials, is not discriminated from the alluvial deposits in Marwick. Turf roof material is similar in sorting value to the control profile top soil. Midden material compared to top soil S/A horizons in Marwick is less well sorted but has a similar range of values to the two Bilbster Series profiles from Sanday.

(c) <u>Skewness</u> (Fig 8:3) Skewness measures the assymetry of a particle size distribution and may be negative or positive. A skewness value of 0 represents a symmetrical distribution. Skewness values from the control profile move from positive to negative down the profile, from +0.15 to -0.25. The three profiles from non deep top soil arable land are both positively skewed, within the range of the control profile. Howe 34 and Howe 31 profiles, the meadowland and hill land profiles respectively, exhibit evidence of extraneous material of a more positive skewness having been deposited on top of a truncated soil profile. Such a process was also noted when discussing mean particle size of these profiles. The gley soil in Marwick is characterised by a consistent relatively large positive skewness, while the alluvial soil profile is the reverse of the trend found in the control profile with the upper

Figure 8:3 Particle size skewness values from suspected input materials and soils surrounding anthropogenic sediments.



sample negatively skewed moving towards positive skewness down the profile.

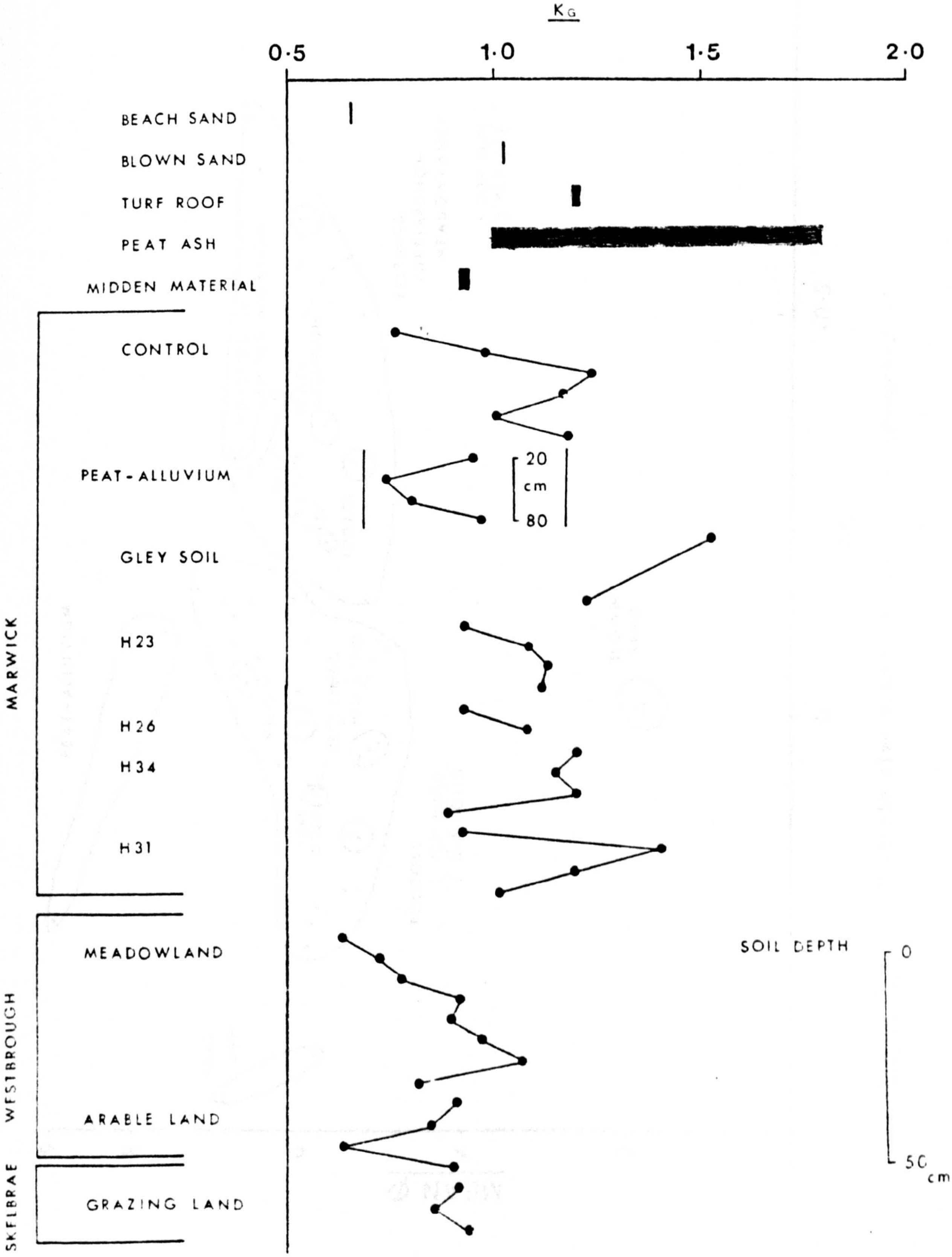
Of the profiles examined on Sanday, both the Bilbster Series profiles exhibit a similar profile skewness pattern to the control profile although the profile at Westbrough is restricted in its skewness range. The Saltings profile at Westbrough is distinctively very positively skewed in its particle size characteristic, together with a general trend towards symmetry down the profile although there are fluctuations.

Of the secondary input material peat ash is discriminated by a comparatively high degree of negative skewness. Turf roof and midden materials cannot be distinguished from the A horizon of the control profile; somewhat surprisingly neither can blown sand although beach sand demonstrates an extreme positive skewness.

(d) Kurtosis (Fig 8:4) Kurtosis values represent the peakedness of a size distribution curve and is a measure of the concentration of particles near the centre of the distribution as opposed to the extremes. A kurtosis value of 1.0 represents a normal distribution. Taken by themselves, kurtosis values do not assist in discriminating between the different materials suspected of being used as anthropogenic sedimentary material. There is considerable degree of overlap between the various materials examined. Thus kurtosis values are of limited use in identifying the materials of deep top soils and farm mounds.

(e) Bivarient Graphs of Particle Size Parameters With four independent particle size distribution parameters for each sample six bivarient graphs could be constructed. Of these six, three failed to give any meaningful partition of the various suspected anthropogenic sediment source materials. Graphs of mean v sorting, mean v kurtosis and sorting v kurtosis were those that failed to partition the data. Mean v skewness, skewness v kurtosis and sorting v skewness were the graphs that did provide a meaningful partition of the data (Figs 8:5 - 8:7) and these are discussed in the paragraphs below.

Figure 8:4 Particle size kurtosis values from suspected input materials and soils surrounding anthropogenic sediments.



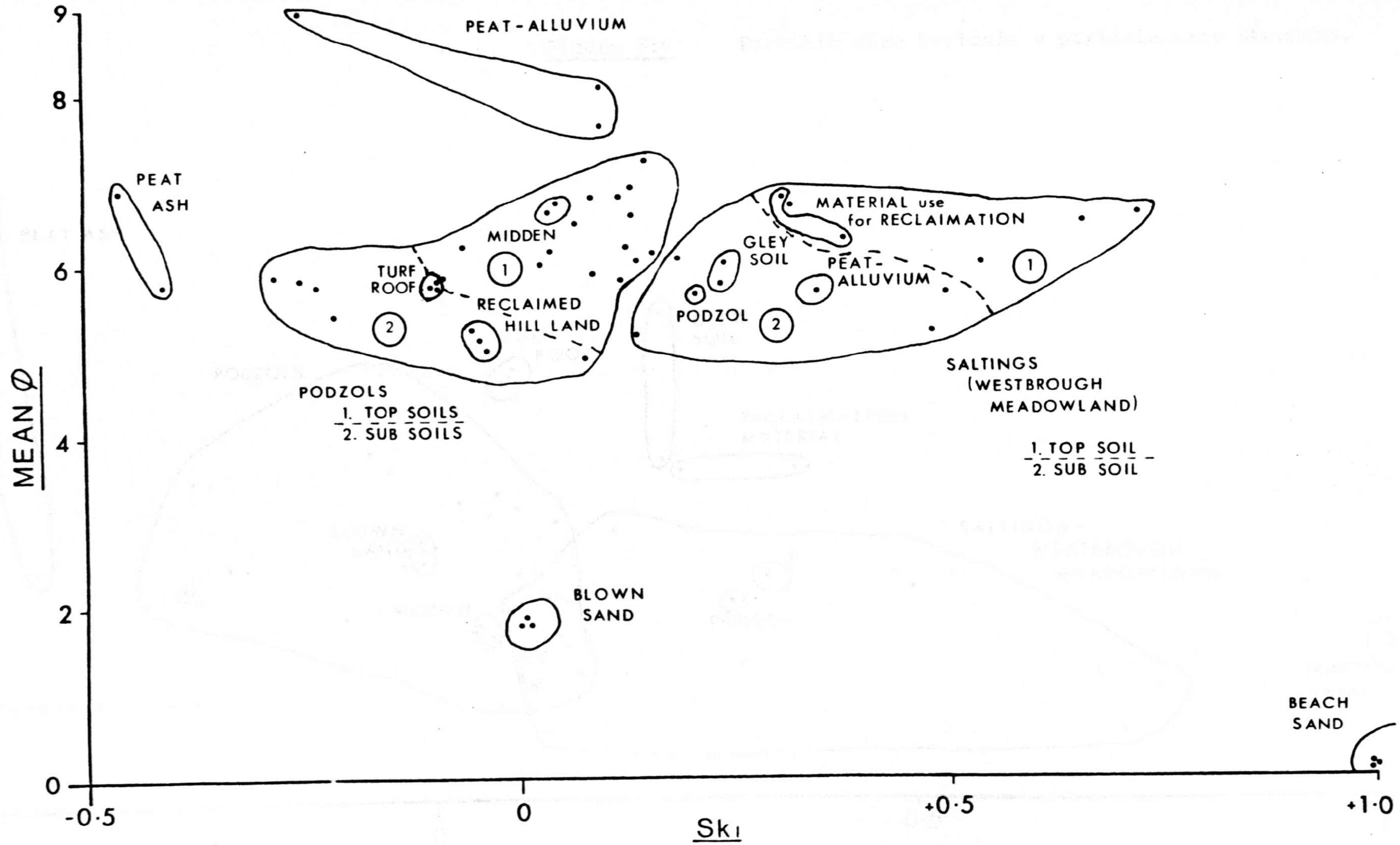
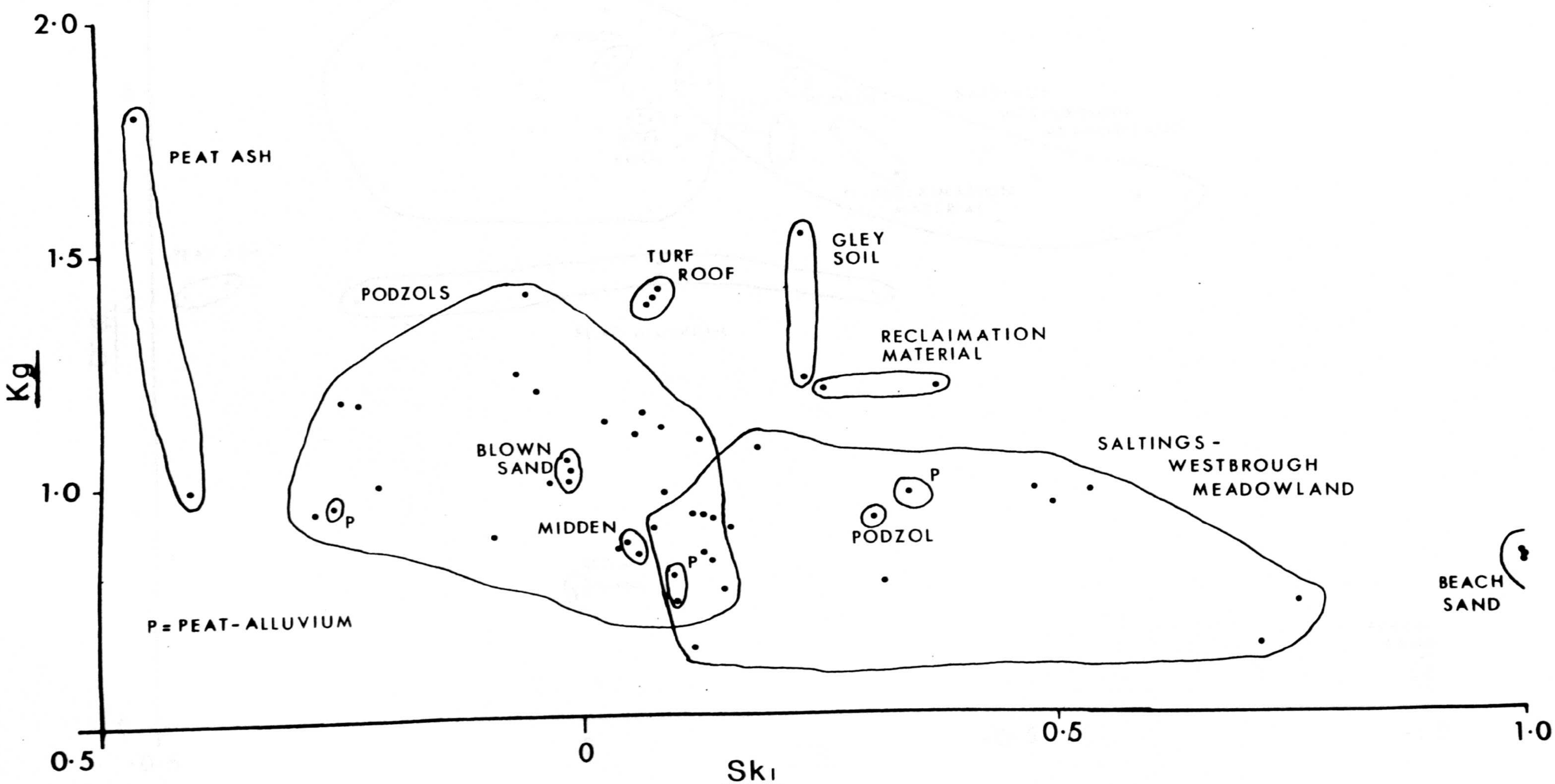


Figure 8:5 Particle size mean v. particle size skewness.

__Figure 8:6__ Particle size kurtosis v particle size skewness.



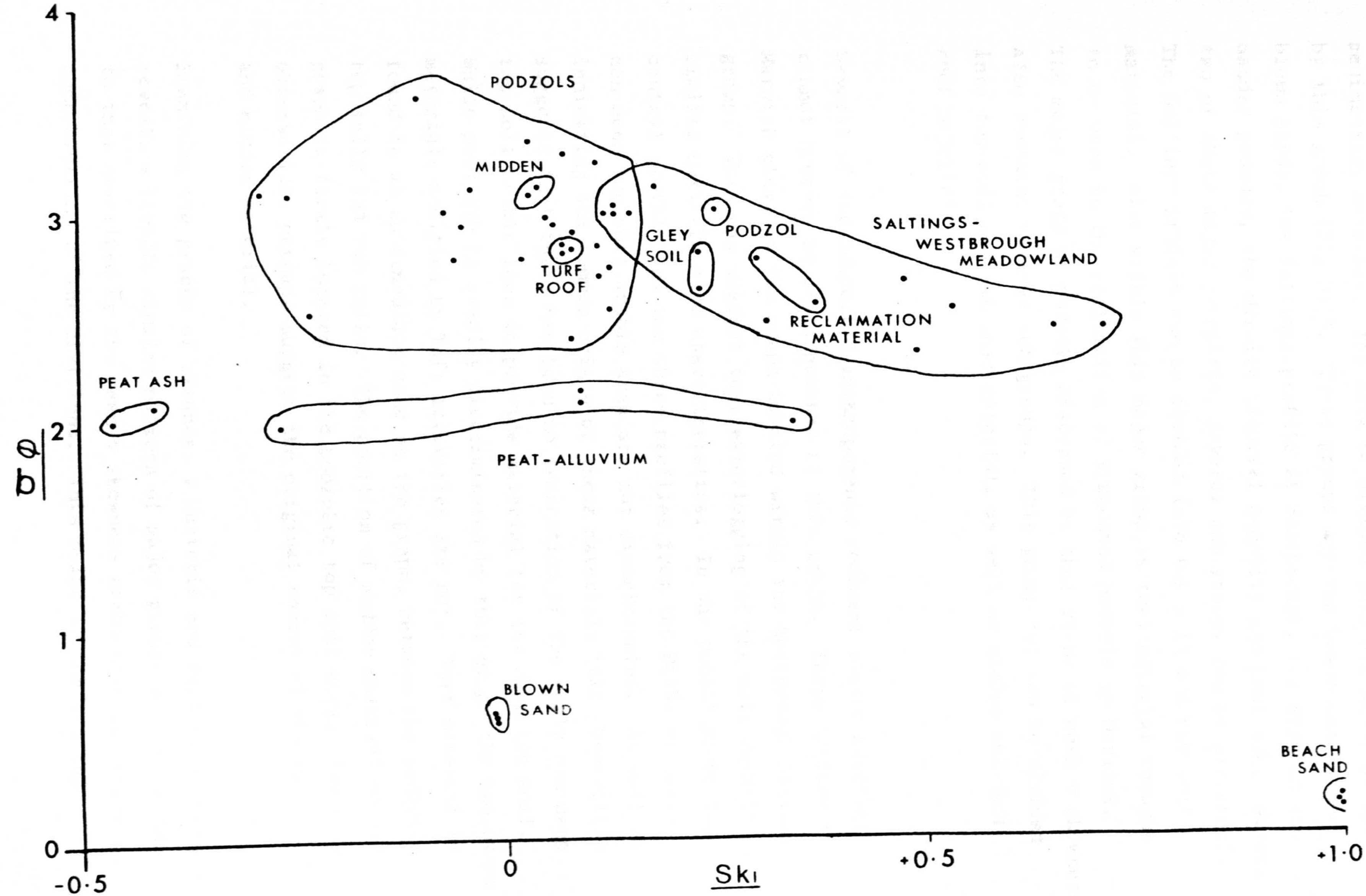


Figure 8:7 Particle size sorting v. particle size skewness.

The bivarient graph of mean v skewness provided the best separation of the data, which represents the possible sources of anthropogenic sedimentary material. The data is divided into six major groups by this graph (Fig 8:5). These groups are the beach sands, the blown sands, the Saltings profile at Westbrough, the Marwick and Sanday podzols, the Marwick alluvial deposits and peat ash. Within two of these major groupings, several sub groups can be discerned. The Saltings profile can be divided into top soil and sub soil material. Also within this major group is that material thought to be used in the reclamation of truncated podzols in Marwick. The major group of podzols discerned by this graph of mean v skewness also contains various sub groups. This group too can be divided into top soil and sub soil material, as well as midden and turf roof material.

Several of the suspected anthropogenic sediment source material cannot however be distinguished by this graph. These include the Marwick gley, on the graph located within the Westbrough Saltings group. This may suggest that waterlogging of the soil results in similar particle size characteristics. In the podzol group the control profile and the three profiles from the Bilbster Series non deep top soil arable area are not discriminated. As well as indicating the common origin of these materials this observation suggests that there has been no truncation of the early non deep top soil arable land to provide material for the deep top soil. While peat ash is readily discriminated by this graph the two other materials modified by Toft activities are not. Turf material is found in an intermediate zone on the graph, between the podzolic top soils and sub soils. The position of midden material on this graph is firmly located in the podzolic top soil area. These two observations perhaps suggest the original source of the turf roof and midden material.

Examining the graphs of skewness v kurtosis and sorting v skewness reveals a broadly similar pattern of major groups and sub groups to that described by the mean v skewness graph although there is some blurring of the divisions. This helps to confirm the discrimination of data outlined above. The additional two graphs do however provide additional separation of materials not separated by the mean v skewness graph. Gley soil material, material used to reclaim the truncated soils and turf roof material are all separated out by the graph of skewness v kurtosis (Fig 8:6). Midden material remains as a secondary source of anthropogenic sediment which is not well separated out. On the graph of sorting v skewness it is however just possible to distinguish midden material as a sub group within the podzolic soil group (Fig 8:7).

Without going into the theoretical reasons, which are in any case not fully understood, it can be concluded that particle size distribution parameters provide a basis for identifying the inorganic materials used in the formation of deep top soils and farm mounds. Source identification can be achieved by considering single parameter plots and bivarient graphs of particle size distribution characteristics to obtain some degree of consensus as to the source of deep top soil and farm mound inorganic materials. Plots demonstrated as able to discriminate in some degree between potential source materials are the mean, sorting and skewness as do graphs of mean v skewness, sorting v skewness and kurtosis v skewness. By examining the particle size characteristics of potential anthropogenic sources,two truncated profiles which had subsequently been reclaimed could be identified. These profiles located in the hill land and meadowland of the early Township indicate that removal of turf by human effort had almost certainly occurred. This material may well have been used ultimately in the formation of the deep top soils. By contrast there is no evidence for truncation in the three early arable land (non deep top soil) profiles of the Bilbster Series in Marwick. It seems unlikely therefore that turf material came from these sources. The plots and graphs of particle size distribution characteristics also allow assessment to be made of pedogenic and diagenic modification of particle size characteristic, similar processes of which may have operated within the deep top soils and farm mounds.

8:2:2 The Inorganic Materials of Deep Top Soil Formation at West Howe, Marwick

The four profiles exposed in the West Howe deep top soil unit (see Chapter 6) were subject to particle size analysis. These profiles formed the major basis for statements made on the inorganic materials of deep top soil formation. Additional anthropogenic sediments in Marwick subject to particle size analysis were the profile exposed in the West Howe farm yard and the profiles of Netherskail and Muce which represent the other two deep top soil units found in the Marwick drainage basin. Inclusion of these additional profiles in the analysis first of all permitted an assessment of the influence of alternative zones of deposition for anthropogenic sediments (ie the farmyard) upon the materials used in the deep top soil formation at West Howe. Secondly it was possible to evaluate conclusions drawn for the West Howe deep top soil in relation to the other deep top soils found in Marwick.

Laboratory procedures for particle size analysis and equations for calculating particle size distribution characteristics are as described in Appendix X . Results are tabulated in Table 8:4. To assist the identification of particle size parameter, trends within the deep top soil at West Howe trend surfaces and their residuals were calculated for single parameters using a Commodore Pet microcomputer with a trend surface analysis programme written by M Thomas of Liverpool University. Calculated trend surfaces and residuals were plotted and isopleth maps drawn. Attempts to identify the inorganic materials of deep top soil formation are based on those particle size attributes best able to discriminate between potential input sources as established in the previous section. Starting with the mean, these attributes are gone through in turn before definite statements are made about the inorganic materials involved in deep top soil formation and the position of those materials within the deep top soil.

(a) Mean Ignoring the B/C horizon values, which like the control profile are generally coarser than overlying S or A horizons, the deep top soils do not exhibit the trend of increasing coarseness down the profile seen in other podzolic soils in Marwick. Indeed

TABLE 8 : 4

PARTICLE SIZE DISTRIBUTIONS FROM MARWICK : DEEP TOP SOILS

PROFILE NAME & NUMBER	HORIZON	SAMPLE DEPTH (cm)	MEAN	SORTING	SKEWNESS	KURTOSIS
Netherskail	S_1	20	7.38	3.23	0.28	0.90
	S_2	40	6.88	2.38	0.21	0.65
	S_2	60	7.00	2.76	0.15	0.67
	B_2	80	6.14	3.25	-0.08	1.34
Muce	S_1	15	6.68	2.63	0.22	0.89
	S_2	30	6.64	2.79	0.31	0.87
	S_2	50	6.72	2.96	0.06	0.96
	$B_{2}g$	70	4.32	3.46	0.02	0.71
Howe 13	S_1	10	6.74	2.55	0.23	0.86
	S_2	20	7.02	2.80	0.11	0.53
	S_2	30	6.96	2.53	0.24	0.57
	S_2	40	7.16	2.42	0.14	0.75
	S_2	50	6.78	2.28	0.10	0.80
	S_2	60	7.04	2.41	0.03	0.84
	S_2	70	7.02	2.61	0.16	0.86
	B_2	80	7.06	2.80	0.24	0.50
Howe 18A	S_1	10	6.74	2.82	0.26	0.92
	S_2	20	6.72	2.70	0.29	0.88
	S_2	30	6.60	2.65	0.30	0.90
	S_2	40	6.66	3.99	0.05	0.96
	S_2	50	7.00	2.67	0.16	0.87
	S_2	60	6.76	3.43	0.06	0.63
	S_2	70	6.96	2.69	0.14	0.87
	B_2	80	6.88	2.79	0.13	0.92
	B_2	90	6.12	3.35	-0.08	1.00
Howe 18	S_1	10	6.64	2.71	0.15	1.07
	S_1	20	6.50	2.65	0.19	1.14
	S_2	30	6.92	2.65	0.23	0.79
	S_2	40	7.12	2.70	0.08	0.75
	S_2	50	6.80	2.83	-0.11	0.89
	$B_{2}x$	60	4.02	3.28	-0.05	1.07
	$B_{2}x$	70	5.36	3.17	0.06	1.07
		80	5.45	3.21	-0.01	1.07
Howe 23A	S_1	10	6.66	2.65	0.15	0.94
	S_2	20	6.82	2.64	0.12	0.93
	S_2	30	7.04	2.74	0.15	0.85
	A_1	40	6.62	3.14	-0.03	1.08
	B_2	50	6.98	2.60	0.04	1.20

TABLE 8:4

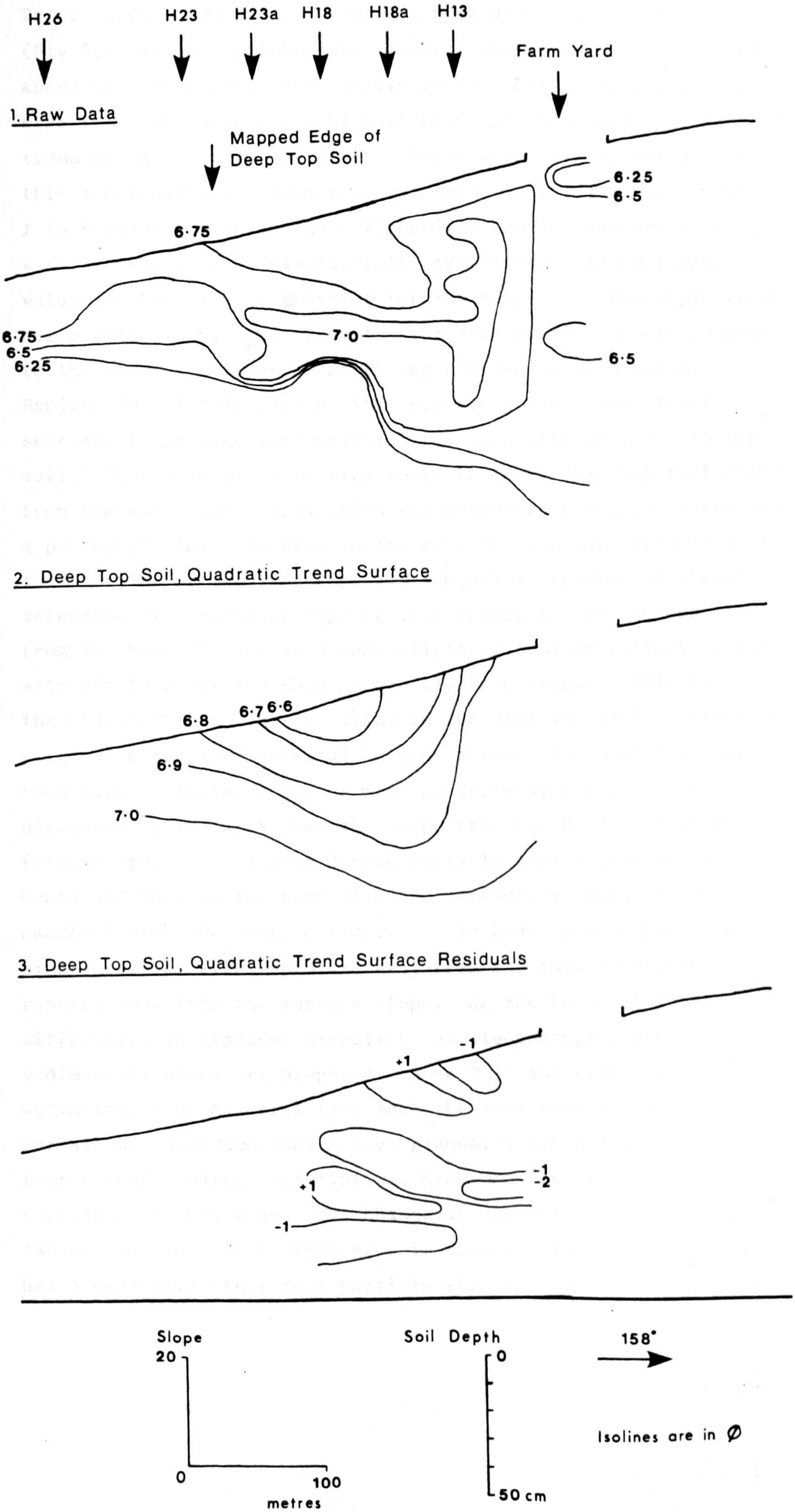
PARTICLE SIZE DISTRIBUTIONS FROM WEST HOWE FARM YARD

PROFILE NAME & NUMBER	HORIZON	SAMPLE DEPTH (cm)	MEAN	SORTING	SKEWNESS	KURTOSIS
West Howe Farm yard		20	5.94	1.85	-0.20	0.82
		40	6.72	2.64	0.09	0.89
		60	6.62	2.66	-0.04	1.01
		80	6.40	2.53	0.02	1.01
		100	6.66	2.63	-0.03	1.05
		120	6.80	2.67	0.02	1.00
		140	6.40	2.80	0.20	1.06

the general trend is for the deep top soil S horizons to become finer with depth (Fig 8:8). Whether this mean particle size pattern is pedogenic or sedimentary in origin is not entirely clear. It is conceivable that the observed pattern is the result of weathering and translocation of fine material to the lower part of the deep top soil. This in part would help explain the anomalous fine mean particle sizes in the B/C horizons of the West Howe deep top soil. If a pedogenic interpretation is placed upon this data then the deep top soils must be considered as fundamentally different in their pedogenic processes and/or rates from other podzolic soils in Marwick and more akin to gley soils. This seems unlikely in view of the similar environment in which deep top soils and the main Bilbster Soil Series are found. In view of the above discussion, while there does indeed appear to be some degree of finer material being translocated into the B/C horizons, indicating pedogenesis, the dominant explanation of the mean particle size pattern seen in the West Howe deep top soil is that it is sedimentary in origin.

The range of mean particle size found in the S horizons of the deep top soil is 6.50ϕ to 7.16ϕ. Thus the materials most likely to have been used in the formation of this deep top soil on the basis of mean particle size data are turf, midden material and peat ash. These materials would appear to have been used throughout the formation of the deep top soils. Declining coarseness with depth in the S horizons may be explained by the stripping of turf continuously from the same source areas and its subsequent deposition as deep top soil. Given that in unmodified podzolic soils mean particle size is finest nearest the land surface,then gradual but continuous stripping of turf from the same area would result in exposure of increasingly coarser material at the land surface. If the material removed was ultimately destined for deposition as the deep top soil then the finest material stripped first from the source areas would be found in the lower parts of the deep top soil. In effect this would mean a reversal of the natural podzolic mean particle size profile within the deep top soil, as is evident in the West Howe deep top soil.

Figure 8:8 Particle size mean in the West Howe deep top soil.



Trend surface analysis of the West Howe deep top soil S horizons (Fig 8:8) while confirming the general characteristics outlined above also identified distinctive zones. Data of mean particle size from this deep top soil unit have only a significant 2nd order trend surface at the 95% level. Three zones are identified by this trend surface. Each zone can be seen in Figure 8:8. Zone 1 is represented by the Howe 13 profile and is characterised by a consistently fine mean particle size having a trend surface value greater than 6.9ϕ except for the sample at 10cm depth which has a value of 6.87ϕ. Results from this profile do not comform to the general pattern of declining coarseness with depth. Explanation of this must be that new areas were consistently selected to provide turf material for this part of the deep top soil. Thus mean particle size would be finer than material coming from the same source area which was gradually being truncated over a period of time. Implied in the results from this profile is that this portion of the landscape was subject to special treatment with selection of a particle type of turf material. Moving downslope from the Howe 13 profile a semi-eliptical contour pattern emerges with its focus at the Howe 18 profile 10cm sample. This focus is the coarsest trend surface value in the deep top soil; from this point deep top soil material becomes finer. Two distinct zones, each with a similar range of mean particle size can thus be discerned in the area down the slope from the Howe 13 profile (Figure 8:8). In Zone 2 mean particle size increases with depth and towards the farm with the contours tending to run parallel with the surface slope. In Zone 3, mean particle size increases with depth and away from the farm with contours running away from the surface slope. On the basis of these differences in gradient direction and steepness, two distinct sedimentary zones are proposed. Zone 2 is the result of gradual accumulation of material from much the same area throughout its formation. With this source area gradually being truncated, increasingly coarser material was provided for deep top soil formation in this zone. The change of contour pattern into Zone 3 can be explained by a difference in source material. This zone has a generally finer mean particle size than Zone 2 while still exhibiting the declining coarseness with depth. It seems most likely therefore that much of the inorganic material for this zone came from the meadowland which Section 8:2:1 indicated was of finer mean particle size than material from the hill land. An alternative explanation of this finer mean particle size at the lower part of the deep top soil is that there has been lateral movement of finer material down the slope. This does not however explain the increasing mean particle size up the slope from the coarsest area of this deep top soil. In conclusion therefore the 2nd order trend surface identifies three distinct sedimentary zones within the West Howe deep top soil, each resulting from different sources of material.

In addition to the deep top soils being a deposition zone for anthropogenic sediments within the vicinity of the West Howe farm, the farmyard is an area where anthropogenic sediments are found. Indeed it may be that the farmyard area of West Howe is a farm mound. A necessary question to be resolved is that of the influence of this alternative area for anthropogenic sediment deposition upon the material used in the formation of the deep top soils. Examination of the fluctuating mean particle size values from the farmyard profile would suggest that much the same material deposited in the farmyard is the same as that in the formation of the deep top soil (Table 8:4). That is the inorganic sedimentary material found in the farmyard is most likely some combination of turf, midden material and peat ash. Peat ash is most likely the dominant material in the upper 20cm of this profile. Assuming that the sedimentary materials found in the farmyard were deposited over much the same period as the deep top soil material then it is possible to conclude that the farmyard had little influence in controlling the types of material used to form the deep top soil. What is more likely is that there was some degree of interplay between the two anthropogenic deposition zones in terms of the volume of material deposited. A surplus of material that otherwise would have been deposited as the deep top soil would, instead, be deposited in the farmyard.

Mean particle size values from deep top soils elsewhere in the

Marwick drainage basin indicate that much the same materials were used as at West Howe (Table 8:4). Similar sedimentary patterns are also evident with, for example, B/C horizons being clearly differentiated from overlying S horizons. Netherskail profile S horizons have a fine mean particle size throughout and a similar process of formation to the Howe 13 (Zone 1) area of the West How deep top soil is proposed. The profile at Muce gives some indication of the reversed podzol pattern seen beyond the Howe 13 profile of the West Howe deep top soil. There is therefore some degree of similarity in deep top soil mean particle size patterns within the Marwick drainage basin.

It is at this point worth summarising the conclusions reached during the discussion of mean particle size values found in the West Howe deep top soil. These conclusions are the working hypotheses against which further discussion of particle size characteristics will be measured.

1. There is evidence for three processes having dictated the mean particle size characteristics in the West Howe deep top soil. These are pedogenesis, lateral movement of fine material (erosion) and the selective deposition of materials by man. Of these three processes, the third would appear to be the most dominant.

2. The inorganic materials involved throughout the formation of this deep top soilare some combination of turf, midden material with peat ash.

3. A general mean particle size pattern of decreasing coarseness with depth is evident. This implies that turf was removed continuously from much the same areas, gradually truncating the source areas surface and thus exposing coarser material which would be taken up during the next phase of turf stripping.

4. The general pattern can be refined by fitting a trend surface to the data. A significant (95%) 2nd order trend surface indicates that there are three distinct zones within the West Howe deep top soil.

(a) Zone 1, which incorporates the Howe 13 profile, characterised by a consistently fine mean particle size throughout. Turf material for this zone is thought to have come from new source areas throughout its formation.

(b) Zone 2, with material coming from the same source area, probably the hill land.

(c) Zone 3, with material coming from the same source area, probably the meadowland. An alternative explanation for Zone 3 which must be considered is that the observed mean particle size pattern results from the lateral movement of finer material down the slope.

5. Other areas of the landscape associated with the West Howe farm which receive anthropogenic sediments (the farmyard) do not influence the sorts of materials used in deep top soil formation.

6. The characteristics of deposition seen in the West Howe deep top soil appears to be similar to deposition characteristics observed in the other deep top soils of Marwick.

(b) <u>Sorting</u> While values for particle size sorting in the West Howe deep top soil discriminates between the B/C horizons and the overlying S horizons,no other significant distribution pattern emerges (Fig 8:9). This is not surprising in view of the fluctuating sorting patterns seen in the control and potential sources'profiles in Marwick. The observed pattern is,however,not inconsistent with an anthropogenic sedimentary origin. Sorting values are consistent with turf being the major source of material for this deep top soil. Evidence for better sorted peat ash material is limited although peat ash may have been a major contributory material between 30 and 50cm of the Howe 13 profile. Use of turf based midden material would appear to be likewise restricted although possibly deposited at 40cm in the Howe 18A profile (Fig 8:9). This anomoly is however so large that some other unidentified material may have been deposited at this

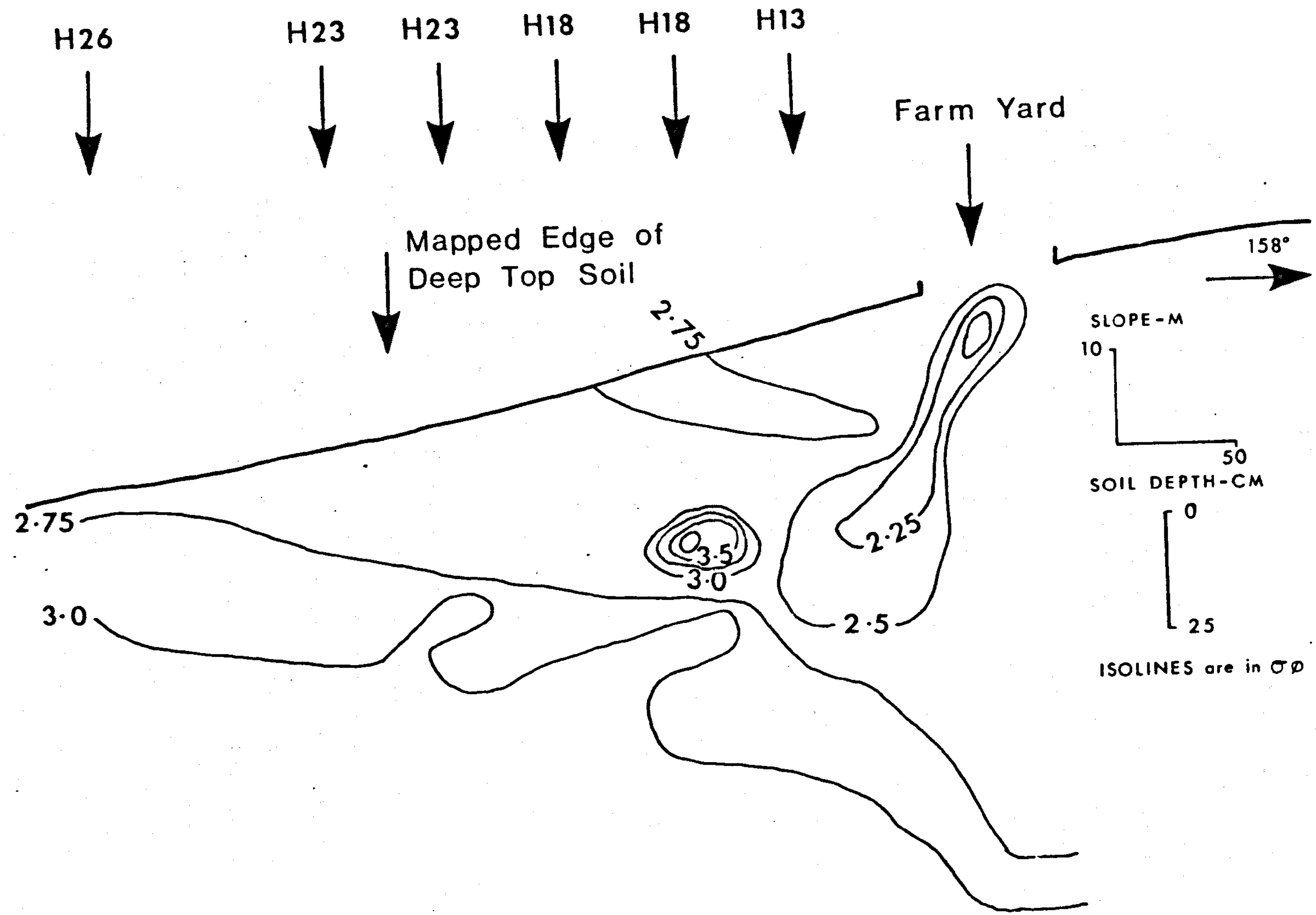


Figure 8:9 Particle size sorting in the West Howe deep top soil.

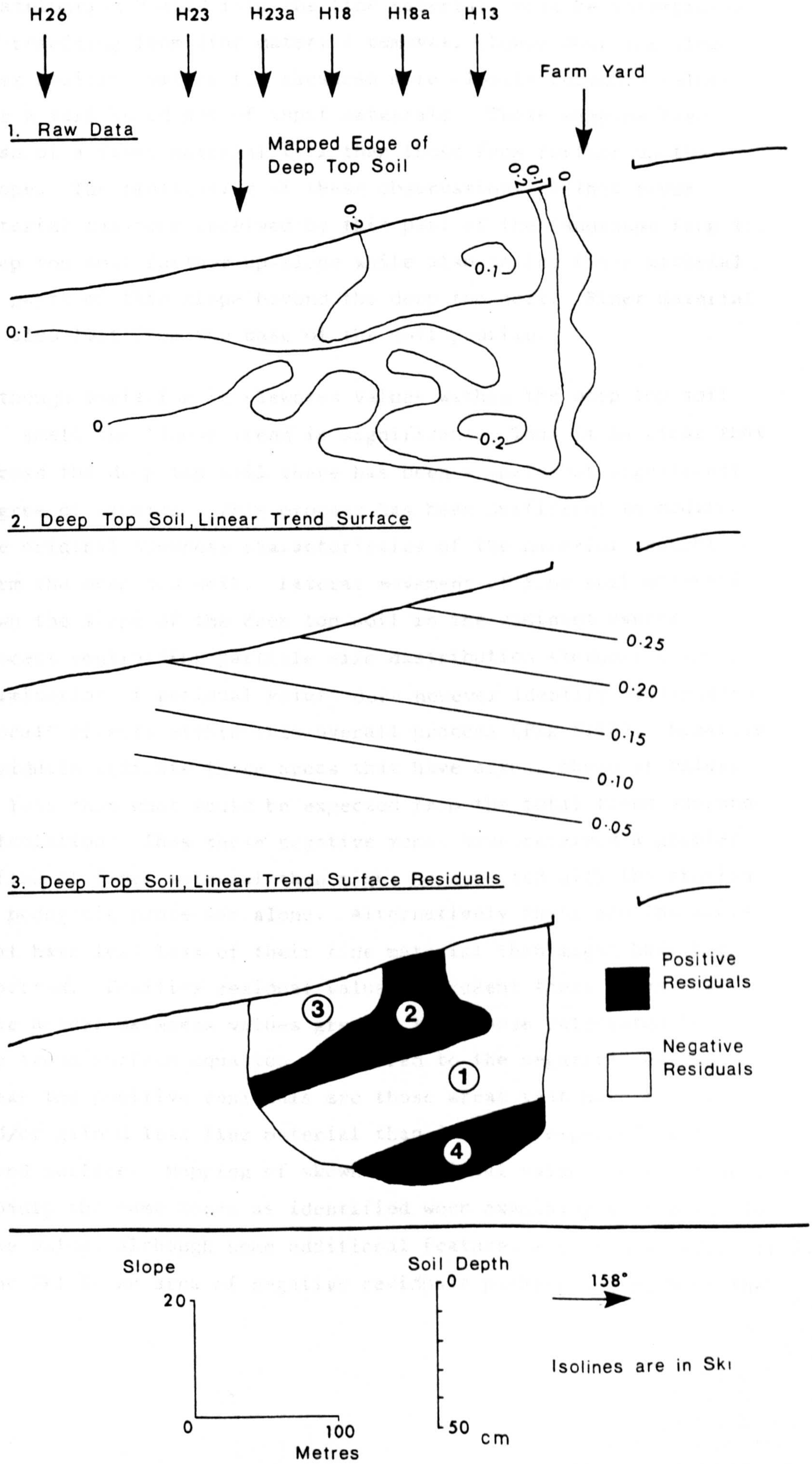
point.

Values of sorting within the farmyard profile have the same range as those found within the deep top soil with the exception of the sample at 20cm. This sample represents in all probability peat ash material. There is nothing to suggest that the presence of this area of anthropogenic sediment deposition influenced the materials used in the formation of the deep top soil. Sorting values from deep top soils elsewhere in the Marwick drainage basin are much the same as those found in the West Howe deep top soil. Poorly sorted subsoils are identified, overlain by material which is slightly better sorted. S horizon material is dominantly turf with pockets of turf based midden material in the Netherskail profile. These results from Netherskail and Muce do not suggest any distinctive difference in materials used or deposition pattern in comparison with the West Howe deep top soil.

Although sorting values from the deep top soils add little to the hypotheses presented as a result of mean particle size analysis, neither do they refute these working hypotheses. These results do indicate the dominance of turf material in the formation of deep top soils but that apart,the hypotheses formulated on the basis of mean particle size are so far held to be valid.

(c) Skewness Examination of particle size distribution skewness values from the West Howe deep top soil calls in some degree for the modification of the hypotheses presented as a result of particle size mean and sorting interpretations. A symmetrical curve has a skewness value of 0.00; one with a tail in the fines has positive values up to a mathematical limit of +1.00 and a curve with a tail in the coarse grains has negative values with a limit of -1.00 (Folk, 1966). Consequently the significant (95%) 1st order trend surface pattern of skewness values in the West Howe deep top soil must be interpreted as resulting from the movement of finer material down the profile and down the slope (Fig 8:10). The skewness values found in the upper and higher parts of the deep top soil are more positive than what is to be expected if turf/manure or peat ash are the materials of formation. This

Figure 8:10 Particle size skewness values in the West Howe deep top soil.



part of the deep top soil is defined by skewness values greater than 0.15. These more positive values, which mean a greater distribution "tail" into the fine material, must be interpreted as resulting from fine material removal. Lower down the slope less positive values for skewness more closely resemble values for a turf-based set of input materials. These samples have less of a finer material tail than those from further up the slope. The implication of these observations is that finer material has been received by this part of the landscape from the deep top soil further up-slope while also losing finer material to parts of this slope beyond the deep top soil. Finer material is also lost from the base of the soil profile.

Although variation in skewness values within the deep top soil is small the linear trend is significant. Thus it is clear that across the deep top soil there has been a small but significant degree of erosion. This process has been sufficient to modify the original skewness characteristics of the material thought to form the deep top soil. Lateral movement of fine soil material down the slope of the deep top soil is the dominant overall process controlling particle size distribution skewness values. Examination of residual values does however identify distinctive "local" effects within this overall process (Fig 8:10). Negative residuals indicate those areas that have actual skewness values of less than what would be expected from the total trend surface calculation. Thus these negative zones have received a greater influx of finer material than might be expected with the erosion or pedogenic processes alone. Alternatively these are the areas that have lost less of their fine material than might have been expected. Positive residual values represent those areas that have actual skewness values greater than those calculated by the trend surface equation. Compared to the negative residual areas the positive residuals are those areas that have lost more and/or gained less fine material than is to be expected on the trend surface. Mapping of skewness residual values serve to define broadly the same zones as identified when examining mean particle size values although some additional features are evident (Fig 8:10). Zone Sk1 is an area of negative residuals picking out much of the

Howe 13 profile together with samples at depth in the deep top soil. Here there is a more significant tail of fine material, a characteristic than can be explained by the deposition of turf material coming from a slightly truncated profile. This is reversed in Zone Sk2 with positive residuals indicating an inheritance of less fine material, material coming from the more truncated source areas. The negative residuals of Zone Sk3 imply finer materials used in its formation and on the basis of discussion on mean particle size values this material may well have come from the adjacent grazing land profile. Zone Sk4 emerges as a new area not previously discerned by other particle size distribution properties. Its positive residual properties are considered to reflect some degree of mixing with coarser B/C horizon materials.

Examination of skewness values from the farmyard zone indicates that turf based material was used in the formation of these sediments. Furthermore this data indicates that this material has been virtually unmodified by erosive or pedogenic effects. Thus the difference in skewness values between the farmyard and the deep top soil sediments can be attributed to variation in post-depositional processes rather than any difference in the materials of formation. The erosion/pedogenic processes also appear to have been operating at Netherskail and Muce. Both the profiles are within the skewness range found in the West Howe deep top soil. Again, a close similarity exists between the deep top soils of Marwick.

Considering the working hypotheses concerning the inorganic materials of deep top soil formation in light of the above discussion indicates that one modification to these hypotheses is required. This modification is in relation to the processes responsible for the pattern of particle size distribution characteristics seen in the West Howe deep top soil. Skewness values clearly indicate that there is a small but discernable erosion effect across the deep top soil. This process is sufficient to alter the skewness values of materials thought most likely to form this anthropogenic sediment. However this alteration is predictable and the original materials can still be discerned once account is made of the erosion/pedogenic effect. Apart from this need to give more emphasis to post-depositional processes within the deep top soil, the hypotheses as presented can still be held as valid.

(d) Bivarient Graphs Examining bivarient graphs of mean v skewness, sorting v skewness and kurtosis v skewness added little to the above discussion. These graphs did however confirm the evidence for a reversal of the podzolic particle size pattern seen elsewhere in the Marwick drainage basin as well as the erosion effect across the deep top soil. In addition the use of turf-based material in deep top soil formation was confirmed but these graphs indicated that peat ash was not an important formation material. Whether turf material had been first used in the byre prior to deposition as the deep top soil is not clear. Only two samples were located in the "midden material" part of the bivarient graphs implying that turf was deposited as the deep top soil without first being used in the byre. This observation is however far from conclusive in view of the small sampling size of midden material together with the fact that it is difficult to make a rigid distinction between turf material and midden material using particle size analysis.

Conclusions The first statement that must be made concerning identification of deep top soil inorganic materials is that its inherited and depositional characteristics have been modified by the erosion and redeposition of fine material. There is also evidence for a small degree of vertical movement down deep top soil profiles. Such statements are based upon particle size distribution skewness values. Presumably these processes are operated throughout the period of deep top soil formation with, for example, ploughing activity down the slope contributing to accelerated erosion. However as skewness values indicate that the erosion effect is more pronounced in the uppermost part of the deep top soil it would appear that only since the cessation of deep top soil formation (c 1800s) has the process become dominant.

Despite the clear evidence for post-depositional modification of the deep top soil it is still possible to identify the main inorganic materials of formation as well as particle size distribution patterns that can be attributed to the process of anthropogenic sedimentation. Identifying formation materials is based on the particle size evidence for truncated profiles of soils developed on glacial tills and particle size characteristics of other sediments in Marwick in comparison with particle size characteristics of the deep top soil. It is clear that societies forming the deep top soil procured their inorganic materials primarily from the hill land and grazing land areas of the early Township. There is no evidence to suggest material having come from the wetter meadowland areas, the sterile beach area, from other, non deep soil, arable areas of the Township or from borrow pits. Deliberate choice of material sources was therefore made. These areas were relatively dry, already supported some degree of vegetation cover, therefore contained some nutrients, and were not already in use as arable areas. Modification of turf material from these sources as a result of Toft activities is limited. There is no evidence to suggest that prior to deposition of turf material as the deep top soil it was used as a roofing material. Neither, in all probability, was it used in the hearth as a fuel. Whether or not the turf material was used as bedding for the byre is not entirely clear from the particle size evidence. Thus three possible pathways of turf transfer from its source to the deep top soil are still possible. The turf material may have been transported to the zone of deep top soil formation direct, it may have been composted with organic materials in the Toft but outside the byre or it may have been used in the byre as bedding and having been impregnated with cattle dung was then deposited as the deep top soil. Identifying the organic materials of formation in the following section will help clarify these pathways.

Particle size distribution patterns within the West Howe deep top soil, primarily mean particle size, identify a general trend of deposition together with three distinct zones. Although differences between mean particle size values are small the general trend is for these values to decrease with depth, a reversal of the pattern seen in podzolic soils surrounding the deep top soil at West Howe. This observation implies that over the period of deep top soil formation turf material has generally come from much the same locations within the two source areas. Thus locations providing turf material were gradually truncated with each new phase of turf stripping activity exposing slightly coarser material to the surface, material that would form the next layer of the deep top soil. The implication of this observation is that, in view of the gradual accumulation rate of the deep top soil, generation after generation of the West Howe inhabitants returned to certain portions of the landscape designated to provide turf for the deep top soil. Stripping of turf was therefore not a haphazard affair. Instead it would appear to have been an activity closely controlled within the landscape economy of the early Marwick township.

Identification of three distinctive sedimentary zones within the general trend outlined above implies that there has been selective deposition of material during the formation of the West Howe deep top soil. That part of the deep top soil represented by the Howe 13 profile is composed of material consistently finer than that found in other parts of the deep top soil except for its lower levels. Here then is evidence to suggest that this portion of the landscape consistently received material from source areas that had not previously been truncated. This implies that this segment of the deep top soil closest to the farm buildings was of particular importance to the late Norse and Medieval cultivator. Specialised selection of materials for this area were practised. The second zone identified occupies the middle segment of the deep top soil and conforms to the general pattern outlined above with material coming from the same increasingly truncated profile throughout its formation. It would seem therefore that less effort was made to procure turf material for this part of the deep top soil. Assuming that the different segments of the deep top soils were formed over the same period then this second zone was probably of less importance to the early cultivator as compared to the Howe 13 zone. A third distinctive sediment zone is evidenced by a break in the contour pattern between it and the second sedimentary zone. Again, this segment conforms to the general pattern, but in comparison with Zone 2 has slightly finer material. It is proposed that this slightly finer material has come from the grazing land, within the boundaries of the early Township, rather than the hill land which provided slightly coarser material. For this segment of the deep top soil therefore a different source area was selected. However use of this source area was restricted, probably because a more important use for this land was livestock grazing. With only a little grazing land turf material available, this material would appear to have been deposited in the least important part of the Tunmal arable land, closest to the material source. Grazing pressure on the hill land would be less given its greater extent and so most of the deep top soil material would come from this source.

The deep top soil at West Howe is clearly not an unstructured deposit with random sources of material. Inorganic materials have been selected for different segments of the Tunmal, which became the deep top soil seen today. How these selections relate to the use of the Tunmal as it evolved is explored in the following chapter. The bulk of the inorganic materials of formation came from the hill land. Sources of deep top soil material were dictated by the nature of land management in the early Township and by the inherent attributes of the material.

8:2:3 The Inorganic Materials of Farm Mound Formation at Westbrough and Skelbrae, Sanday

One profile was examined for particle size characteristics from both the Westbrough and Skelbrae farm mounds on Sanday. These profile particle size characteristics are now described and considered in relation to surrounding soils and other suspected input materials which were examined in Section 8:2:1. In doing so this permits an assessment to be made of inorganic materials used in forming the Westbrough and Skelbrae farm mounds.

The laboratory procedures adopted for particle size analysis and the equations used in the calculation of particle size distribution characteristics are outlined in Appendix X. Results are tabulated inTables 8:5 and 8:6. Section 8:2:1 indicated

TABLE 8 : 5

PARTICLE SIZE DISTRIBUTIONS FROM WESTBROUGH FARM MOUND

SITE & PROFILE NUMBER	HORIZON	SAMPLE DEPTH (cm)	MEAN	SORTING	SKEWNESS	KURTOSIS
Farm Mound Westbrough 2	1	17	6.62	2.54	0.25	0.89
	2	30	5.32	2.38	0.11	1.66
	3	39	6.24	2.68	0.25	0.93
	4	52	6.14	2.52	0.10	1.00
	5	67	6.40	2.63	0.09	0.93
	6	76	6.00	2.42	0.13	1.08
	7	73	5.82	2.41	0.25	1.13
	8	82	6.14	2.44	0.22	1.01
	9	83	6.34	2.64	0.13	0.94
	10	87	5.84	2.71	0.13	1.12
	11	97	5.76	2.39	0.25	1.05
	12	106	- no data : horizon too narrow -			
	13	108	- no data : horizon too narrow -			
	14	110	5.60	2.26	0.17	1.33
	15	115	5.86	2.37	0.24	1.19
	16	130	5.78	3.05	0.00	1.18
	17	150	6.82	2.67	0.05	0.84
	18	170	- no data : organic horizon -			
	18	190	- no data : organic horizon -			
	18	210	6.40	2.93	0.18	0.86
	19	230	6.30	2.94	0.08	0.84
	19	250	6.42	2.81	0.02	0.92
	19	270	6.22	2.90	0.07	0.98

TABLE 8:6

PARTICLE SIZE DISTRIBUTIONS FROM SKELBRAE

PROFILE NAME & NUMBER	HORIZON	SAMPLE DEPTH (cm)	MEAN	SORTING	SKEWNESS	KURTOSIS
Farm Mound						
Skelbrae 1			6.24	2.86	0.21	0.90
			5.94	2.81	0.41	0.89
			6.18	2.72	0.23	0.88
			6.40	2.86	0.19	0.80
			6.48	2.85	0.17	0.85
			6.34	2.93	0.26	0.81
			6.22	2.86	0.29	0.91
			5.80	3.12	0.18	0.98
			--	no data :		
			--	" "	"	--
			--	" "	"	--
			--	" "	"	--
			--	" "	"	--
			--	" "	"	--

that the particle size characteristics of mean, sorting, skewness, mean v skewness, sorting v skewness and kurtosis v skewness were best able to discriminate between the various possible materials of farm mound formation. Thus these are the particle size characteristics examined in the two farm mound profiles under consideration. To assist with the identification of distinctive sedimentary zones within the farm mound profiles, mean, sorting and skewness particle size distribution values are plotted against depth. Both farm mounds are considered together to allow their comparison and contrast.

(a) Mean Mean particle size values from both the Westbrough and Skelbrae farm mounds reflect a sedimentary pattern rather than any evidence for pedogenic processes. The basis for such a statement lies with two observations. Firstly the widely fluctuating patterns of mean particle size values within the Westbrough and Skelbrae profiles are quite distinct from the general increase in coarseness with depth of surrounding soil profiles (Fig 8:11 and 8:12; see Section 8:2:1). Secondly, in parts of the farm mound profiles where there is a trend of increasing coarseness with depth that increase is generally greater than that observed in surrounding soils. Thus if it is accepted that, in terms of mean particle size, pedogenic alteration of farm mound sediments is minimal then it is possible to proceed with the attempt to identify the inorganic materials of formation from mean particle size values and patterns.

Examination of the profiles from Westbrough and Skelbrae indicates no emergence of any general pattern. However within the Westbrough profile two separate zones of mean particle size values can be identified. One zone exhibits a considerable degree of fluctuation in mean particle size down the profile from the mound surface to 130cm depth (Fig 8:11). Within this zone the range of mean particle size values is from 5.32ϕ to 6.62ϕ. In itself this fluctuating pattern suggests a variety of materials deposited at random during this phase of mound formation. This conclusion is supported when attempt is made to precisely define what these materials are and where they came from by comparison with suspected formation

Figure 8:11 Mean particle size distribution in Westbrough Profile 2.

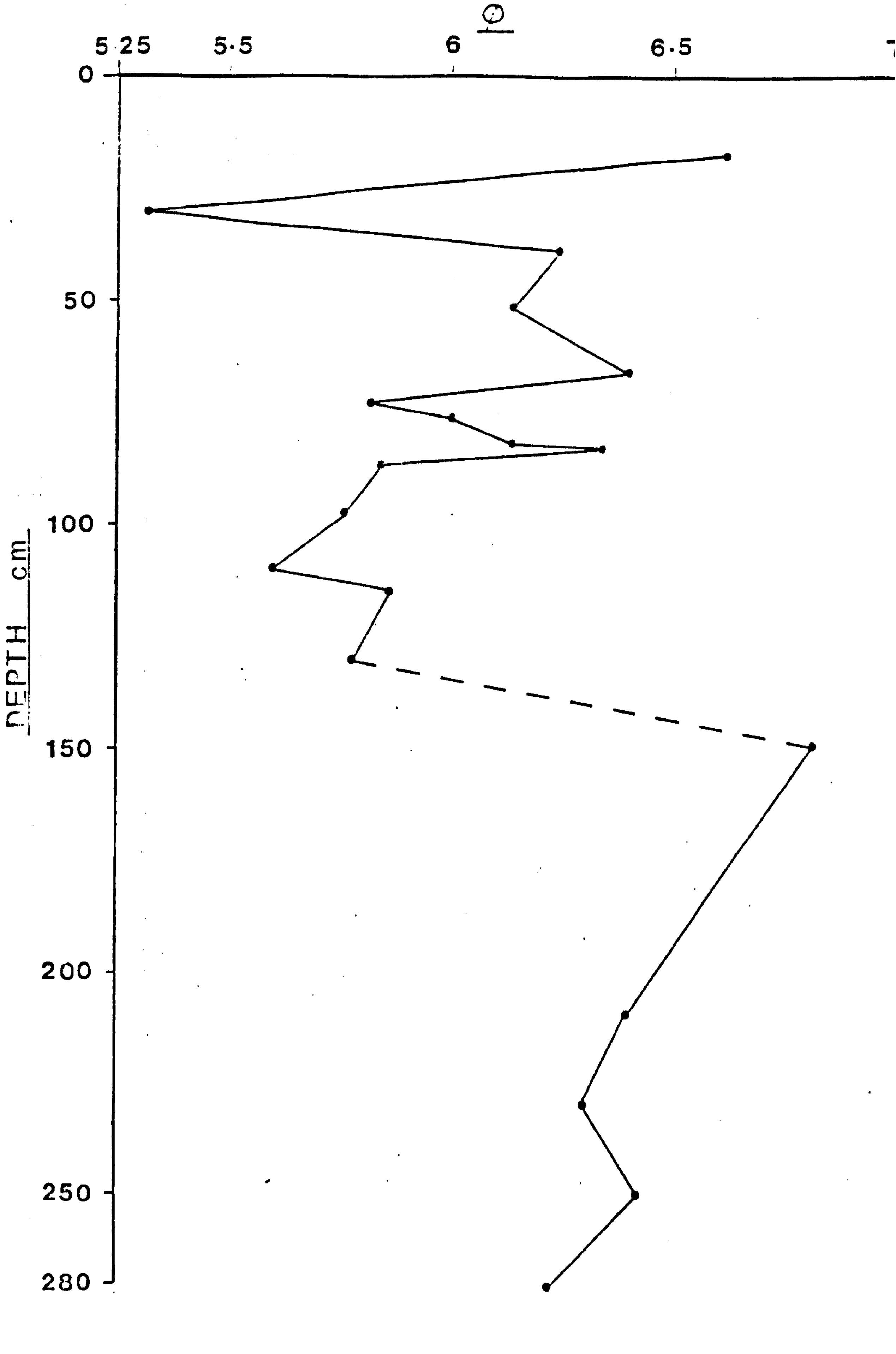
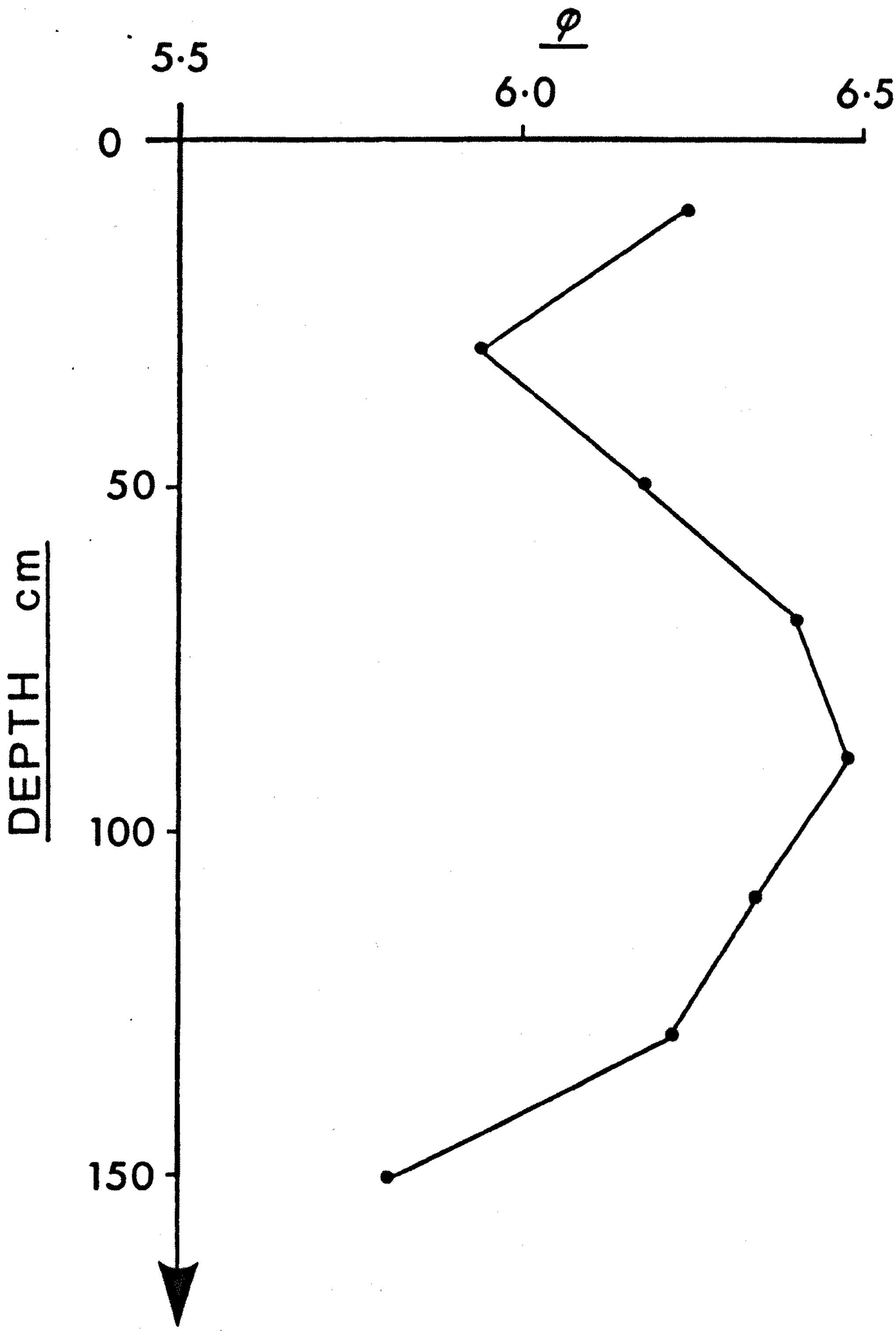


Figure 8:12 Mean particle size distribution in the Skelbrae 1 profile.



materials. Such an attempt quickly leads to the conclusion that individual mean particle size values from this zone generally represents a mixture of materials. Peat ash, turf roofing material, midden material, material from the adjacent saltings and Bilbster Series soils can all be proposed as being involved in this part of the Westbrough farm mound's formation. By comparing the mean particle size values from this part of the Westbrough farm mound with the nearest plotted value of suspected input materials in Fig 8: 1, peat ash would appear to be the dominant material involved, occurring throughout much of this zone. Secondary materials in this zone of mixture include turf roofing material, or possibly material used for dwelling construction, between 87 and 130cm. Above this, possible roofing material is found material from Bilbster Series soil, while the surface horizon of the mound would appear to be material originating from the saltings. Minor differences include the occurrence of midden material. It is evident then that material involved in the formation of this part of this farm mound has come from a variety of sources; material has come from surrounding soils as well as being material modified by anthropogenic activities within the Toft.

The second distinctive mean particle size zone of this farm mound occupies the lower part of the mound from 150cm, a zone that incorporates an organic layer betwen 170 and 220cm depth. Again peat ash would appear to be the dominant inorganic material involved in the formation of this lower part of the farm mound. However midden material and, to a lesser extent, material from the Bilbster Soil Series is also evident. Thus the inorganic materials of formation in this part of the farm mound are less diverse than the materials of formation above this zone. Reasons for this difference are discussed in the following chapter.

Turning attention to the Skelbrae farm mound, the mean particle size values from this farm mound are less complex in pattern as compared with Westbrough. Samples for particle size analysis were only available down to 150cm depth. Within this zone of the examined profile the mean particle size range is from 5.80ϕ to 6.48ϕ. While there is some degree of mean particle size fluctuation down the profile there are not the sharp breaks in pattern seen in the Westbrough profile. This may in part be due to the lack of samples from below 150cm depth. The part of the Skelbrae farm mound that there is information for indicates that its formation is dominantly the result of Bilbster Soil Series material and/or peat ash. Minor components involved in its formation include midden material and turf roofing material. Fluctuations in mean particle size pattern may be attributed to variation in the precise ratio of these materials in an individual sample. In conclusion this part of the Skelbrae farm mound profile can be considered as one unit. It is similar to the upper part of the Westbrough farm mound, but is composed of less diverse materials. Consequently fluctuations in pattern are less extreme in the Skelbrae farm mound as compared with the Westbrough farm mound.

Examination of the mean particle size characteristics from the two farm mounds under consideration permits certain conclusions to be made as to identifying the inorganic materials of farm mound formation. As was the procedure in the examination of deep top soils these conclusions are summaried below and form the working hypotheses against which other particle size characteristics from the farm mound profiles are assessed. This allows the hypotheses to be confirmed or refuted as well as permitting the development of new hypotheses. The conclusions of the above discussion on mean particle size values are as follows.

1. Mean particle size values in both the Westbrough and the Skelbrae profiles indicate a sedimentary pattern with little or no modification by pedogenic processes.

2. Materials from a wide variety of sources, including from surrounding soils and the Toft, are involved in the formation of these farm mounds.

3. Two distinct inorganic sedimentary zones can be discerned in the Westbrough farm mound. The upper zone, from the mound surface to c130cm depth, has a fluctuating pattern and is dominantly peat ash with secondary materials of turf roofing

material, soil from the Bilbster Series and soil from the adjacent saltings. A similar but less accentuated fluctuating pattern is seen in the Skelbrae profile down to 150cm depth. The lower part of the Westbrough farm mound consists of finer material than that overlying and is thought to be dominantly peat ash and midden material.

(b) Sorting Sorting values of the particle size distribution from the two farm mound profiles under consideration confirm the first two hypotheses presented in the paragraph above. That is there is little or no evidence for pedogenic modification of the sediments and, secondly, there is a considerable variety of materials involved in the formation of these features. Upon examining the third hypothesis presented above in light of the particle size distribution sorting values,some degree of hypothesis modification is required. In the Westbrough profile, three distinctive zones can be discerned instead of two. Furthermore there is contradiction on the precise nature and source of formation materials both at Westbrough and at Skelbrae (Figs 8:13 and 8:14).

All sediments within the examined Westbrough profile are poorly sorted but within this broad classification three distinctive inorganic sedimentary zones can be seen. The upper zone is seen from the surface of the mound to 115cm depth with values of between 2.26 and 2.71. Like Zone 1 seen with mean particle size values, the sorting values show considerable fluctuation down the profile, indicating a variety of materials and/or mixtures of materials. Sorting values from this zone can only establish that a mixture of materials from various sources were involved in this part of the farm mound formation. Plotting of the values from the mound on Fig:8:2 of suspected materials of formation demonstrates that the mound sorting values generally lie between the values of suspected input materials. What the precise composition of this mixture is cannot really be established by particle size analysis alone. Some sorting values from this part of the mound do suggest a definite material. The use of material from the saltings is implied by the values from between 73cm and 97cm. However this is

Figure 8:13   Particle size sorting values in Westbrough Profile 2.

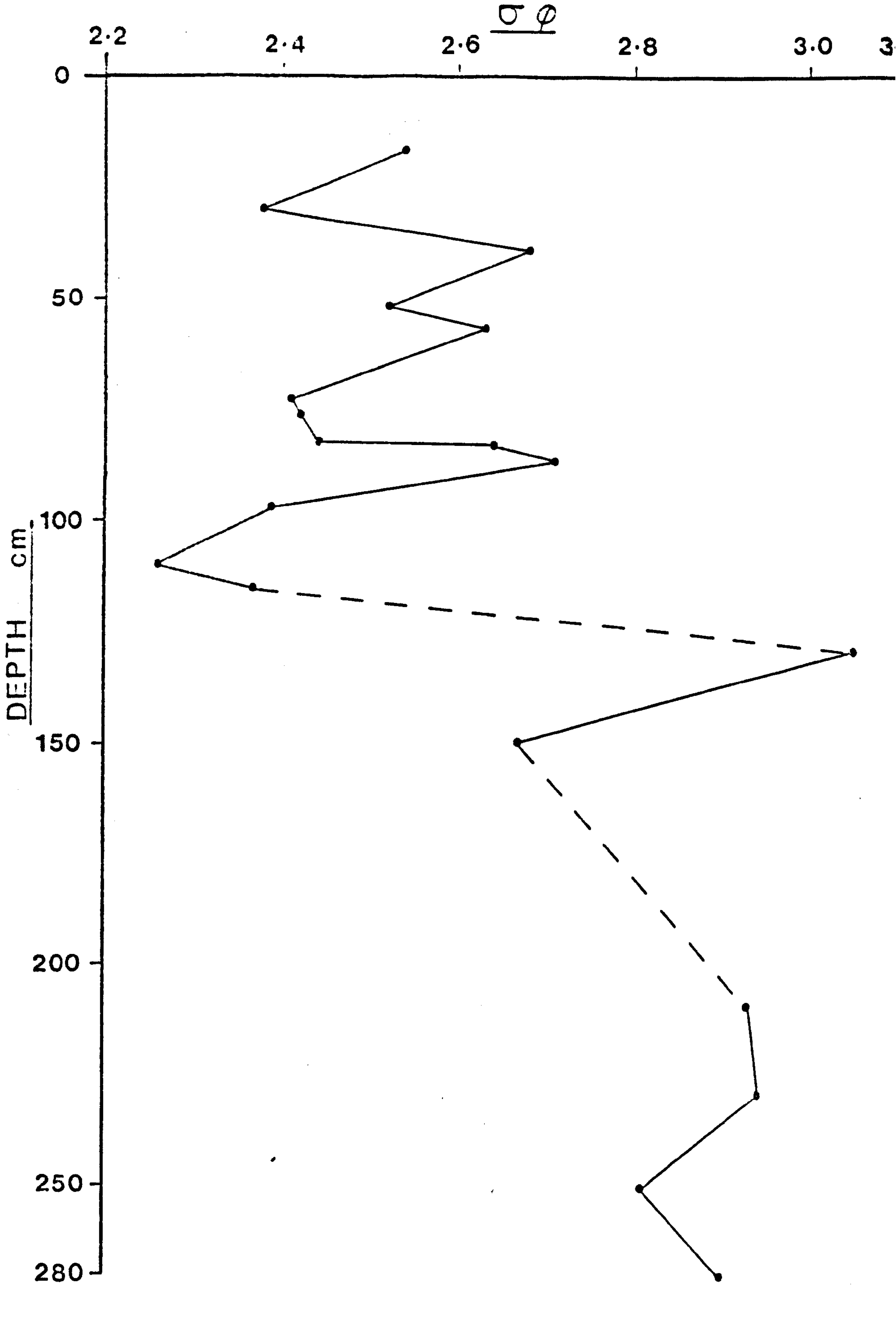
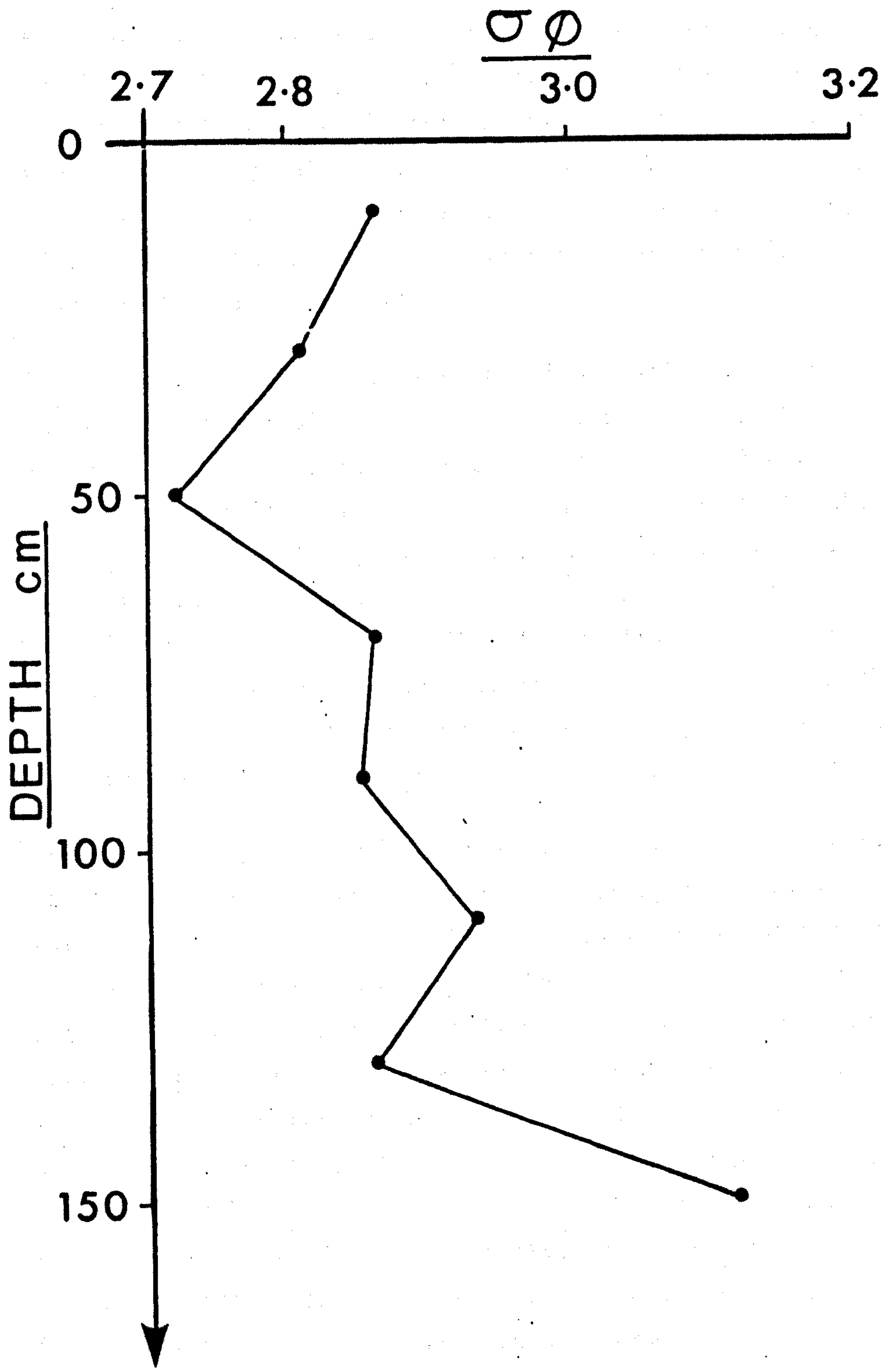


Figure 8:14 Particle size sorting values in Skelbrae Profile 1.



contrary to the conclusions reached from mean particle size values. Thus in view of this and the generally mixed nature of this part of the mound, it is concluded that between 73 and 97cm the material is also a mixture with sorting values just happening to be similar to those from the adjacent saltings.

A second distinctive sedimentary zone, based on sorting values, can be seen between c130 and 150cm. This material lies on top of the organic layer seen in this profile and has a considerable range of sorting value (2.67 to 3.05). The upper sample of this zone is considered most likely to be Bilbster Series soil material/ midden mix, with the lower sample representing an indeterminate mixture of source materials.

Beneath the organic layer lies a third distinctive zone of inorganic sedimentary material with a sorting value range of between 2.81 and 3.05 . By comparing these sorting values with values for suspected materials of formation it is apparent that this zone is formed dominantly by material from the Bilbster Soil Series. There is also some indication for the deposition of turf roofing material within this zone. Thus the contrast between this zone of sedimentary material and the overlying zones is quite marked. While the upper zones are formed with a fluctuating mixture of different materials the lower zone is comparatively uniform in its composition.

Examining the profile of sorting values from Skelbrae confirms the fluctuating pattern observed when examining mean particle size values. No distinctive zonation is observed except perhaps at the lowest part of the examined profile where the sorting value reaches 3.12 . As with the upper portion of the Westbrough farm mound, sorting values from Skelbrae indicate a mixture of materials involved in its formation (Fig 8:14). Peat ash is however unlikely to have been involved contrary to the findings of mean particle size values. The lower sample at 150cm depth can, on the basis of sorting values, be identified more precisely, its dominant material being midden. Although only one sample, this perhaps suggests a shift in the material types involved in the formation of this farm mound.

On reviewing the implications of sorting values for an interpretation of farm mound formation materials it becomes apparent that the third of the three hypotheses presented after examining mean particle size analysis requires some modification. The first modification is as a result of the identification of additional zones of inorganic sediments within the farm mound profiles. One of these additional zones can be observed between c130 and 150cm in the Westbrough profile; the other, possible, additional zone is found at the base of the examined Skelbrae profile, represented by a sample of poorer sorting at 150cm. The second modification to the hypothesis is in relation to the attempt to define precisely the materials of formation. Sorting values from these farm mound profiles while not refuting entirely the conclusions based on mean particle size values, do indicate that peat ash is probably a component of less importance than was previously thought. These values also indicate that much of these mounds are composed of mixtures of materials, mixtures which cannot readily be separated out into their component parts based on particle size sorting values alone. With this hypothesis modification in mind examination is now made of particle size distribution skewness values.

(c) <u>Skewness</u> As already discovered when examining the deep top soil at West Howe, skewness values are sensitive to the pedogenic movement of deposited sedimentary material. For the reasoning behind this statement, the reader's memory will be refreshed by turning back to Section 8:2:2(c); evidence for pedogenic movement of finer material in the Skelbrae profile is quite clear. Skewness values from this profile, which have a range of between +0.17 and +0.41 , are consistently more positive than the values found in the suspected input material and the adjacent Bilbster Series soil profile. As reasoned when examining the West Howe deep top soil, such comparatively high positive skewness values imply that finer material has been lost from the profile, presumably by pedogenic translocation. This pedogenic process has not however been sufficient to disguise a fluctuating sedimentary pattern, a pattern already noted within this profile for other particle size characteristics. Skewness values demonstrate similar trends in profile pattern to the mean particle size values, the fluctuating pattern indicating some degree of diversity in the material involved in farm mound formation at Skelbrae (Fig 8:16).

Placing a pedogenic interpretation on the positive skewness values on the Westbrough profile cannot be done with the same certainty as was the case at Skelbrae. This uncertainty stems from the fact that many skewness values from the upper part of this profile (from 0 to 115cm depth) are intermediate between material from the saltings and other possible sources of material (Fig 8:15). It is conceivable therefore that the mound material is a mixture of these two sets of sources. Alternatively it may be that saltings material does not form a component part of the farm mound in this upper section. This would mean that the positively skewed values greater than +0.17 have been subject to pedogenic modification. Whatever the precise cause of observed skewness values in the Westbrough farm mound, evidence for a three part zonation of this profile again exists as has already been identified by other particle size distribution characteristics particularly sorting values. It can be stated that any degree of pedogenic modification within these sediments has not destroyed the broad sedimentary patterns. The upper part of the skewness profile again identifies a fluctuating pattern broken at 115cm into a zone of more normal distribution to c150cm. Beneath the organic layer lies the third zone with skewness values of between +0.02 and +0.18 . These zones, it is proposed, represent three distinctive types of sediment deposition - as already established by previous particle size distribution characteristics - but definite statements about the composition and source of this material cannot be made on the basis of skewness values. In conclusion there is need to modify slightly hypothesis (1) presented after discussion of mean particle size values in the farm mounds. There is evidence at least in the Skelbrae profile for some degree of sediment modification by pedogenesis but this process is not sufficient to mask sedimentary patterns within the farm mound.

(d) Bivarient Graphs Plotting mean v skewness values, sorting v skewness values and sorting v kurtosis values from the farm mounds upon the bivarient graphs of suspected input material only confirm

Figure 8:15 Particle size skewness values from Westbrough Profile 2.

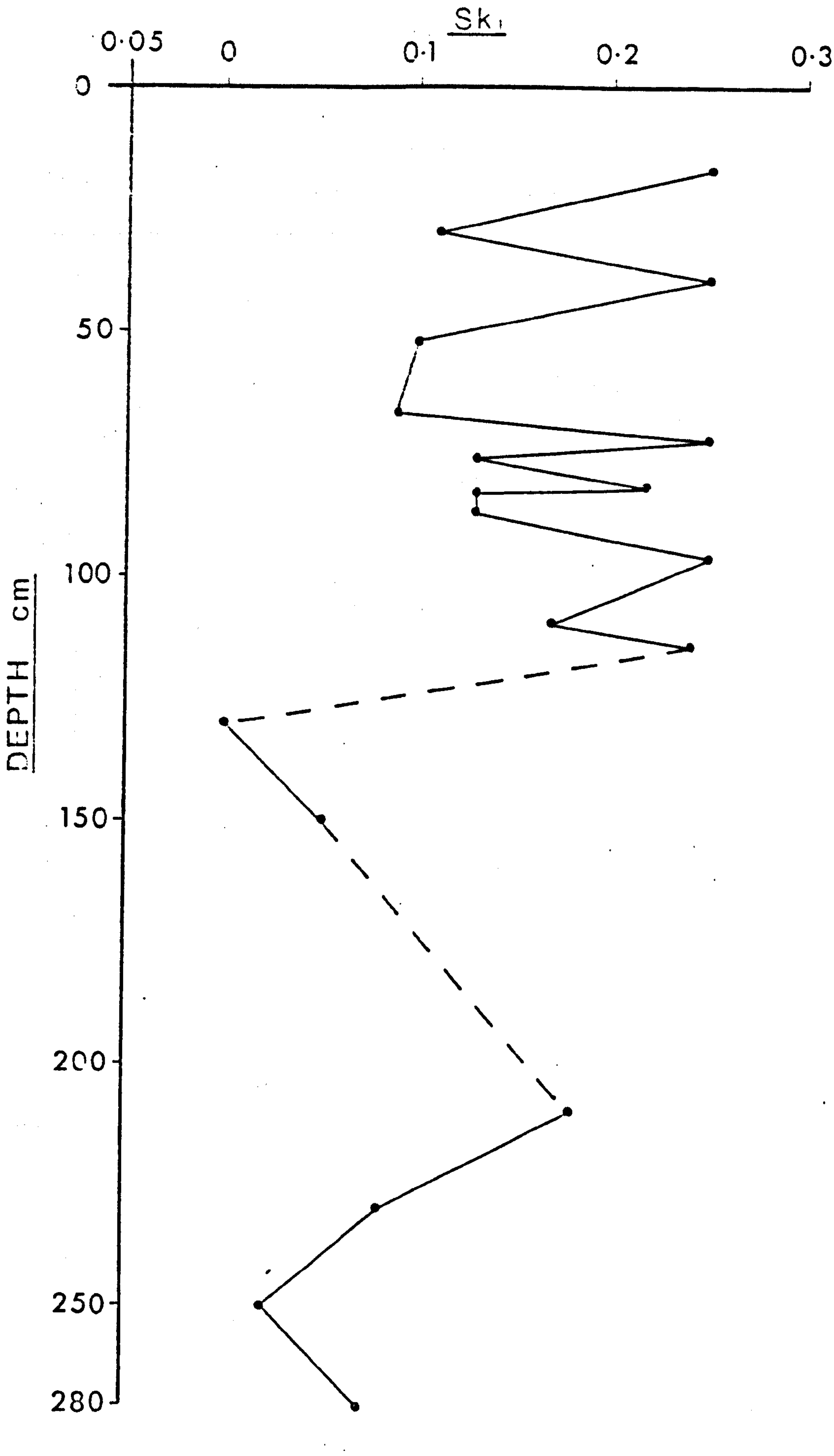
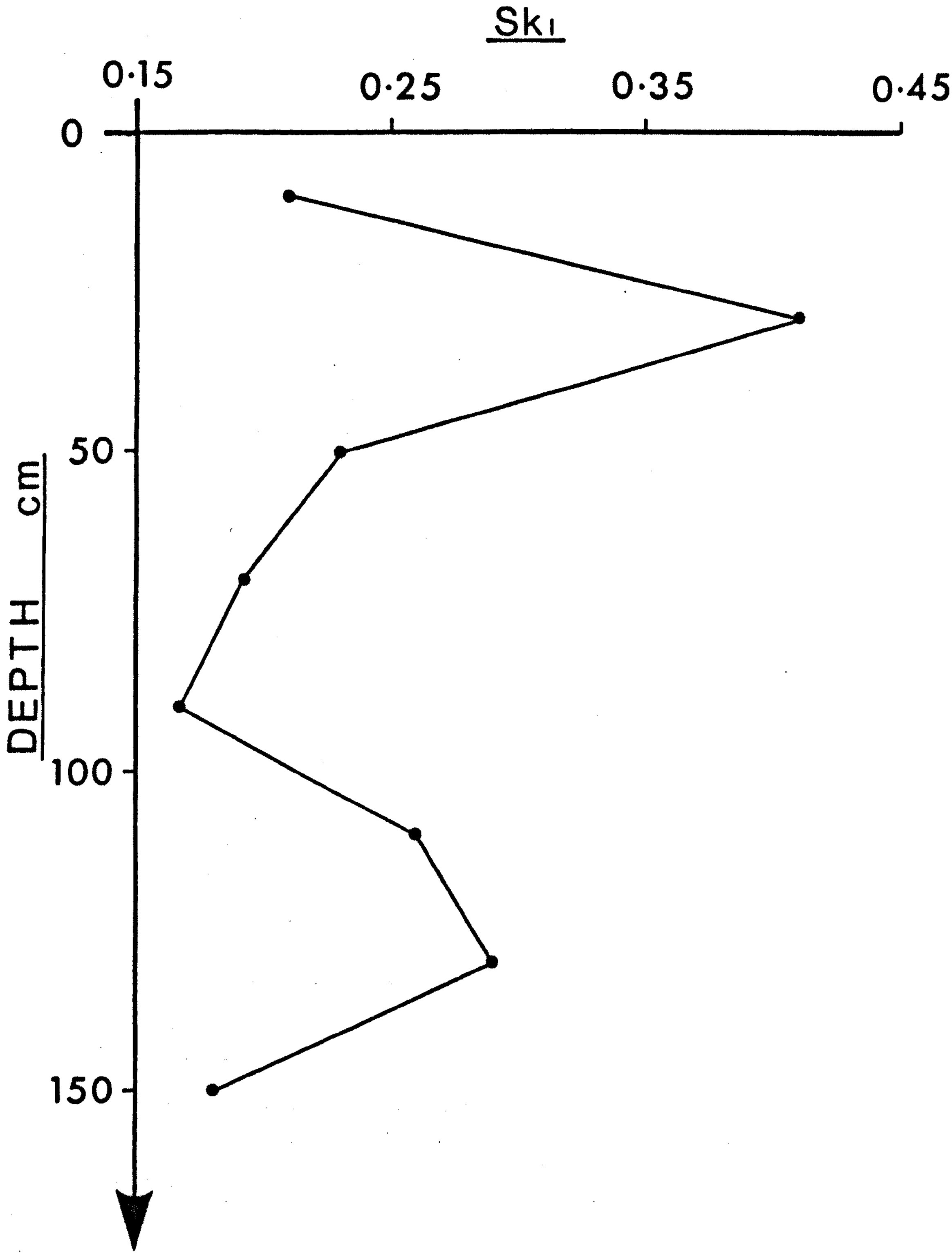


Figure 8:16 Particle size skewness values from Skelbrae Profile 1.



the hypotheses presented earlier. The three inorganic sedimentary zones in the Westbrough farm mound are evident in all three bivarient graphs. They confirm a zone between 0 and c115cm depth of indeterminate mixed material, a zone between c115 and c150cm depth of material from Bilbster Soil Series sources with the sample at 150cm depth being midden material. This second zone overlies a peaty organic layer beneath which from c190cm to the mound base is a third zone of Bilbster Soil Series based midden material. At Skelbrae the material is an indeterminate mixture throughout, probably turf based material from the surrounding Bilbster Soil Series modified by the activities of the Toft and, to a lesser extent, by pedogenic translocation of the finer material.

<u>Conclusions</u> Based on the consensus of particle size distribution characteristics, the hypotheses presented after considering mean particle size values from the two farm mounds examined can be held as generally valid. Values for particle size distribution within the profiles at Westbrough and Skelbrae can be interpreted as the result of anthropogenic sedimentation activity. This conclusion can be made in view of the fact that pedogenic processes have been insufficient to destroy the general sedimentation patterns. Within the two profiles it can be stated that all the materials involved in their formation have been modified by various Toft activities prior to deposition and thus probably represent Toft wastes. Identifying the precise source of the original material is not however possible with the available data.

More specifically, within the Westbrough profile, three distinct sets of inorganic sediment types can be observed. Starting at the base of the mound, from a depth of c210cm probably to the pre-depositional land surface is the first sediment zone composed dominantly of Bilbster Soil Series, turf based midden material. Thus the anthropogenic sedimentary history of this material was for turf (incorporating inorganic material) to have been stripped from adjacent Bilbster Series soils, transported to the byre where it was modified by trampling activity, followed by deposition to form the base of the farm mound. It seems an unlikely possibility that the Westbrough site was an area where cattle were housed with no associated human habitation. It seems equally unlikely that a farmstead community generating the amount of midden material observed in this basal section of the Westbrough farm mound was not also generating other waste materials such as ash and old roofing material. This being the case it would appear that there was a deliberate selection of material to form the base of the Westbrough farm mound. Only midden material was used and whether there was any functional reason for this is fully discussed in the next chapter. An alternative possibility is that other Toft waste materials were deposited at other locations either at or beyond the farm mound. In these circumstances 'selective' deposition of materials in certain areas may simply be conditioned by the deposition areas proximity to the waste producing area. Thus byre wastes would be deposited in close proximity to the byre, ash close by the dwelling area and so on. This would create a distinct zonation in the pattern of material deposition. Only fuller examination of the farm mound will be able to verify or refute this possibility.

Above this first inorganic sedimentary zone lies the organic layer between c150cm to c210cm depth. The precise nature of this layer is fully discussed in the following section. Lying immediately above the organic layer is a second inorganic sediment zone between c115 and c150cm depth. As with the basal inorganic sediments of the mound this zone appears to be dominantly composed of Bilbster Series top soil material modified to midden material. Consequently the discussion on the materials of the lower section of the farm mound given in the above paragraph can be applied to this zone. It is however possible to differentiate between the upper and lower part of this zone. While the lower portion is dominantly midden material, the upper portion is composed primarily of Bilbster Series soil material, unmodified. Whether this is of any significance in terms of differences in deposit type is not clear. It may be that a different selection criteria was used for deposition of material at this point in the farm mound's evolution.

The third inorganic sedimentary zone is evident from the present-day surface of the mound to c115cm depth. This zone is characterised by a fluctuating pattern and would appear to be composed of a mixture of source materials. Implied in the results from this zone is that a diversity of materials were involved in its formation. There was evidently no systematic arrangement of materials as would appear to have been the case in lower sections of the farm mound. This haphazard arrangement of material indicates that material was deposited with no specific purpose other than to remove it from the habitation area. One question of importance that does emerge however is if the individual horizons in this sedimentary zone are of mixed material, where did this mixing take place as it seems unlikely that it is a post depositional effect? One distinct possibility is that represented within this mixed material is the ash of midden material that has been used as a fuel source. This combustion process may be sufficient to alter particle size distribution characteristics of midden material. Another possible reason for these 'mixed' characteristics is that ash as well as turf may have been used in the byre as bedding thus giving a composite midden material. In any event it is clear that mixing of the basic input materials has occurred prior to deposition resulting in a distinctive inorganic sediment zone in the upper parts of the Westbrough farm mound.

By comparison with Westbrough, the farm mound particle size profile from Skelbrae is considerably simpler although this may be explained in part by the fact that the profile does not examine the full depth of the mound. Of that part of the profile examined to a depth of 150cm, a fluctuating pattern of indeterminate material emerges. Thus the profile can be regarded as a single sediment type. These characteristics make the Skelbrae profile similar to the upper portion of the

Westbrough farm mound. Consequently much of what has been said about this zone of the Westbrough mound can be applied to Skelbrae. It should however be pointed out that the intensity of fluctuation here is less than that seen at Westbrough. One possible reason for this is that it would appear that only Bilbster Soil series top soil is the material modified by Toft activities prior to deposition as the farm mound. There are no other primary source materials. This would have the effect of reducing the intensity of fluctuation within the profile. Fluctuations that are observed can therefore be attributed to Toft activity only, rather than any difference in primary source materials. Only at the lowest part of the examined profile is there any hint of deviation from the sediment characteristic outlined in the above sentences. The sample from 150cm depth does suggest that its material may be dominantly midden rather than a mixture of materials. Thus again there is a parallel with the Westbrough farm mound, midden material being found in the lower sections of both mounds. However at Skelbrae whether this midden material continues to a greater depth or is simply an anomaly cannot be determined.

8:3 Identifying Organic Materials of Formation

Of the techniques considered in the effort to identify the organic materials of formation, stable carbon isotope analysis ($\delta^{13}C$) was best able to satisfy the criteria for selection outlined in the introductory paragraphs of this chapter. Based on the available literature element analysis would appear unable to differentiate between the various organic source materials. Identification of compounds such as sterols and examination of humic substance structures could not be subject to routine analysis with the resources available to the Author. Of biological relic material, pollen was in an extremely poor state of preservation except in the peaty organic layer of the Westbrough farm mound. Phytoliths were evident in thin section (see Chapter 7) but grassy turf material in which phytoliths form is only one component of the possible carbon sources used in anthropogenic sediment formation.

By contrast there are good theoretical grounds, substantiated by experimental observations, for believing that the suspected input material will have the mutually exclusive $\delta^{13}C$ range looked for and that such differences are maintained under pedogenic conditions. Furthermore this technique was technologically feasible. The theoretical aspects involved in the application of stable carbon isotope analysis to the identification of anthropogenic sediment organic materials are now outlined together with the experimental data of other workers.

8:3:1 Stable Carbon Isotope Fractionation in the Environment

In general carbon isotopes behave in the same manner for a given physical or chemical process. However the heavier carbon-13 has a lower vibrational energy than carbon-12 thus decreasing the specific reaction rate of a process (Craig, 1953; Raaen et al 1968). This kinetic isotope effect means that isotopic discrimination will occur in physical and chemical processes, both intramolecularly and intermolecularly. Such a phenomenon is known as isotopic fractionation. Figure 8:17 identifies the suspected input material under consideration, the processes that lead to them and the already well established fractionation effect(in ‰) for those processes. Carbon from all the materials under consideration here is ultimately derived from atmospheric CO_2. As carbon-12/carbon-13 ratios are not modified by climatic differences (Harkness and Miller, 1980; Balbane, 1983), then isotopic fractionation in suspected input materials can be ascribed wholly to non atmospheric processes. Atmospheric CO_2 is depleted in carbon-13 relative to marine carbonate during the hydration process (Degens, 1969). The resulting carbonate value in the marine reservoir of between -2 to +3‰ is maintained by shell forming marine organisms. Photosynthesis, by the classic C_3 metabolism in these latitudes, represents a whole set of processes which cause depletion of the heavier carbon-13 isotope. Troughton (1972) and Park and Epstein (1960) identify gaseous diffusion of CO_2 into the plant, diffusion in the liquid phase, the carboxylation step and the subsequent transformation

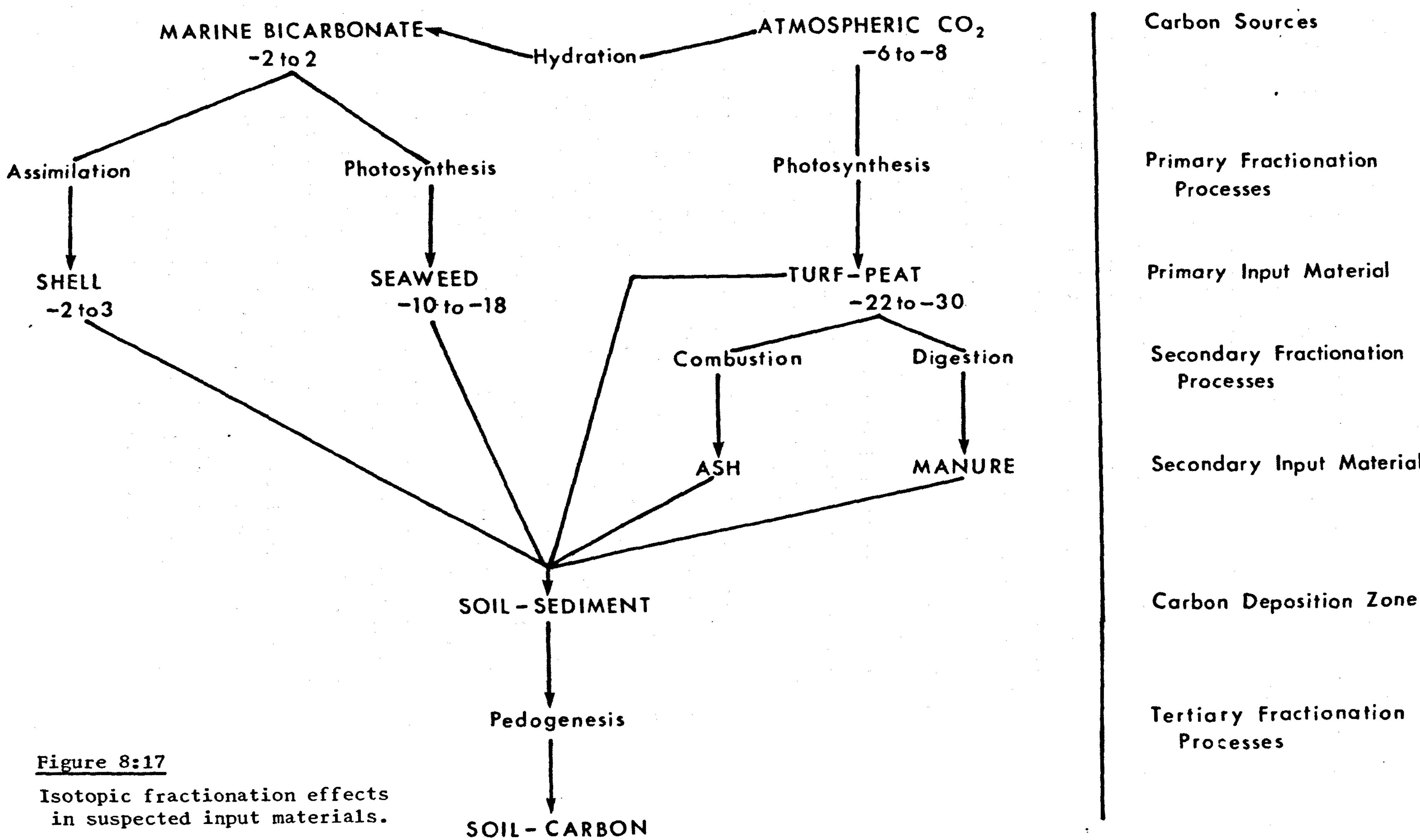


Figure 8:17

Isotopic fractionation effects in suspected input materials.

of the photosynthetically produced carbon compounds as those processes which give rise to carbon-13 depletion. The differences in $\delta^{13}C$ values between marine plants and terrestrial plants occurs because of the different sources of carbon. The marine plants assimilates marine bicarbonate while terrestrial plants assimilate atmospheric CO_2.

There is less evidence for carbon isotope fractionation effects associated with the processes of digestion although DeNiro and Epstein (1978) do provide evidence of isotopic fractionation in faecal material relative to dietary material from studies on insects. It is to be expected that the undigested material remaining after hydrolysis, fermentation and absorption by higher animals such as cattle will demonstrate a $\delta^{13}C$ value different from their original food material. Evidence for carbon isotope fractionation effects associated with combustion is also limited. Combustion is an oxidation reaction converting carbon compounds to CO_2 and thus it may be expected that any carbon remaining in the ash due to incomplete combustion will be depleted in the lighter isotope relative to the fuel material. This postulate is supported by Burleigh, et al's(1984) examination of $\delta^{13}C$ values published in Radiocarbon between 1970 and 1978. Of 183 $\delta^{13}C$ samples of plant material other than wood or charcoal from Europe the mean $\delta^{13}C$ value is -25.2 (‰ relative to PDB). 797 samples of wood give a mean of -25.7 (‰ relative to PDB) while 938 charcoal samples have a mean of -24.8 (‰ relative to PDB).

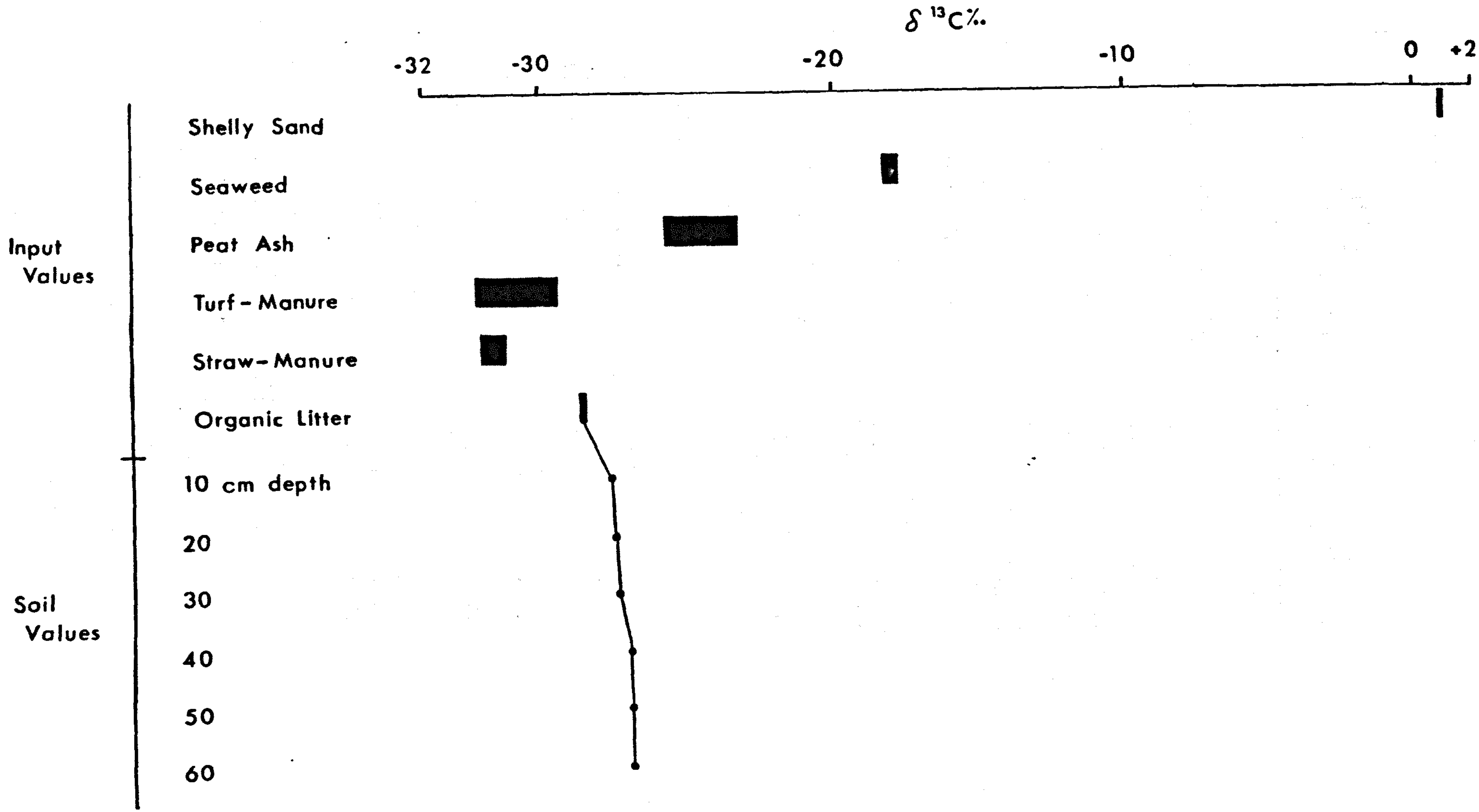
There is also evidence to suggest that isotopic differences in input materials are indeed preserved under pedogenic and diagenic conditions. $\delta^{13}C$ measurement to evaluate sources of organic matter in recent sediments under anaerobic conditions has already been used extensively (Degens, 1969) and such measurements are considered to reflect the input material values. Such studies however confine themselves to non terrestrial environments. Consideration must therefore turn to the comparatively few studies of terrestrial soils and sediments to obtain some insights into how the stable carbon isotopes may behave in the Orcadian anthropogenic sediments. Troughton et al (1974a) and Stout et al (1975) have used $\delta^{13}C$ measurement to indicate variations in the proportions of C_3 and C_4 metabolism plants contributing to soil organic matter. A variation in $\delta^{13}C$ values between -15‰ and -21‰ with increasing soil depth at a site in Queensland, Australia, suggests a shift from a C_3 to a C_4 dominant vegetation type. The time period over which this shift took place is given as 14,000 to 8,000 years BP, thus suggesting a prolonged residence time for stable carbon isotopes, at least under certain soil conditions. Similarly, variation in $\delta^{13}C$ values of the flora of a peat forming area permitted an evaluation of the relative contribution of different species to peat formation at Wicken Fen, England (Troughton et al 1974a).

At this point some notes of caution are required. Ladyman and Harkness (1980) made use of carbon isotopes to provide an index of soil development. Variations in $\delta^{13}C$ values of up to 2.5‰ relative to the organic litter, over 30cm depth, were established. These observed differences were considered to reflect a particular stage in humification. Isotopic differences in specific biochemical components of plant tissue (Smith, 1972) and their varying decomposition rates were proposed as controlling such isotopic differentiation. This reasoning also accounts for possible differences between soil $\delta^{13}C$ values and $\delta^{13}C$ values in CO_2 released from the soil (Galimov, 1966). Isotopic fractionation effects have also been observed to occur during the dynamics of the humification process. Nissenbaum and Schallinger (1974) demonstrated a consistent $\delta^{13}C$ enrichment in fulvic acids compared with humic acids by 0.9‰ .

8:3:2 $\delta^{13}C$ Values in Suspected Input Materials and 'Control' Soil Profile in Orkney

$\delta^{13}C$ analysis was carried out on suspected carbon containing input materials gathered from various parts of Orkney as outlined in Chapter 6. Thus calcareous shelly sand, peat ash, seaweed, straw/manure, turf/manure and the organic litter from the podzolic control profile were examined. This analysis was done to demonstrate that the isotopic fractionation effects outlined in the previous section operated within the Orcadian environment. Additionally samples from a Bilbster Soil Series profile were analysed for $\delta^{13}C$ values to establish the isotopic fractionation effect associated with podzolic processes in Orkney. This profile was the unreclaimed hill land profile from Marwick (HY 245 524), the control profile, and this gave an indication of the isotopic fractionation effect in soils unmodified by anthropogenic input of materials. More detail of the isotopic fractionation effect during humification was derived by obtaining $\delta^{13}C$ values from humin, humic acid and fulvic acid from 40cm depth in the Netherskail deep top soil (HY 234 246). Analytical procedures adopted in the determination of $\delta^{13}C$ values for the above materials are outlined in Appendix X(2) Analytical precision is estimated at $\pm$ 0.2‰ .

$\delta^{13}C$ measurement of suspected input materials demonstrate the theoretical isotope fractionation effect outlined in the previous section (Table 8:7 ; Fig 8:18). The different suspected sources of carbon entering the two anthropogenic sedimentary systems are clearly evident, permitting a broad division between material from marine and terrestrial sources. Isotopic fractionation effects within the terrestrial class of material are small but still significant. Importantly, the input materials demonstrate a $\delta^{13}C$ differentiation greater than the 2.5‰ fractionation effect which may be attributable to the pedogenic processes of decomposition of humification (Fig 8:18). The exception to this is a value for turf/manure but it is likely that the $\delta^{13}C$ range of this material is attributable to differing proportions of manure and turf in the combusted sub-sample. Examination of the control profile values reveal that the isotopic fractionation effect within this soil profile is not as great as 2.5‰ . A mean $\delta^{13}C$ value



<u>Figure 8:18</u> $\delta^{13}C$ values from suspected input materials and the 'control' soil profile, Marwick.

TABLE 8:7

$\delta^{13}C$ MEASUREMENT AND TOTAL CARBON(%) OF SUSPECTED INPUT MATERIAL, CONTROL PROFILE AND ORGANIC FRACTIONS

SUSPECTED INPUT MATERIALS

	% Carbon	$\delta^{13}C$ ‰
Peat ash	1.72	-25.7
	1.36	-23.2
Turf/manure	26.5	-32.1
	25.4	-29.4
Straw/manure	30.6	-32.0
	29.2	-31.3
Seaweed	30.5	-18.2
	30.5	-17.7
Calcareous sand	ND	+0.9
	ND	+1.1

CONTROL PROFILE

Horizon	Depth(cm)	% Carbon	$\delta^{13}C$ ‰
Surface letter	0	25.95	-28.5
Surface letter	0	22.23	-28.6
A_1	10	9.51	-27.7
A_2	20	6.68	-27.6
A_2	30	4.74	-27.5
B_2	40	1.91	-27.1
B_2	50	0.41	-27.1
B_2	60	0.45	-27.1

ORGANIC FRACTIONS FROM THE NETHERSKAIL DEEP TOP SOIL AT 40CM

Organic Fraction	$\delta^{13}C$(‰)
Humin	-27.7
Humic acid	-28.2
Fulvic acid	-27.6

of -28.55‰ for the soil litter and one of -27.1‰ in the B horizon leaves a difference of 1.4‰ in this particular profile. Excluding the soil litter value, the internal profile variation is 0.6‰ . Consideration of the humin, humic acid and fulvic acid $\delta^{13}C$ values from the Netherskail deep top soil indicate an isotopic fractionation effect of up to 0.6‰ attributable to the humification process (Table 8:7 This is the same value as the internal profile variation found within the control profile. However in view of the difficulties encountered in the analysis of humin, humic acid and fulvic acid (See Appendix X(2)), too much emphasis should not be placed on these results.

Based on the above analysis it is possible to take 1.4‰ a the maximum and 0.8‰ as the minimum fractionation effects expected as a result of the incorporation of organic litter into the soil body. 0.6‰ can be taken as the maximum fractionation effect once organic material is incorporated into the soil matrix. One other observation of relevance is that $\delta^{13}C$ values become consistently less negative with depth in the soil profile; thus the pedogenic effect is directional. While these figures may be applicable in a soil profile unaltered by organic amendments, what the carbon isotope fractionation effect may be on say for example, seaweed, applied and incorporated into the soil of the arable land is not known. There is real need for experimental data of this sort. In its absence however the fractionation effects due to pedogenesis seen in the Marwick control profile is cautiously applied to the anthropogenic sediments of Orkney. With this background information some preliminary conclusions can be drawn as to the origins of the organic matter in deep top soils and farm mounds.

8:3:3 Identifying Organic Materials of Formation in the West Howe Deep Top Soil by $\delta^{13}C$ Analysis

$\delta^{13}C$ analysis of the West Howe deep top soil is incomplete.

Seven samples from the farmyard at West Howe and the nine samples from the Howe 18A profile are missing (Table 8:8; Fig 8:19). Thus the spatial characteristics of $\delta^{13}C$ values within the deep top soil are considered only briefly. The influence of alternative areas of anthropogenic sediment deposition (ie the farmyard) on organic material deposition in the formation of the deep top soil cannot however be considered without the missing data. Nevertheless a general indication of the major organic materials utilised in deep top soil formation in Marwick can be obtained from the six profiles for which $\delta^{13}C$ values are available (Table 8:8). These values can be examined in relation to $\delta^{13}C$ values of suspected input material from Orkney and the control profile which gives some indication of pedogenic influences on $\delta^{13}C$ values. Using the data from the control profile it is possible to adjust the $\delta^{13}C$ values from deep top soils to allow for pedogenic influence upon the original input material. This gives a $\delta^{13}C$ value which is considered to represent more closely the original $\delta^{13}C$ values of the organic materials deposited as the deep top soil. It is upon these adjusted figures that the discussion below is based.

Examination of the adjusted $\delta^{13}C$ values from deep top soils in Marwick demonstrate a range of between -27.8% and 31.2% . Thus it is clear that the organic materials used in deep top soil formation are dominantly terrestrial in origin. In the absence of peat ash material (see Section 8:2:2) fluctuations in $\delta^{13}C$ values within these deep top soils can be interpreted as primarily because of variation in the ratio of turf to manure in the deposited material. Taking -31.5% as the $\delta^{13}C$ value for manure material and -28.5% as the mean value for turf material (Table 8:8) permits the relative proportions for these two materials within the deep top soils to be derived. Based on these figures it is possible to state that organic sub-soil material in the Howe 13 profile is derived from turf material. Immediately above this sub-soil, at the base of the deep top soil,

TABLE 8:8

$\delta^{13}C$ MEASUREMENTS AND TOTAL CARBON(%) OF SOILS AND SEDIMENTS IN MARWICK

PROFILE NAME	SAMPLE DEPTH (cm)	HORIZON	CARBON (%)	$\delta^{13}C$‰	ADJUSTED $\delta^{13}C$ VALUE
Howe 13 (deep top soil)	10	S1	7.23	-28.3	-29.1
	20	S2	2.23	-28.2	-29.1
	30	S2	1.97	-27.4	-28.4
	40	S2	1.82	-27.8	-29.2
	50	S2	1.48	-27.5	-28.5
	60	S2	1.40	-27.3	-28.7
	70	S2	1.65	-27.6	-29.0
	80	B2	0.62	-27.0	-28.4
Howe 18A (deep top soil)	10	S1	2.7		
	20	S2	2.55		
	30	S2	1.8		
	40	S2	1.9		
	50	S2	1.7		
	60	S2	1.2		
	70	S2	1.0		
	80	B2	0.6		
	90	B2	0.6		
Howe 18 (deep top soil)	10	S1	0.51	-27.9	-28.7
	20	S1	2.12	-27.8	-28.7
	30	B2	2.12	-27.3	-28.3
	40	S2	1.81	-27.0	-28.4
	50	S2	1.30	-26.8	-28.2
	60	B2X	0.69	-26.8	-28.2
	70	B2X	0.36	-26.8	-28.2
Howe 23A (deep top soil)	10	S1	2.42	-28.2	-29.1
	20	S1	1.68	-27.5	-28.4
	30	S2	1.53	-27.3	-28.3
	40	A1	0.71	-27.3	-28.3
	50	B2	0.63	-27.2	-28.6
Netherskail (deep top soil)	20	S1	3.08	-28.6	-29.5
	40	S2	2.54	-28.6	-30.0
	60	S2	2.60	-28.7	-30.1
	80	B2	0.63	-27.6	-29.0

Muce /

TABLE 8: 8 Cont'd

PROFILE NAME	SAMPLE DEPTH (cm)	HORIZON	CARBON (%)	$\delta^{13}C$‰	ADJUSTED $\delta^{13}C$ VALUE
Muce (Deep top soil)	15	S1	3.12	-28.7	-29.8
	30	S2	2.89	-28.6	-29.6
	50	S2	2.90	-28.3	-29.7
	70	B2g	0.62	-29.8	-31.2
Howe 23 (Bilbster Series)	10	S1	2.60	-28.1	-28.9
	20	S1	2.66	-27.8	-28.7
	30	B2x	1.83	-26.8	-27.8
	40	B2X	0.93	-27.0	-28.4
West Howe Farmyard	20		3.2		
	40		3.0		
	60		2.6		
	80		2.4		
	100		3.8		
	120		2.8		
	140		2.6		

No carbonate reaction was evident in any of these samples.

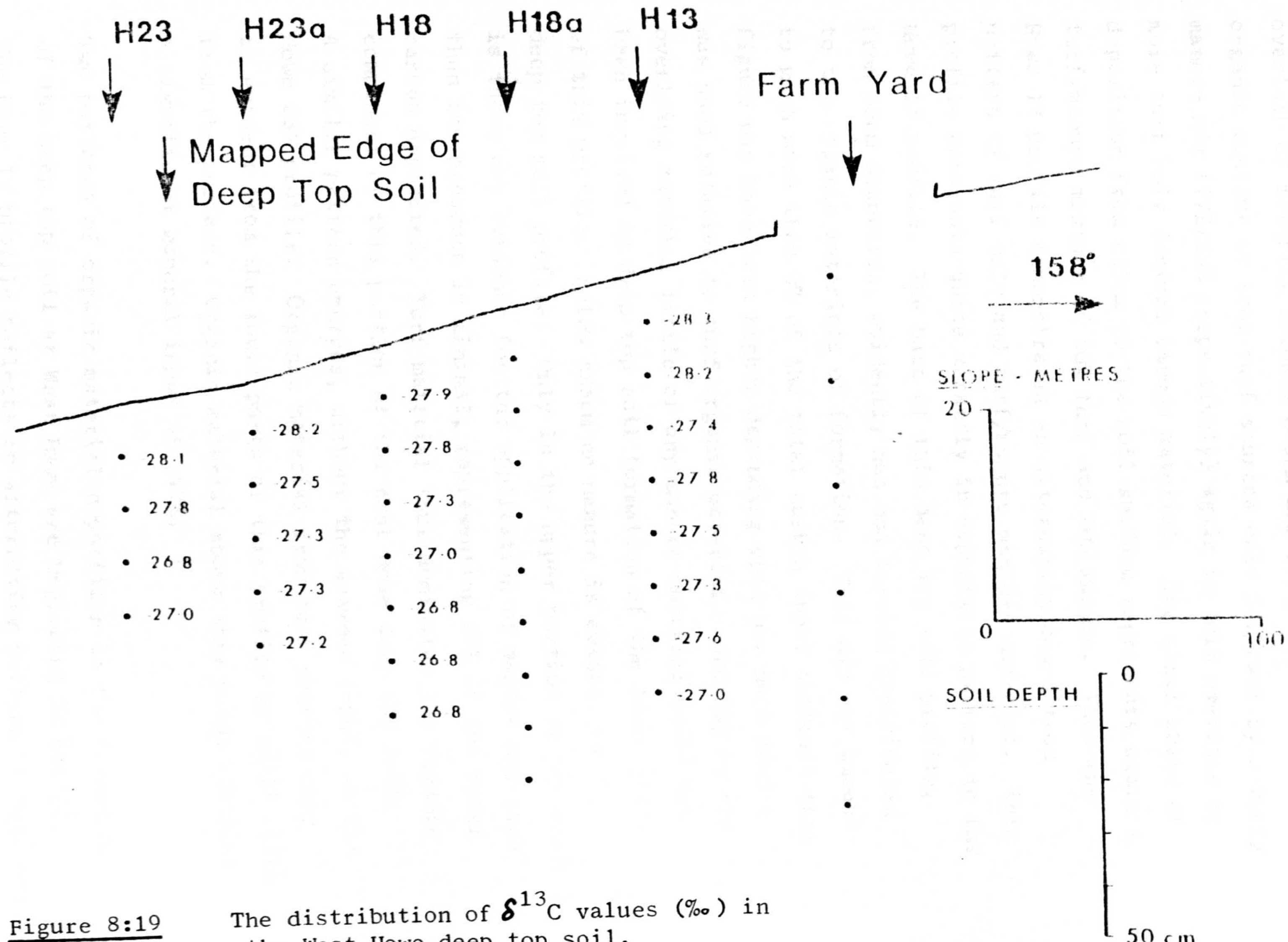


Figure 8:19 The distribution of $\delta^{13}C$ values (‰) in the West Howe deep top soil.

a turf/manure mix is evident comprised of c17% manure material and 83% turf material of its total carbon. This in turn is overlain by material between c45cm and c65cm depth whose organic content is from turf sources only followed by a turf/manure mix (77%/23% respectively) again in turn overlain by more turf only derived carbon material. The final phase of deposition from c25cm to the soil surface represents again a turf/manure mixture of 80% turf and 20% manure. Thus the Howe 13 profile demonstrates an alternating deposition pattern of turf only and turf/manure mixture material. This profile contrasts quite markedly in deposition pattern to the Howe 18 profile. The base of this deep top soil profile, from 45cm downwards, evidently has had seaweed contributed to the organic materials of formation. This did not amount to much more than 3% of the total carbon input although this figure may have been higher depending upon how much manure was used relative to turf organic material. Judging by the overlying material little of any manure material would have been involved in deep top soil formation of the lower parts of this profile. Below c25cm no manure is evident in this deep top soil profile. Only in the upper portion of the profile is there any evidence for the application of manure and even then its presence is minimal, representing c7% of the total carbon deposited. Turf material thus dominates the organic component of this portion of the West Howe deep top soil. A similar pattern emerges, without the seaweed input, at the Howe 23A profile. Organic material from turf sources only is evident from the lower parts of this profile up until c15cm from the surface. Organic material above this point contains a significant manural input of c17%.

Two patterns of organic material deposition in the formation of the deep top soil at West Howe are beginning to emerge. The Howe 13 profile reflects an alternating pattern of turf and turf/manure mix with manure when present representing c20% of the carbon input. The other two profiles within this deep top soil examined by $\delta^{13}C$ analysis, Howe 18 and Howe 23A, are further away from the farm buildings at West Howe (Fig 8:19). These profiles indicate that only latterly was manure involved in the formation of these profiles. Organic material from turf dominates the carbon input although at the base of the Howe 18 profile a minor seaweed input is noted. This pattern of seaweed input followed by turf material in turn overlain by a turf/manure mixture is repeated, in a compressed manner, immediately beyond the confines of the deep top soil as represented in Howe 23 profile (Table 8:8). This perhaps emphasises that no rigid distinction should be made between the activities that form the deep top soil and activities in arable areas beyond the deep top soil (Fig 8:19). Distinction can only be made in terms of intensity of those activities.

Examination of the $\delta^{13}C$ values from Muce and Netherskail deep top soils demonstrate a greater level of manure use in the formation of these profiles as compared to the profiles at West Howe. At Muce manure consistently formed c40% of the total carbon material deposited as the deep top soil, a figure which may have been higher judging by the greater negative sub-soil $\delta^{13}C$ value. The Netherskail profile had a manure component amounting to some 50% from the base of the top soil to c35cm depth in the profile. Above this the level of manure application dropped to c33%. At both Muce and Netherskail the balance of organic material is made up from turf sources. There is no evidence of any seaweed being utilised in the formation of these deep top soils. The greater utilisation of manure at Muce and Netherskail as compared with West Howe may reflect differences in the ability of these farms to generate manure material. A number of reason may be advanced for this. For example it may be that population levels were greater at Muce and Netherskail, thus a greater amount of cattle manure was generated. Another explanation might be that cattle from West Howe were not kept indoors as often as those at Muce and Netherskail,reducing the amount of available manure. Yet another explanation may relate to variation in land fertilization practice between the different farmsteads with Muce and Netherskail applying all available manure to one small part of the arable land while at West Howe the manure was spread more evenly over its arable land and eked out with turf material. A final explanation relates to the presence of what is probably an anthropogenic farm mound at the West Howe farmyard. If $\delta^{13}C$ values from this mound demonstrate that manure material was involved in its formation then this mound would clearly reduce the amount of manure available for land fertilization. Thus less manure would be involved in the formation of the West Howe deep top soil.

The above interpretation of $\delta^{13}C$ values from deep top soils is highly simplistic. Notably no attempt is made to take account of dilution effects caused either by the decomposition of crop roots in the soil or the application of seaweed. Both of these carbon sources for the deep top soil would serve to give a less negative $\delta^{13}C$ value than would be expected in soils with a high manure input. Thus estimated manure levels within the examined deep top soils may in fact be greater than those calculated above. It is not possible to calculate precise amounts of different organic materials utilised in the deep top soil formation from $\delta^{13}C$ values alone. $\delta^{13}C$ values give only a first approximation of organic formation materials in deep top soils.

In conclusion, $\delta^{13}C$ values from deep top soils in Marwick have demonstrated that the organic formation materials are dominantly terrestrial in origin. Within the West Howe deep top soil the Howe 13 profile demonstrates an alternating pattern of turf and turf/manure (probably byre material) organic inputs. Further from the farm steading manure was only used in the latter stages of deep top soil formation. Prior to this, turf, and at the base of the Howe 18 profile, a small amount of seaweed was used. In the West Howe deep top soil manure represents no more than 23% of the carbon input material at any one point. This stands in contrast to the other deep top soils in Marwick, at Muce and Netherskail, where up to 50% of the carbon input may have been manure. Amounts of manure input to the Muce and Netherskail deep top soil profiles are greater than those found in the West Howe deep top soil. For a number of possible reasons manure was in relatively short supply for the West Howe deep top soil, particularly during the earlier phases of deep top soil formation. The manure that was available during this early perood was mixed with turf and applied to the land nearest to the farmstead, implying the relative importance of this area represented by the Howe 13 profile compared with other areas of the deep top soil. This area of land close by the farmstead was therefore fertilized, thus providing additional nutrients for crop growth and the soil deepened which would help overcome the stoniness and soil rooting depth problems that exist in Orkney. Elsewhere the deep top soil developed because of the deposition of turf material intermixed with a small amount of seaweed which acted as a soil fertilizer. During the latter part of deep top soil formation at West Howe manure was more plentiful and this, having been mixed with turf, presumably in the byre, was spread across the whole area of the deep top soil and on to the Townsland arable land which lay beyond the deep top soil.

As with the examination of inorganic materials of formation the Howe 13 profile emerges as representing an area of the landscape subject to special attention relative to the remaining area of the deep top soil at West Howe. What this means in terms of land use will be examined in the following chapter.

8:3:4 Identifying Organic Materials of Formation in the Farm Mounds of Westbrough and Skelbrae by $\delta^{13}C$ Analysis

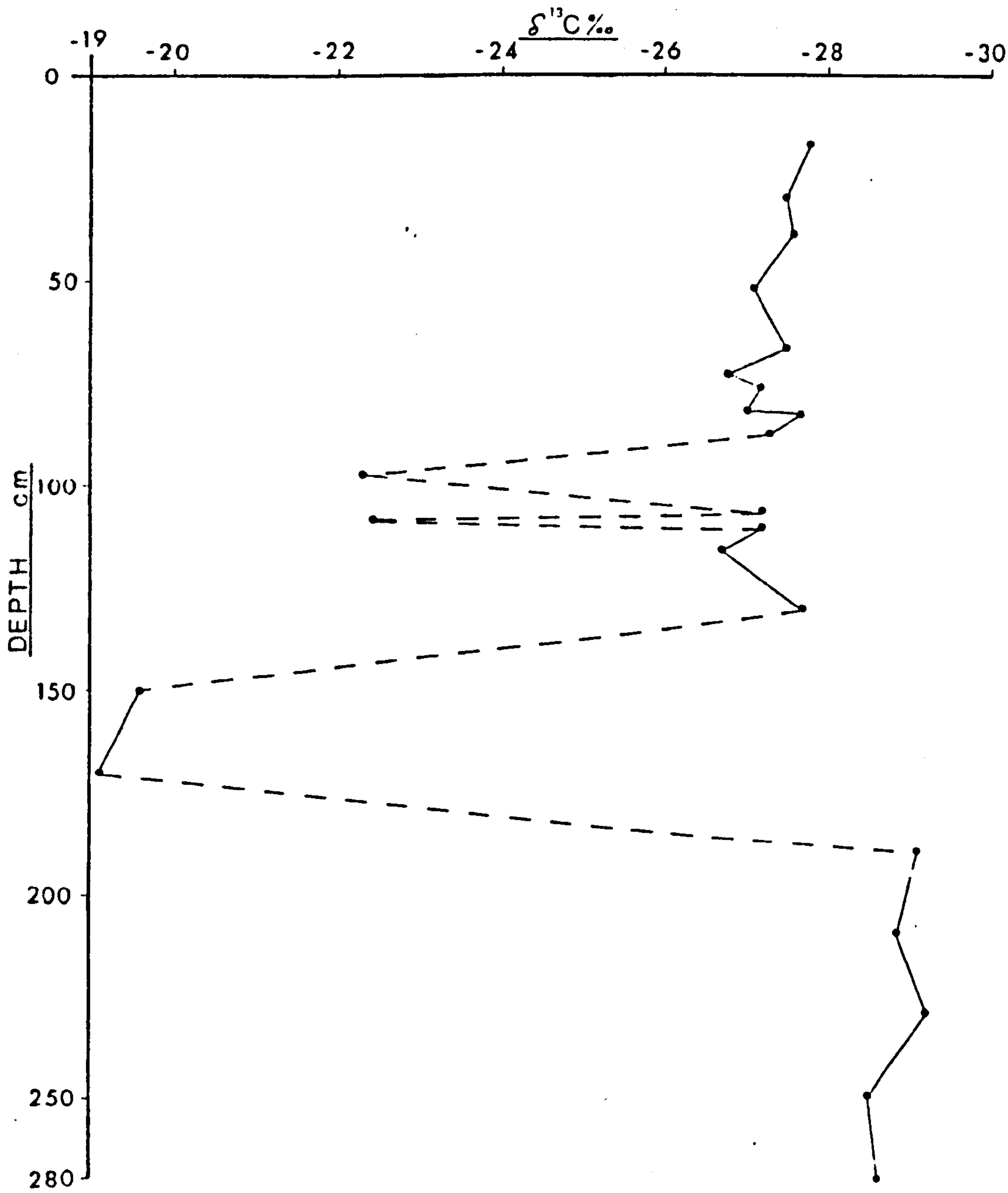
Like $\delta^{13}C$ values from the deep top soils, discussion here is based upon adjusted $\delta^{13}C$ values which remove the effect of isotopic fractionation due to pedogenesis. Results of $\delta^{13}C$ analysis from the farm mound profile at Westbrough demonstrate three distinctive zones of organic material deposition (Table 8:9 ; Fig 8:20). These three zones are considered to be the result of

TABLE 8:9

$\delta^{13}C$ MEASUREMENT AND TOTAL CARBON(%) OF WESTBROUGH FARM MOUND PROFILE 2

Horizon No	Sample No	Sample Depth (cm)	Carbon (%)	$\delta^{13}C$(‰)	Carbonate Reaction & $\delta^{13}C$ value (‰)	Carbonate %	Adjusted $\delta^{13}C$ Values
1	1	17	4.00	-27.8	-		-28.6
2	2	30	1.07	-27.5	-		-28.5
3	3	39	2.19	-27.6	-		-29.0
4	4	52	1.90	-27.1	-		-28.5
5	5	67	2.58	-27.1	-		-28.9
6	6	76	1.76	-27.2	-		-28.6
7	7	73	1.66	-26.8	-		-28.2
8	8	82	2.28	-27.0	-		-28.4
9	9	83	3.01	-27.7	-		-29.6
10	10	87	1.58	-27.3	-		-28.7
11	11	98	1.43	-22.3	-		-23.7
12	12	106	0.36	-27.7	-		-29.1
13	13	108	3.03	-22.4	-		-23.8
14	14	110	0.73	-27.2	-		-28.6
15	15	115	1.15	-26.7	-		-28.1
16	16	130	2.25	-27.7	-6.1	0.17	-29.1
17	17	150	16.77	-19.6	-		-21.0
18	18	170	22.43	-19.1	-		-20.5
18	19	190	34.23	-29.1	-		-30.5
18	20	210	9.81	-28.9	-		-30.3
19	21	230	9.57	-29.5			-30.6
19	22	250	8.06	-28.5	-0.2	0.55	-29.9
19	23	270	8.53	-28.6	-		-30.0

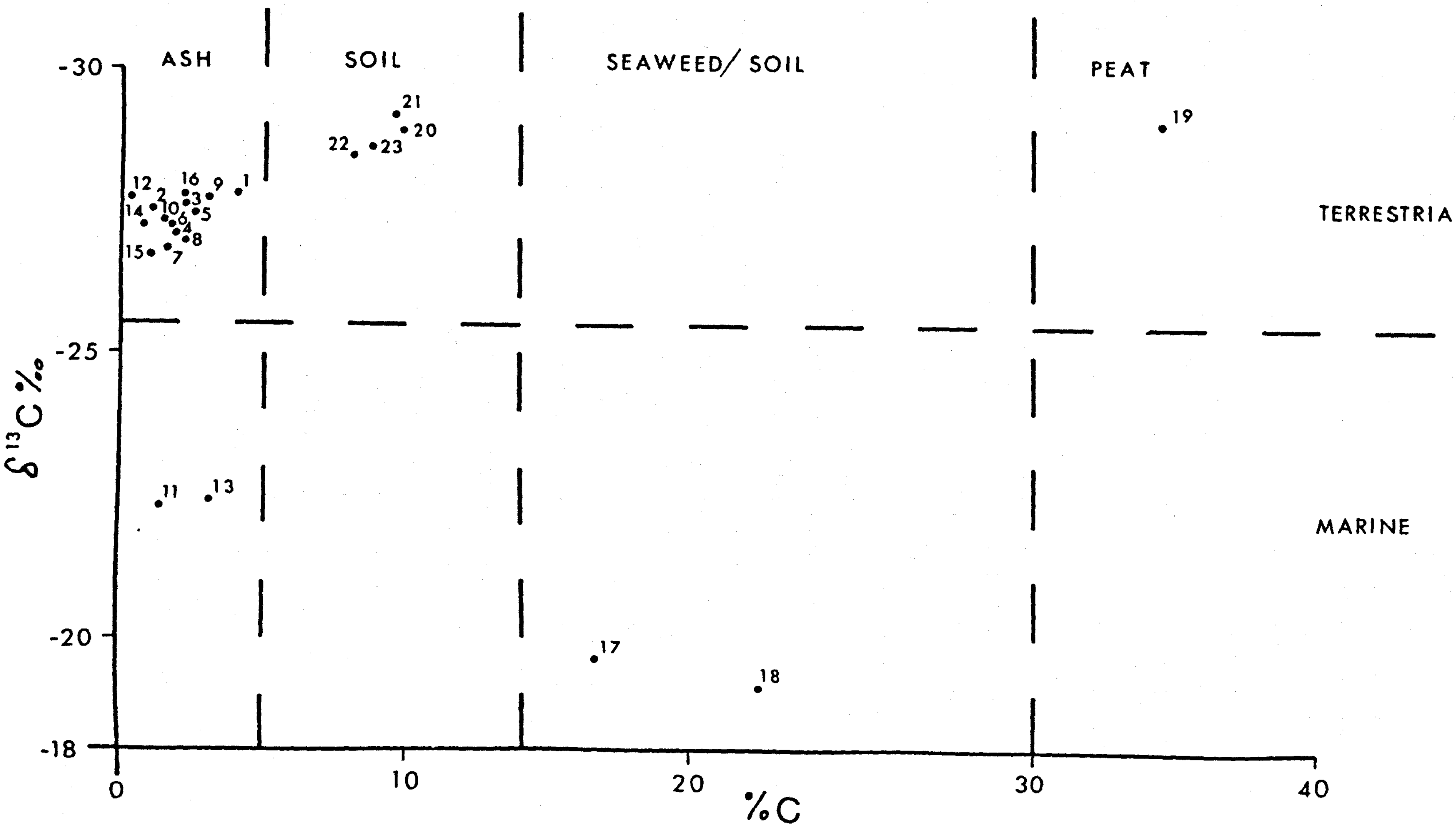
Figure 8:20 The distribution of $\delta^{13}C$ values (‰) within Westbrough Profile 2.



differences in sedimentary material. The lower zone is found between c190 and 270cm in the farm mound profile and has an adjusted $\delta^{13}C$ range of between 29.9 and 30.6‰ . On the basis of $\delta^{13}C$ values from suspected input materials, presented in Section 8:3:2, it is proposed that a turf and manure mixture is the chief composition of this portion of the mound. This serves to confirm the conclusions of the particle size analysis. Slight fluctuations represent slight variations in the precise proportions of turf to manure material. The average percentage of manure is estimated at c60% with turf comprising 40% of this part of the mound. A small amount of inorganic carbonate is present in Sample No. 22 and because of the slightly negative $\delta^{13}C$ value represents badly decomposed shell fragments. Inorganic carbon is however a negligible component of this part of the mound. Plotting $\delta^{13}C$ values against percentage carbon of a sample assists to further differentiate the material composition in this zone (Fig 8: 21). Samples 23 to 20, the lowermost samples, have percentage carbon values of between 8% and 10% and can be separated from Sample 5 which has a percentage carbon value of 34.23%. The lowermost samples can be interpretated as turf having been stripped from adjacent Bilbster Series soils, mixed with animal manure, either in a byre or in a fold, prior to their deposition as the lower part of this farm mound. Sample 19 represents manure mixed with organic peat material rather than material from the podzolic Bilbster Series. It seems unlikely that this peat came from within Sanday in view of the absence of peat on this Island today. This material may have come from the adjacent island of Eday which, historically, provided Sanday with peat.

Immediately above this lower portion of the mound lies a zone of distinct marine input. With the lack of any carbonate reaction, seaweed is the major input to this zone given the adjusted $\delta^{13}C$ range of between -20.5‰ and -21.0‰. The significance of this seaweed input is difficult to ascertain on the basis of these results alone but considering them in relation to the function or usage of the mound may help clarify the reason behind seaweed deposition.

Figure 8:21 $\delta^{13}C$ values (‰) plotted against total carbon (%).



Samples 1 to 16, like the particle size values, represent a zone of fluctuating pattern. The range of adjusted $\delta^{13}C$ values within this zone is between -23.7‰ and -28.6‰ . The organic material here is dominantly terrestrial with exceptions at sample points 11 and 13, which have a major marine input. Again, because of the absence of a carbonate reaction, these samples must be interpreted as containing organic carbon from seaweed sources. As well as having a distinctive $\delta^{13}C$ range this zone of the farm mound is characterised by a comparatively low percentage carbon range of between 0·36% and 4.00% (Fig 8:21). On the basis of this it is possible to argue that the material of this zone is dominantly ash, the waste material from the hearth. Under this hypothesis the material combusted was not peat whose ash material yields a mean $\delta^{13}C$ value of -24.5‰. Instead turf, manure and to a lesser extent seaweed were the materials used. This hypothesis explains the comparatively low total carbon percentages in this part of the farm mound. $\delta^{13}C$ values can be explained as resulting from incomplete combustion of the turf, manure and seaweed fuel materials which are mixed in varying proportions. That combustion of this material is incomplete is evidenced by the fact that farm mound samples have not been depleted in carbon -12 as much as might be expected by the comparison of $\delta^{13}C$ values for peaty organic litter and peat ash material (Table 8:7). Such a comparison suggests a 4.0% fractionation effect associated with combustion. This theory of incomplete combustion assumes that the material forming this part of the farm mound is indeed turf, manure and seaweed ash material. An alternative interpretation of this zone however is that it is a mixture of materials such as manure and peat ash. Combinations of these two materials would result in intermediate $\delta^{13}C$ values similar to those observed in the farm mound. Although there is historical evidence in Orkney for the use of peat ash in the byre to soak up cattle waste, this interpretation seems less likely than the previous hypothesis. The basis for this assertion lies in the low percentage carbon totals which are less than might be expected if the material was a mixture of ash and organic animal manure. This material has a comparatively high total carbon content.

To summarise, four separate types of organic materials can be identified within the Westbrough farm mound. The lower zone between c190 and 270cm comprises of a turf/manure mixture. This is overlain by a thinner zone of terrestrial peaty material evidenced by the sample at 190cm depth. Above this, between c150 and 170cm depth there has been deposition of seaweed. The bulk of the upper portion of the mound from its surface to c140cm depth is dominated by ash waste with the material combusted being various combinations of seaweed, manure and turf What the significance of these deposited materials are in relation to the function of this farm mound is examined in the following chapter.

Compared to Westbrough, the organic material pattern of distribution in the Skelbrae farm mound profile fluctuates less (Table 8:10; Fig 8:22). Similarly fluctuations that are evident are greater then those that might be expected purely from pedogenic processes. Such fluctuations therefore represent variations in the organic materials of anthropogenic sedimentation. Discussion of these $\delta^{13}C$ fluctuations to elucidate the organic materials of farm mound formation at this site are based upon adjusted values which remove the effect of pedogenic isotopic fractionation.

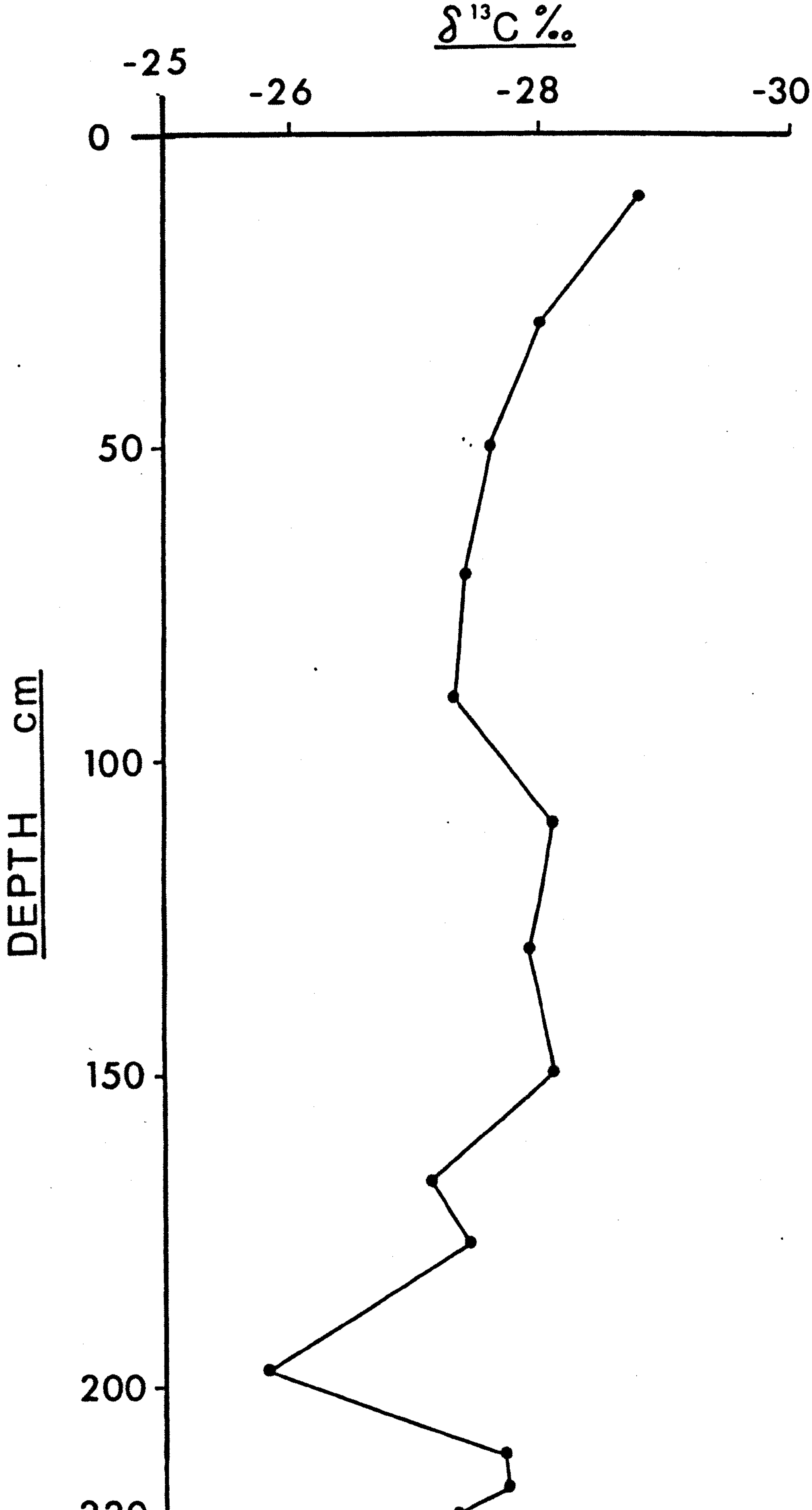
The podzolic B horizon soil material underlying this farm mound demonstrates a virtually identical $\delta^{13}C$ value to those of the Control profile (-28.5‰ , adjusted). The A horizon of the original land surface soil would appear to have been subject to organic amendment with animal manure being mixed into the original top soil. Immediately above the original land surface, representing the basal levels of the farm mound is material containing an identifiable component of seaweed, the only part of the examined Skelbrae farm mound profile with a significant seaweed input. The organic material of this zone cannot be said to be purely seaweed on the basis of an adjusted δ^{13} values of -27.2‰ . There is some degree of mixing with terrestrial carbon material, perhaps manure. The percentage of seaweed in the original material is estimated as 12%.

TABLE 8:10

$\delta^{13}C$ MEASUREMENT AND TOTAL CARBON(%) OF SKELBRAE FARM MOUND PROFILE 1

SAMPLE NO	SAMPLE DEPTH (cm)	CARBON %	$\delta^{13}C$(‰)	CARBON REACTION $\delta^{13}C$ VALUE(‰)	% CARBONATE	ADJUSTED FIGURES $\delta^{13}C$(‰)
1	10	1.99	-28.8	-1.9	0.87	29.6
2	30	1.22	-28.0	-2.3	-.17	29.0
3	50	1.27	-27.6	-5.8	0.28	29.0
4	70	2.11	-27.4	----		28.8
5	90	2.12	-27.3	----		28.7
6	110	1.70	-28.1	----		29.5
7	130	3.43	-27.9	----		29.3
8	150	3.08	-28.1	----		29.5
9	165	3.68	-27.1	----		28.5
10	175	3.25	-27.4	----		28.8
11	195	3.05	-25.8	----		27.2
12	210	4.05	-27.3	----		28.7
13	215	3.42	-27.7	----		29.1
14	220	3.29	-27.1	----		28.5

Figure 8:22 The distribution of $\delta^{13}C$ values (‰) within Skelbrae profile 1.

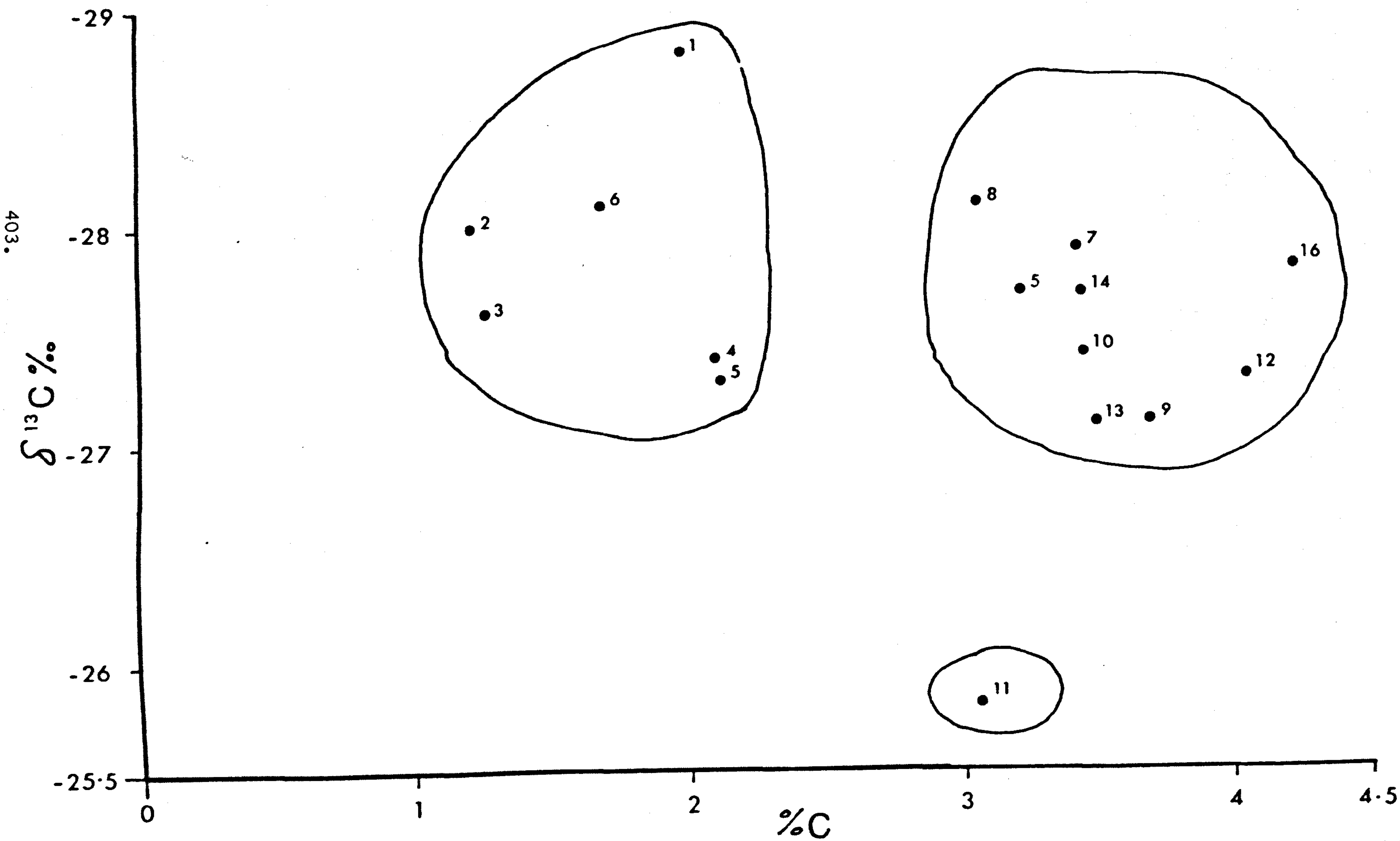


The following phase of organic material deposition reflects terrestrial material, declining in manure input with sample point 9 being purely turf material. This implies that turf material has been deposited on the evolving farm mound straight from its source area(s). There has been no use of this material in other Toft activities. Deposition of this material must therefore have been a deliberate effort to raise the level of the mound or to cover that which is now underlying.

Like the Westbrough farm mound the upper part of the Skelbrae farm mound profile from its surface to c 150cm depth would appear to be predominantly ashy material. This assertion is based upon the relatively low percentage carbon totals (Fig 8:23). This being so, then this zone represents ash waste material the original combustion material being turf and manure. The fluctuating pattern indicates the variation in relative proportions of these materials. An alternative explanation for these lower total carbon percentages is a high degree of biological activity on account of the slightly basic pH levels found in this profile. (see Chapter 3). These pH levels are controlled in part of the application of calcareous shelly sand material in the upper c 60cm of the farm mound. However, similar pH levels in the lower part of the mound suggest that a similar degree of biological activity would also have been operating at these levels. This implies that the first explanation of the relatively low percentage of the carbon values, ie that these samples represent ash material, is the more valid.

To conclude this discussion on the organic materials of farm mound formation at Westbrough and Skelbrae,it is worth emphasising the diversity of organic materials involved. All organic materials of the two farm mounds examined were, or were derived from, three basic material types. These materials were turf, peat and seaweed. This indicates that the only two major sources of organic materials, local terrestrial and marine, available to the farm mound constructors of Orkney were both exploited. In some parts of the farm mounds turf, peat and seaweed was deposited without prior modification. This implies that these materials were gathered, transported and

Figure 8:23 $\delta^{13}C$ (‰) values plotted against total carbon (%).



deposited because they enabled, maintained or enhanced a particular usage of the farm mounds. Other organic materials deposited as the farm mounds were Toft wastes. These waste materials are dominantly ash from the domestic and/or kiln hearths and dung impregnated turf animal bedding from the byre. The question as to whether such materials were deposited simply as Toft wastes or had a more positive purpose leads into the following chapter. A fundamental contention of this thesis is that both inorganic and organic materials were deposited as anthropogenic sediments for some purpose or reason. Thus the next chapter seeks to integrate the available evidence of land uses associated with anthropogenic sediment types.

CHAPTER 9

PROCESSES OF FORMATION 4 : SYNTHESIS, TOWARDS A GRAVITATIONAL MODEL OF ANTHROPOGENIC SEDIMENTATION IN ORKNEY

9:1 Evaluation of Data in Chapters 7 and 8

The data required to elucidate fully a gravitational model for anthropogenic sedimentation in Orkney may be described as follows. Firstly it is necessary to establish linkages (or pathways) between zones of anthropogenic deposition and zones of the landscape supplying sedimentary materials used in anthropogenic deposition. Secondly it is necessary to establish relationships between the characteristics of the zone receiving sediments and characteristics of the sedimentary material, its source and its volume. Thirdly, and derived from the above two, it is necessary to identify how much effort was required in terms of time by the society in question to form the anthropogenic sediments. This requires knowledge of the precise distance between source and deposition zones, the nature of the terrain and the mode of transporting sedimentary material together with its volume. Together these parameters control the formation of anthropogenic sediments.

The resolution limits of the data and conclusions presented in Chapters 7 and 8 take us only a small part of the way towards elucidating a gravitational model for the formation of deep top soils and farm mounds in Orkney. Nevertheless, assuming that the data interpretation of these chapters is valid, some important conclusions on anthropogenic sediment formation processes can be reached. In the first instance it is possible to establish linkages between zones of deposition and areas of the early Orcadian landscape that supplied the sedimentary material. This basic linkage can be taken further with the available data by matching the land use activities associated with landscape areas of anthropogenic sediments to the material types used in the formation of these sediments. Such relationships, it may be argued, form the dynamic of any gravitational theory for anthropogenic sedimentary processes. This dynamic is based upon the decision to develop land in a particular manner and the selection of sedimentary materials to permit, maintain or enhance a particular land use by the societies responsible for anthropogenic sedimentation. What must await future thought and research is the building into the presently available data certain assumptions that would permit a derivation of the volume of material types utilised in anthropogenic sedimentation. More precise definition of anthropogenic source areas which will permit establishment of the time cost to society for anthropogenic sediment formation and more statistically representative sampling of anthropogenic sediments and suspected sediment source areas must also await further research. For the moment one must be content with that part of the gravitational model that examines the relationship between land use and anthopogenic sediment type, a relationship that involves synthesising the contents of the previous two chapters.

9:2 Formation Processes of a Deep Top Soil : West Howe, Marwick

The deep top soil occurring downslope from the West Howe farmstead can be said to define the limits of the Tunmal land of the early Township. This portion of the landscape, owned by an individual(s) in a semi-permanent way, represents the most intensively cultivated arable area of the Township. That is, this land was kept in continuous cultivation with barley, a cereal that makes a high demand upon soil nutrients. This Tunmal land is therefore distinct from other arable areas within the Township, the Townsland and the Backs.

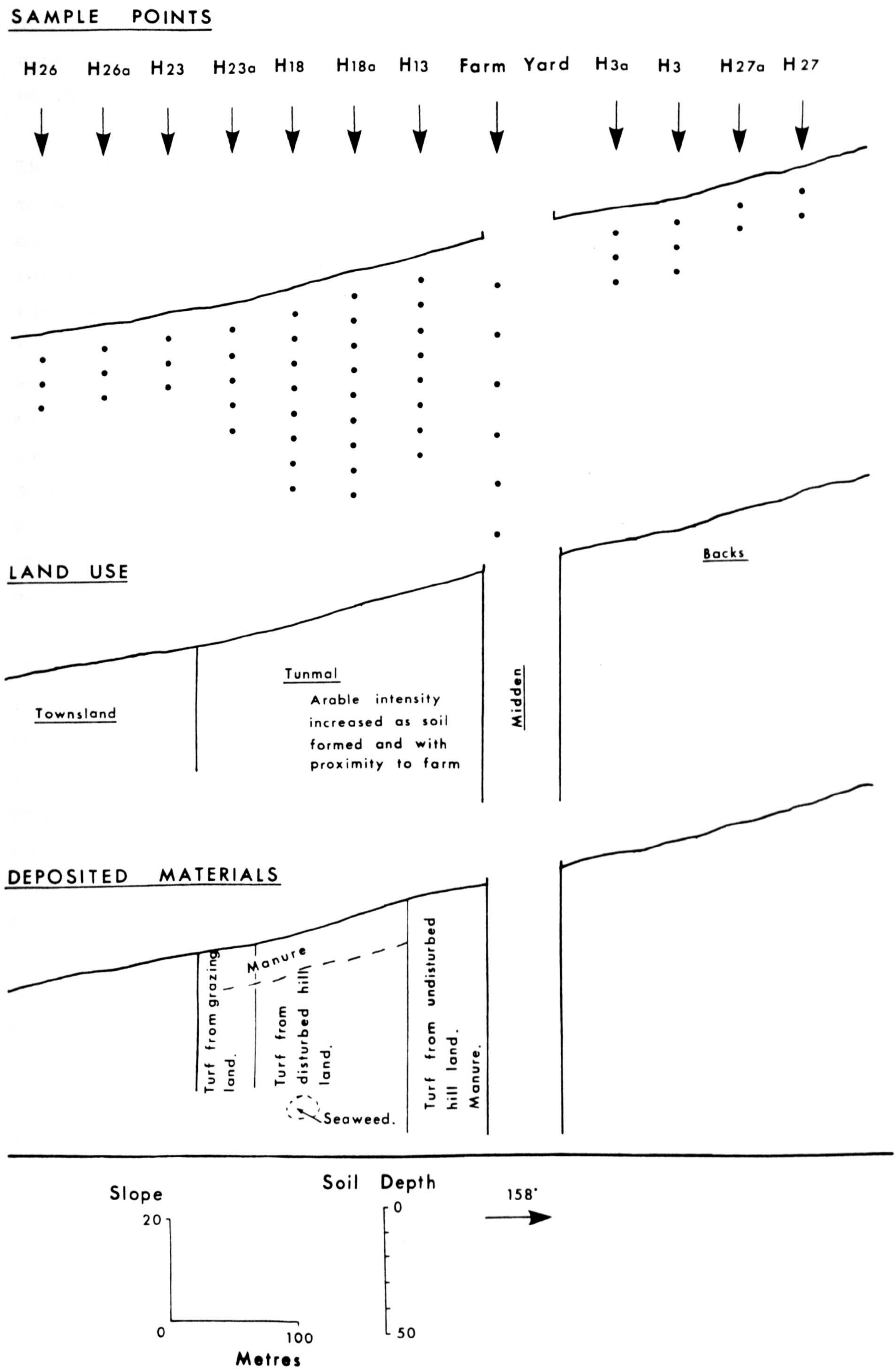
To enable this pattern of intensive cultivation to be maintained several types of sedimentary material, both inorganic and organic, were transported by the West Howe farmstead inhabitants or their domestic animals and deposited in the Tunmal area. It is the gradual but continuous deposition of this material in the Tunmal area that has resulted in formation of the West Howe deep top soil. Three types of material in varying proportions were involved in deep top soil formation at West Howe. These materials were turf, manure and seaweed. The bulk of the turf material came from the hill land beyond the confines of the hill dyke which enclosed the early Township. Some turf material also came from the grazing land within the Township but only in limited amounts. No turf material came from the early meadowland areas which were presumably considered as too wet to provide material for arable activity. Neither did material come from other arable areas within the Township, areas that would be conserved for arable activity, or from the sterile beach sand area of the coastline. Instead of these sources turf was deliberately taken from areas where grazing pressure was least and land that provided relatively dry material. Turf material was applied to the Tunmal land directly as well as being composted with animal manure. Composting could either have been carried out in the byre where the turf material would have acted as cattle bedding or else on the compost heap located within the confines of the Toft. Cattle grazing occurred on the hill land in summer and to a lesser extent on the grazing land within the Township. By being kept in the byre overnight in the summer and twenty-four hours a day in winter the manure for use in the Tunmal was collected. Again therefore the hill land and the Township grazing land ultimately provided material that went to form the deep top soil at West Howe. The use of seaweed in deep top soil formation at West Howe is more restricted but is evident. This observation therefore establishes a linkage between the coastline at Marwick Bay and the arable Tunmal area.

The material deposited in the Tunmal area of the Township served both to fertilize the soil and to alleviate the rooting zone limitations that are prevalent over much of Orkney. Maintaining soil fertility levels were the primary objective, made essential by the intensively cultivated nature of the Tunmal. Deposition of sedimentary material was piecemeal, judging by the incorporation of the original surface soil A horizon into the deep top soil material. This implies that deposition was not intended to overcome a rooting zone limitation. To do this a large amount of sedimentary material deposited all at once would have been required, an act that would have preserved the A horizon of the original surface soil.

The above paragraphs outline the general linkages that existed between the Tunmal arable area of West Howe and the hill land, grazing land and coastal bay areas of the late Norse and Medieval landscape of Marwick. These linkages can be seen in terms of the latter three areas of the landscape providing sedimentary materials to permit the intensive cultivation of the Tunmal area. This movement of sedimentary material resulted in deep top soil formation (Fig 9:1). Furthermore these linkages reflect the optimal use of landscape resources in the Marwick Township. They reflect the interdependence of pastoral and arable activity in the conservation of landscape and material resources.

Closer examination of the soil properties found within the West Howe Tunmal permits a detailed discussion of the relationship between arable activity and the selection and deposition of sedimentary materials. Both intensities of arable activity and types of sedimentary materials deposited within the Tunmal have been demonstrated to vary in a systematic manner (See Chapters 7 and 8). Intensity of Tunmal cultivation increased as the deep top soil developed with time and also with increasing proximity to the farmstead at West Howe. In the upper region of this deep top soil three distinct zones of arable intensity can be seen, although they too may be incorporated within the general trend of decreasing arable activity with distance from the farmstead. What exactly these differences in arable intensity meant is hinted at by the inorganic phosphate fractionation values obtained from this deep top soil. Less intensive arable activity during the earlier phases of deep top soil formation would appear to be comparable with the Townsland arable area. Thus during this phase of deep top soil formation less soil fertilizing material was applied to the land and, secondly crops were probably less demanding in their nutrient requirements. It may be that oats were cultivated during the earliest phases of deep top soil formation. By contrast the upper portions of the deep top soil have a phosphate fractionation

Figure 9:1 Summary of deep top soil formation processes at West Howe.



pattern that confirms an exceptionally intensive arable practice. During this phase of deep top soil formation arable activity would have been similar to that described in the late Medieval documentary sources. That is, within the Tunmal the land was heavily manured upon which was cultivated a nutrient demanding cereal such as barley with a comparatively high yield per acre.

The increasing intensity of cultivation with time does not appear to have markedly influenced selection of inorganic sedimentary materials for the purpose of assisting the maintenance of soil fertility. Criteria for selection of turf sod material remains the same throughout the period of deep top soil formation. By contrast the declining intensity of arable activity in the Tunmal away from the farmsteading has influenced selection of turf sod material from the hill land and grazing land. To a certain extent this pattern is reversed for the organic materials involved in deep top soil formation. Distance from the farm does not have a major effect on the use of organic formation materials but the passage of time does, as evidenced by $\delta^{13}C$ changes from the base to the surface of the deep top soil.

Throughout the formation of this deep top soil that portion of the landscape represented by the Howe 13 profile was subject to the most intensive late Norse and Medieval cultivation. The importance of this portion of the landscape in the early arable economy around West Howe is reflected in the selection of turf sod material. This material always came from a part of the hill land that had not previously been cut over to provide turf for the Toft or for the Tunmal. Here then is evidence for deliberate selection of a particular kind of turf material to be used in the most intensively cultivated part of the Tunmal. Turf material from areas not previously cut over must have been perceived as having advantageous soil fertility properties. Whether in fact they did so is another matter, particularly as they came from podzolic environments. Nevertheless, considerably more effort must have gone into acquiring this material as compared to the material for the remainder of the deep top soil. Areas that had not been cut over must have become increasingly scarce and distant from the farmstead as the deep top soil formed. Additional organic materials composted with the turf material applied to this part of the landscape were not always used. When they were the additional organic material was always animal manure, probably cattle manure. Composting took place in the byre or in farmyard compost heaps. The impression gained from the pattern of organic material distribution is that manure material was used as and when available, its deposition concentrated in this portion of the landscape to enhance fertility levels in this intensively cultivated area. The absence of any seaweed input perhaps reflect its extremely limited supply in Marwick where only a small part of the coastline is accessible.

Parts of the deep top soil further away from the farmstead, in zones of less intensive arable activity have formation materials of different characteristics to those found in the Howe 13 profile just discussed above. Implied in this observation is that different materials were used to maintain a slightly less intensive form of arable activity within this part of the Tunmal. Over the generations the farmers at West Howe returned to much the same areas for turf material to enhance arable activity in this portion of the Tunmal gradually cutting over the supply areas. For the central portion of this deep top soil that supply area was most likely the hill land. For that part of the deep top soil furthest from the farmstead turf material most likely came from the nearby grazing land. Here less effort was required for deep top soil formation. There was no perceived need to exploit new undisturbed areas of the landscape to provide turf material; the new growth of turf from previously exploited areas was considered adequate for this part of the Tunmal. It is possible to speculate that an incomplete new growth cover over previously cut over areas of the landscape implied to the early cultivators a less fertile material. Hence it was taken to supply turf for the less intensively cultivated parts of the Tunmal. Any comments on the perceived characteristics of materials used to aid arable activity in the Tunmal must however remain speculative. As with that area of the Tunmal represented by the Howe 13 profile use of additional organic materials was conditioned by their availability. Only latterly in the formation of this deep top soil, as cultivation intensity increased, was sufficient manure material generated by the farmstead to permit its deposition at the less intensively cultivated parts of the Tunmal. Prior to this, in the absence of available manure material, organic material involved in deep top soil formation came primarily from turf only. This is except for a small amount of seaweed used in the initial formation stages of the Howe 18 profile which again reflects the limited availability of seaweed for arable land fertilization purposes (Fig 9:1).

While the above discussion outlines the processes of deep top soil formation at West Howe, in conclusion it is worthwhile emphasising the key principles governing formation of this deep top soil. This can be outlined as follows. Selection, movement and deposition of sedimentary materials by human effort was determined by (1) the specialized arable land use activities associated with the Tunmal; (2) the availability of particular materials within the constraints of what the material environment provided and the requirements of various land use activities in non-anthropogenic sediment deposition areas within the early Township. Finally it is worth noting that late Norse and Medieval agricultural societies here emerge as making optimal use of landscape resources in terms of both careful landscape organisation and landscape "development". Further there is careful integration of arable and pastoral activities. This picture is far removed from that painted by advocates of the 19th Century agricultural improvements. Medieval society was to them inefficient and cumbersome in its agricultural activity. A consideration of deep top soil formation within its wider Township context suggest that such statements are not entirely accurate.

9:3 Formation Processes of Farm Mounds at Westbrough and Skelbrae

From the outset, early cartographic evidence clearly demonstrates that at least over part of the formation period the farm mounds are found within the Toft area of the Orcadian Township. The farm mounds are therefore mostly likely features which have arisen because of a particular set of habitation activities. At Westbrough four phases of farm mound function, or distinctive uses, can be identified in the examined profile. The profile examined in the Skelbrae farm mound also exhibit four phases of habitation activity. Formation of the Westbrough farm mound will be considered first.

The farm mound at Westbrough is located on the edge of the podzolic Bilbster Series soils, used for early arable activity, and the waterlogged saltings. However based on reports from the local farmer who excavated part of the mound for a new cattle court and the discovery of blue mottles indicative of periodic waterlogging towards the base of the exposed profile, it seems clear that much of this farm mound overlies waterlogged soils. To the people responsible for farm mound initiation this would have represented an unuseable part of the landscape except for some very poor grazing. In a period of comparatively high population density on Sanday and consequent pressure on arable and good grazing land, steps were taken to utilize more fully part of this waterlogged area of the landscape. These steps involved the alleviation of the waterlogging problem. The first phase of farm mound formation is therefore characterized by the rapid deposition of material to form a raised living surface. From c210cm to the farm mound base a turf/manure mixture, most likely byre waste, was deposited at the edge of this waterlogged area. The use of byre wastes for this purpose resolved two problems with one act. It permitted the creation of a raised living platform, secondly, it provided a convenient means of disposal for byre waste material. In the northern isles of Orkney byre wastes were often deposited in the sea, which for the Westbrough farmstead was several hundred metres away. Clearly deposition of byre wastes in the adjacent saltings was considerably easier. Use of byre wastes in the construction of this living platform also represented economy of effort in the sense that stripped turf material acted as animal bedding as well as the core of the living platform. Thus a double usage was obtained from the turf material and this was probably the major reason for using midden material in living surface construction instead of simply turf. Ashy material from the Toft hearths was not used presumably because of their insufficient bulk. The immediate source of farm mound core material at Westbrough is quite evidently the Toft byre, the material transported in a matter of a few minutes to the mound site. This would have been accomplished by shovelling or by carrying in baskets. Where the exact original sources of the turf components were cannot be ascertained on the basis of the available data. Presumably this came from the poorer grazing land.

Clearly a surface layer of midden material would not be a satisfactory habitation surface. This was a view certainly shared by the early mound constructors who, after laying down the core material, covered it with a peaty material. Again the origins of this peaty material are uncertain. It may have come from the adjacent island of Eday. Alternatively it may have come from a peaty podzol area nearby to Westbrough, in an area being reclaimed for agriculture. The precise function of the living platform at this part of the mound was that of a garden plot. Evidence for this comes from the physical re-organisation of the sediment matrix by plant root activity and possibly some sort of tillage activity. Fertilization of this garden plot was provided for to some extent by animal manures but, dominantly, seaweed was used. With seaweed in abundant supply on Sanday (see the following chapter), its use in garden plot fertilization is not a surprise. The living platform did however have other functions as is evident by the large flagstone in a profile further along the examined section of this farm mound (see Chapter 7). Such a flagstone probably represents a pathway across the mound.

At some indeterminate point in time, at the part of the farm mound examined by Westbrough profile 2, the living platform fell into disuse. What followed was a period when this portion of the farm mound was used simply as a midden. Here the wastes of the Toft accumulated. These wastes form approximately half the depth of the mound profile under consideration. The material is dominantly ash material from the hearth. Material used in the hearth was dominantly turf(but not peat) and manure with a significant seaweed component. Whether the latter formation stages in other parts of this farm mound are the same must be open to question but certainly the five examined profiles from the Westbrough farm mound do exhibit the characteristics of a midden in their upper portion.

The final phase of farm mound formation at Westbrough is the deposition of material dug out from the mound during the construction of the cattle court. This however forms only a minor component of farm mound formation material.

In conclusion the following summary of farm mound formation processes at Westbrough may be presented, based on Westbrough Profile 2 (Fig 9:2).

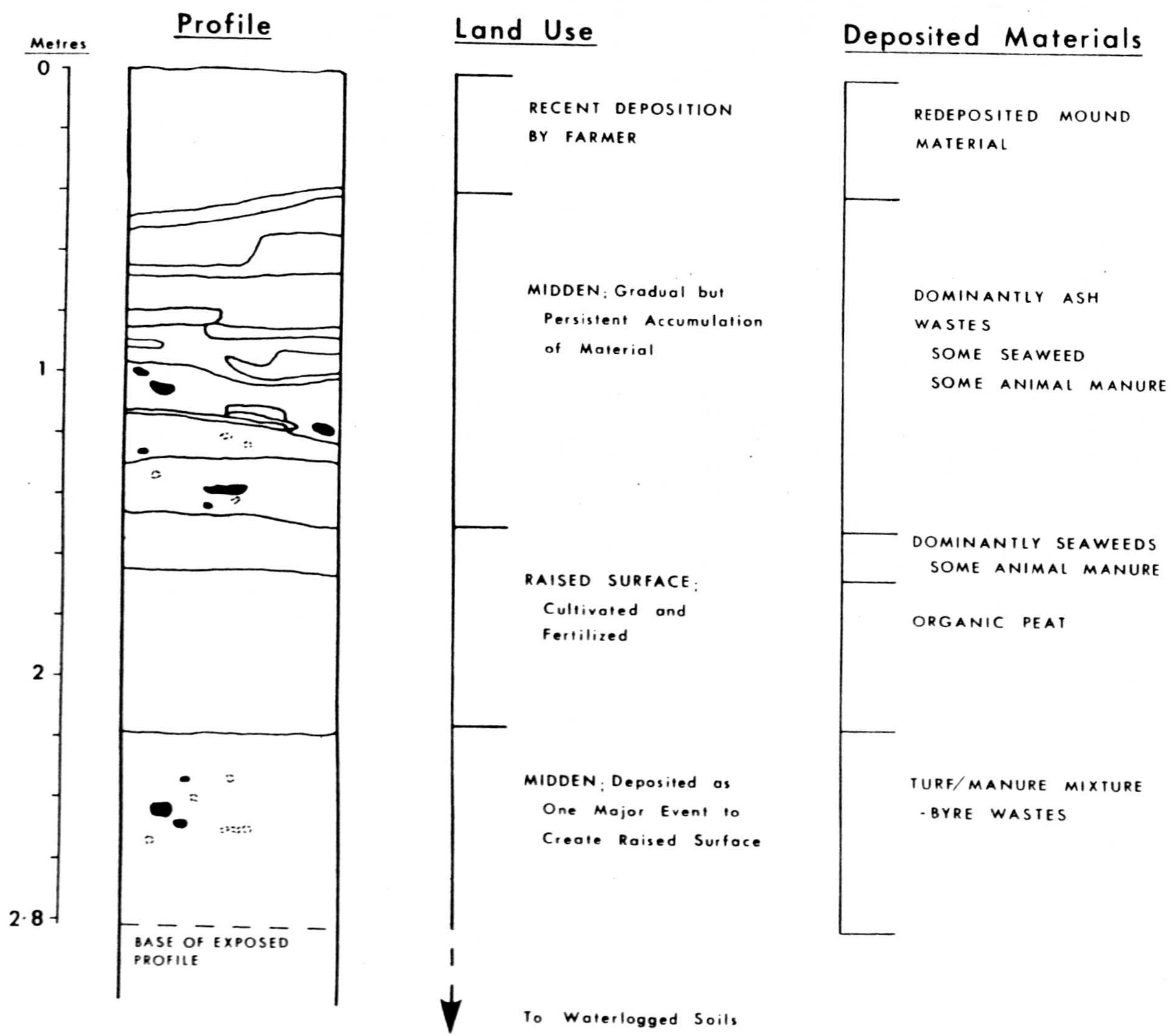
(1) Phase 1. Deposition of turf based midden material on waterlogged soils provided a base for a living platform free from the drainage hazards.

(2) Phase 2. Probably immediately after the deposition of Phase 1 material peat was deposited to create a suitable living surface. This surface was used as a garden plot and fertilized with manure and seaweed. Phases 1 and 2 together may be considered as analagous to terpen or wurt site formation (see Chapter 4).

(3) Phase 3. The mound was used as a midden, a place to deposit Toft waste which in the examined profile was dominantly ash material. Population at the Westbrough site declined as this part of the farm mound developed.

(4) Phase 4. This phase represents recent additions by the present farmer during the construction of a cattle court which cuts through the farm mound.

Figure 9:2 Summary of farm mound profile formation at Westbrough, Sanday.



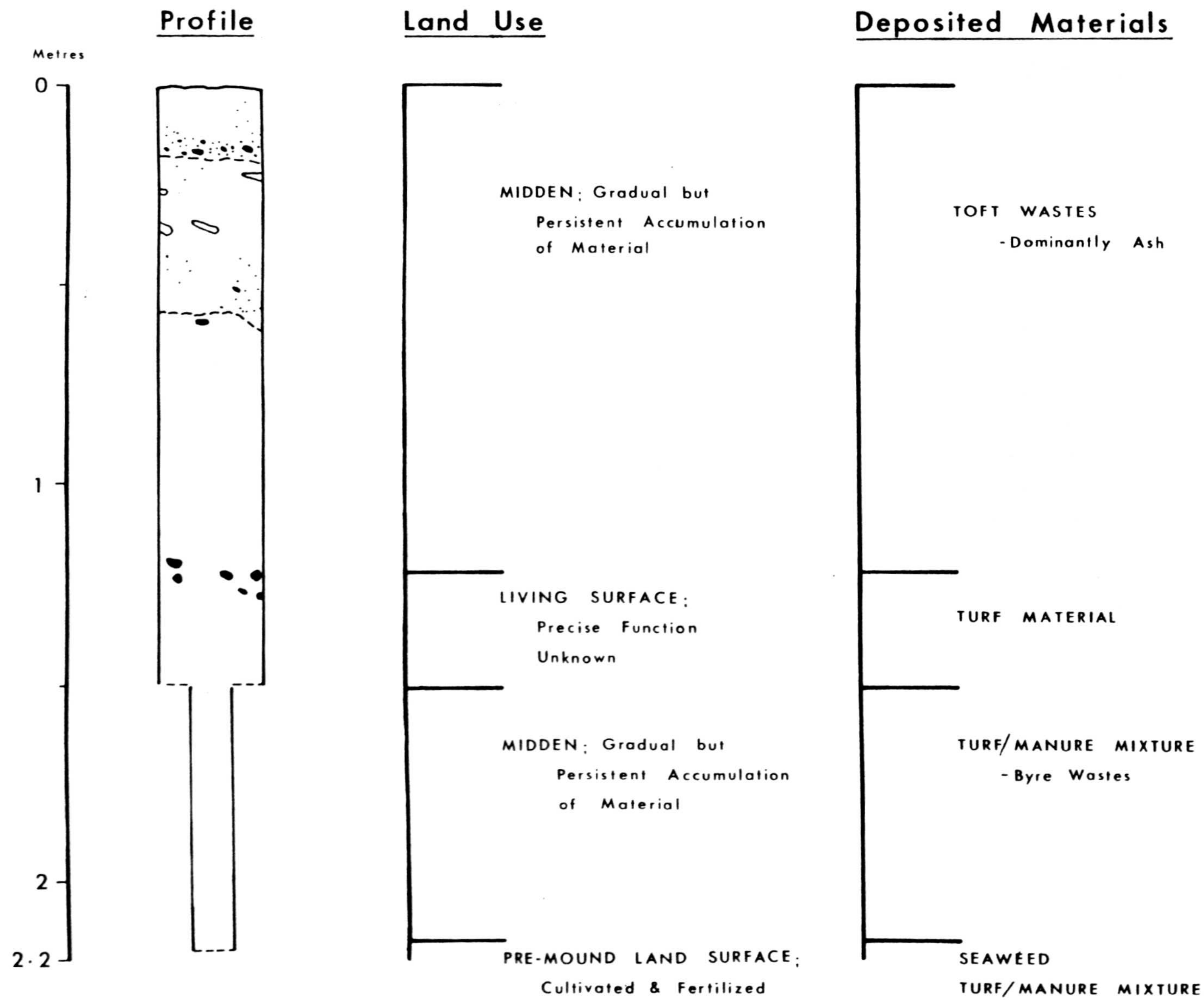
Turning attention to formation processes at Skelbrae, based on Skelbrae Profile 1, it would appear that a similar pattern to Westbrough emerges. There are however some significant differences notably that soil buried by the Skelbrae farm mound is a Bilbster Series soil. That this soil had perhaps been cultivated prior to farm mound formation is certainly possible given the comparatively high total phosphate values and the seaweed input together with terrestrial materials suggesting land fertilization for arable purposes. Farm mound formation therefore began with arable activity but this was superceded by deposition of Toft wastes. That is, the area of land represented by the farm mound today was used as a midden with a mixed deposit of turf, manure and ash. Clearly the habitation requirements to remove Toft wastes from the immediate vicinity of the farmstead overruled arable activity. Whether or not this material was deposited to form a core or a raised living platform like that at Westbrough is not clear. What is certain however is that Bilbster Series turf material was deposited upon the earlier midden material to provide a functionable living surface. The precise nature of habitation activities upon this surface are also not clear from the available data. Nevertheless the parallel with the Westbrough farm mound is striking. The final phase of farm mound formation as represented by this profile is the reversion to usage of this portion of the landscape as a midden. Again there is a parallel with Westbrough, dominantly ashy material being deposited within the constraints of a declining population. The original material prior to combustion in the hearth appears to have been a mixture of turf and manure.

Farm mound formation processes at Skelbrae can be summaried as below (Fig 9:3).

(1) Phase 1 Arable activity upon the original land surface Bilbster Series soil necessitated the application of materials to sustain soil fertility. Seaweed and possibly turf and manure were those materials.

(2) Phase 2 An outspreading of the habitation site

Figure 9:3 Summary of farm mound profile formation at Skelbrae, Sanday.



presumably in response to increasing population density is evident by the deposition of byre wastes on top of the earlier arable area.

(3) Phase 3. The deposited byre waste material was covered with Bilbster Series turf material to provide a satisfactory living surface. The precise nature of the activities associated with this living surface are unclear.

(4) Phase 4. The area of the landscape represented by the Skelbrae 1 Profile reverted to use as a midden where much of the Toft waste material was deposited. At Skelbrae Profile 1 this material consisted dominantly of ash from the hearth, originally being turf and manure prior to combustion.

CHAPTER 10

SPATIAL CONSTRAINTS ON DEEP TOP SOIL AND FARM MOUND FORMATION

10:1 Introduction

Anthropogenic sedimentation only occurs in certain areas of the Orcadian landscape. Earlier chapters have established that, where they occur, deep top soils and farm mounds are restricted to the Tunmal and Toft respectively of the early Township. At the regional scale distinctive spatial patterns are also evident. Deep top soils are found only in West Mainland and Stronsay; farm mounds are restricted in their distribution to Sanday and North Ronaldsay (see Figs 1:2 and 1:3). In this chapter an explanation is sought for the causes of this regional distribution pattern.

10:2 Factors Potentially Constraining the Spatial Distribution of Anthropogenic Sedimentation in Orkney

As a first attempt to identify the constraints upon the distribution of deep top soils and farm mounds, five factors are considered. These factors are population density, seaweed availability, turf availability, the inherent soil characteristics of Orkney and land tenure. These factors give an indication of the human potential energy to move sedimentary materials to and from different parts of the landscape, the major materials used in the formation of anthropogenic sediments, the inherent need for land fertilization to sustain arable activity, the susceptibility of land to waterlogging and sand blow, and the possible innovators of deep top soil formation. Previous chapters have indicated that these factors are of importance to anthropogenic sedimentation in Orkney. It is argued therefore that variation in such factors across the landscape will dictate the occurrence of anthropogenic sediments. How spatial (and indeed temporal) variations in these factors may influence anthropogenic sedimentation in Orkney is now briefly discussed.

10:2:1 Population Density

The basic hypothesis in exploring the relationship between anthropogenic sedimentation and population density is that all other factors being equal, they will demonstrate a positive correlation. Such an assertion is based on the principle that human energy provides the means by which material is moved from one point of the landscape to another in the formation of deep top soils and farm mounds. Thus the greater the population, the more energy is available for this purpose. Furthermore, as population increases there is a related increase in the generation of waste materials, be they human wastes, cattle manure or ash. These materials were used to generate deep top soils and farm mounds. Conversely, however, it may be that areas with ample manpower may result in anthropogenic sediments being disposed of in another way. An example of this is the dumping of manure on the beach to be washed away by the incoming tide (Fenton, 1978). It is clear therefore that variation in population density across Orkney during the period of anthropogenic sedimentation might be expected to relate to the distribution of anthropogenic sediments.

10:2:2 Seaweed Availability

The use of seaweed as a means of maintaining soil fertility is widely recognised in the historical literature of Orkney. Indeed seaweed, where it was available, was, for the purposes of maintaining soil fertility, preferred to animal manure or turf. The Old Statistical Account (1791-1799) describes how farmyard manure was dumped in the sea on Shapinsay and the New Statistical Account (1841) states that cotters were obliged to clean out the laird's dung courts and cart the manure to the sea. It was seaweed that was very much "the backbone of the old husbandry" (Old Statistical Account, 1791-1799). Vast quantities of both tang (littoral rock weeds) and ware (sublittoral seaweeds) were applied to the arable land having been carted or carried by horse or human from the shore.

Seaweed was therefore a material that would be used in preference to plaggen manure in maintaining soil fertility levels. If plentiful seaweed were available then it was to be expected that plaggen manuring and hence deep top soils would not occur.

Similarly, if byre manure was generated by a farm and not applied to the arable land, it is entirely possible that this material would accumulate close to the farmstead providing that it was not carted to the sea. This may contribute to farm mound formation.

Thus differences in availability of seaweed throughout the islands maybe of some significance in explaining the distribution pattern of anthropogenic sediments.

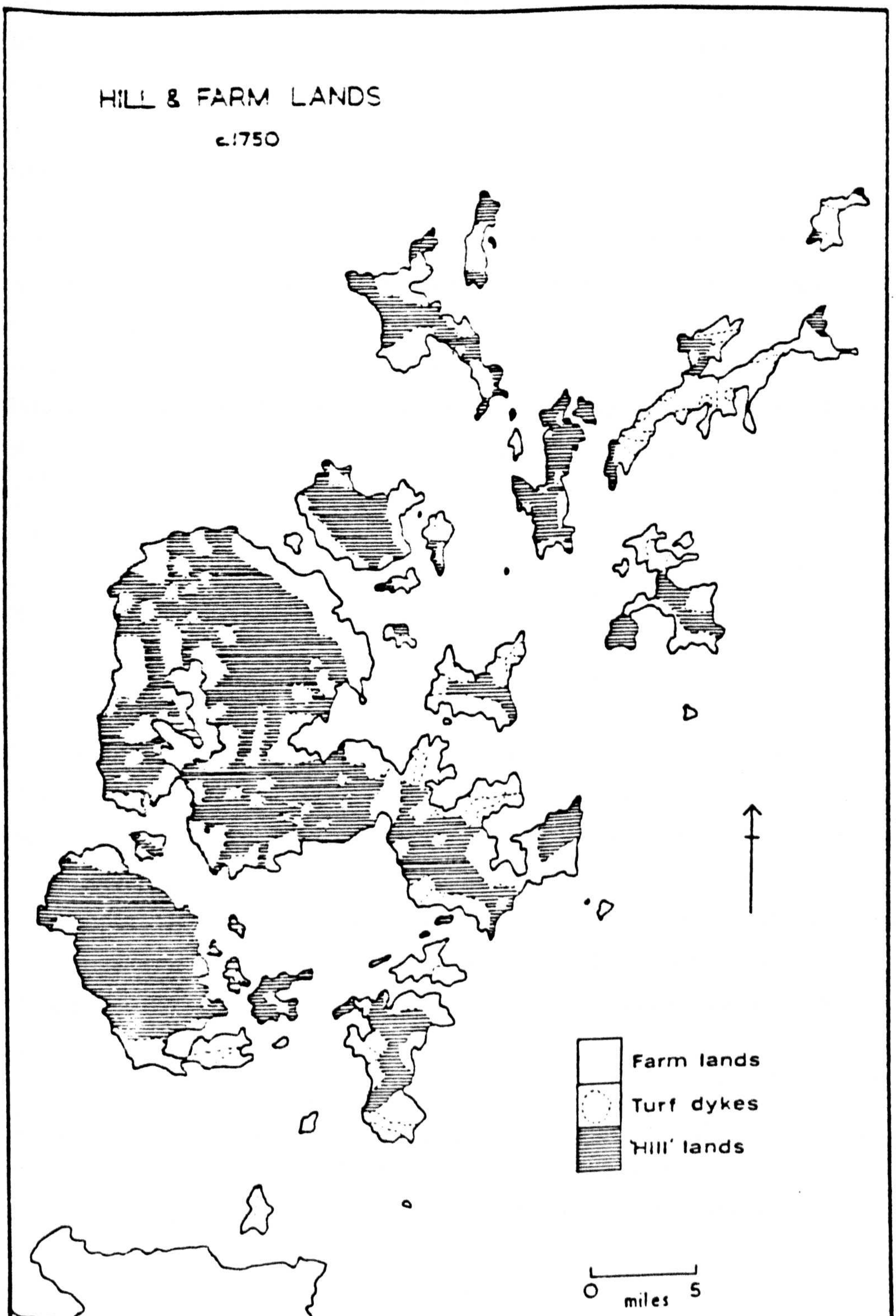
10:2:3 Availability of Turf

Turf was an essential constituent of byre waste material as already outlined earlier. Any shortage of this material would be expected to restrict anthropogenic sedimentation both as deep top soils and farm mounds. Examination of Figure10:1 reveals that over much of Orkney hill land turf would be easily available. Where hill land turf might be in short supply during the later stages of anthropogenic sedimentation - in North Ronaldsay, Sanday, the Walls peninsula and Tankerness - turf was probably readily obtained from the rough grazing and pasture land within the confines of the hill dyke. In short there is little or no spatial variability in turf availability. Turf was probably in abundant supply throughout the islands. Consequently this factor must have played little or no part in dictating the zone of anthropogenic sedimentation in Orkney.

10:2:4 Soil Type, Geology and Drainage

The underlying soil type of the Townships in which deep top soils and farm mounds evolved is considered to be a possible constraining factor because of the inherent fertility levels. Geologically, Orkney is comparatively uniform (See Chapter 2) and so the general inherent fertility of the parent material is similar throughout the islands. The important exception is soils derived from calcareous sands which have a greater fertility status than other soils on the islands. Otherwise soil fertility is controlled by drainage conditions except where human activity has altered this. Podzols which are freely drained are likely to be poorer in fertility status whereas gleys will tend to retain nutrients.

Figure 10:1 Hill and Farm lands of Orkney, circa 1750. (Based on the Chart of Murdoch Mackenzie; after Willis, 1983).



Three broad soil groups are considered therefore in relation to deep top soil and farm mound distribution - calcareous sands, gleys and podzols, in decreasing order of soil fertility. The hypothesis under scrutiny is that deep top soils are more likely to be found in areas where inherent soil fertility is low while farm mounds occur where byre manure and household wastes were not required to maintain soil fertility, ie in areas of good inherent soil fertility.

A further hypothesis requires to be tested using this soil information. If the farm mounds were deliberately raised as a living platform to counteract ground water or sand blow, this will be reflected in their spatial relationship with poorly drained soils or wind blown sands. The soil groups identified above also indicate the likely degree of drainage problem and wind blown sand and therefore are also used to test the "living platform" hypothesis.

10:2:5 Land Tenure

Land tenure may have been of particular importance to deep top soil formation in view of the fact that there was in Orkney a considerable bishopric estate. One hypothesis for the genesis of deep top soils is that they were introduced by the early monastic community (Chapter 5). Careful consideration suggests that land tenure was unlikely to influence anthropogenic sedimentation. One reason is that almost certainly anthropogenic sedimentation continued despite changes in land tenure which occurred over the period of deposition (Clouston, 1924). A second reason is that no matter who owned the land, be it udaller (farmer-owner), bishop, earl or king, the occupier still had to till and fertilise it in order to support himself and pay rent. It seems most unlikely therefore that land tenure was a significant factor in controlling anthropogenic sedimentation.

There are then three major factors which are thought to play a dominant role in constraining anthropogenic sedimentation in

Orkney. These factors are population density, seaweed availability and soil type. With regard to deep top soil formation the deductive hypotheses under consideration are that in Townships with limited seaweed availability, poor inherent soil fertility and relatively high population density, deep top soils are more likely to be found. Townships where there is an abundance of available seaweed, good inherent soil fertility and high population density might be expected to express the farm mound form of anthropogenic sedimentation. In this case the farm mound would simply be the accumulation of settlement wastes. A possible alternative constraint on farm mound formation is poorly drained soils or wind blown sands. These constraints would be of relevance if the farm mound was deliberately constructed as a raised living platform. Finally it is necessary to point out that where the above levels and combinations of factors do not occur then no anthropogenic sedimenation is expected. It is now necessary to test these hypotheses.

10:3 Mapping the Spatial Distribution of Population Density, Seaweed Availability and Soil Type in Orkney during the Period of Anthropogenic Sedimentation.

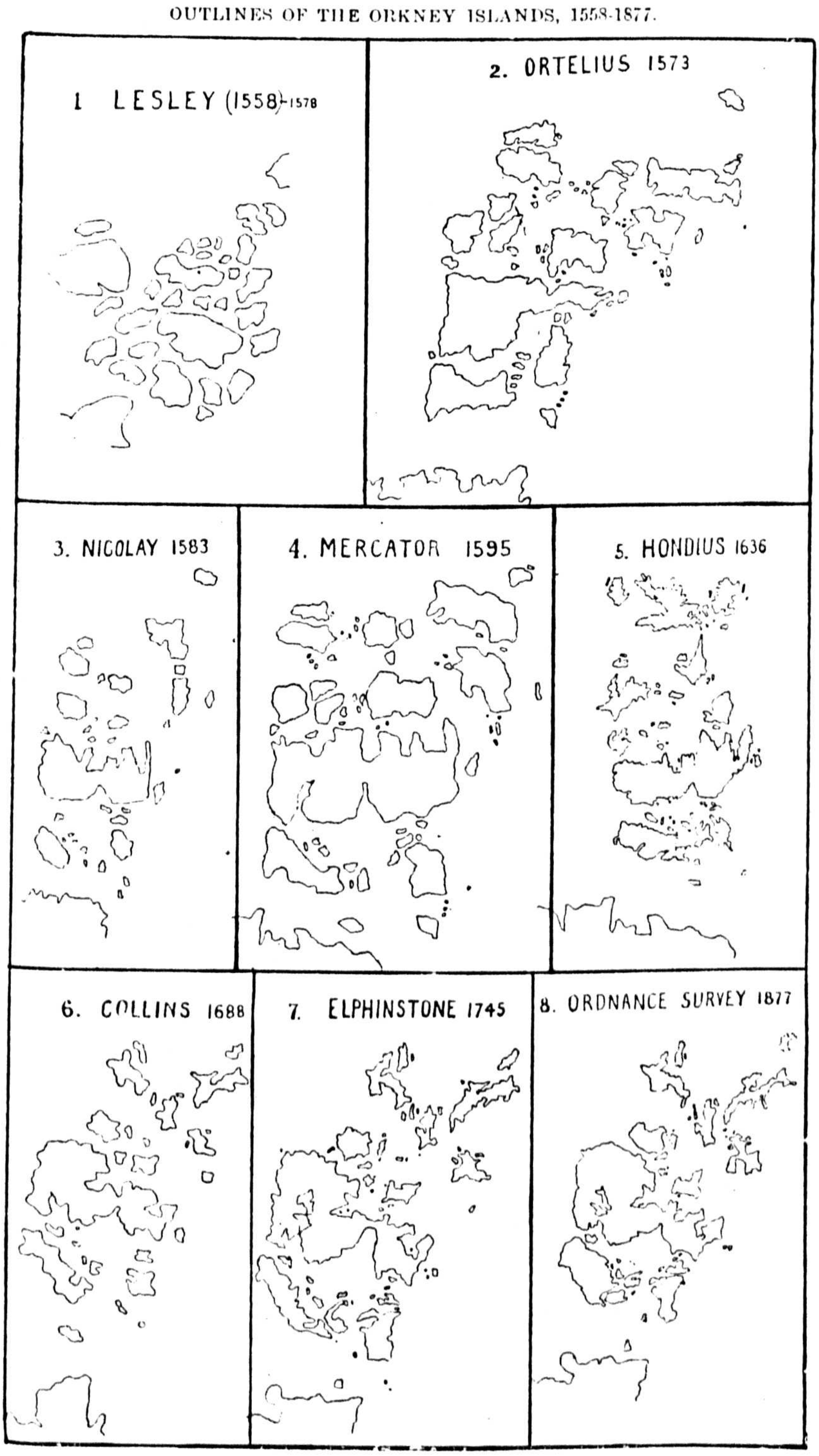
Before it is possible to examine the spatial relationship between the anthropogenic sediments and the postulated constraining factors it is necessary to identify how these constraining factors vary across the Orcadian landscape. Distribution maps of the three factors under consideration are now constructed by considering a number of different sources.

10:3:1 Mapping Population Densities

Population in Orkney during the Norse and Medieval periods was concentrated in the farmland townships which formed discrete areas scattered over Orkney. Clearly these townships were to be found where it was possible to practise agriculture given the technological limitations of the day. Deep top soils and farm mounds are all to be found within these township areas. Before one can establish whether or not there is any spatial relationship between population density and anthropogenic sedimentation it is necessary to identify the spatial variability of population density over Orkney. Hassan (1978) outlines various procedures for estimating population densities of past societies but none were entirely relevant to the Orkney situation. The most appropriate procedure for identifying population density across Orkney is based on the two elements of township areas and the skat (tax) values of those areas.

The first problem to be overcome with using this procedure is the accurate identification of the old township boundaries. Early townships in Orkney were generally delimited by a turf dyke which separated the farmlands from the hill lands. Destructive forces such as ploughing have long obliterated much of the visible traces of these early dykes. Fortunately early maps, particularly the "Orcades" series of Murdoch McKenzie (1750) which are used here, recorded the locations of many of these dykes. Not all of the turf dykes in Orkney date from the Norse/Medieval period and do not necessarily delimit the boundaries of the townships. The Treb dykes, remains of which are still to be found on Sanday and North Ronaldsay (R.C.A.M.S.1980) are in all likelihood pre-historic in origin. On North Ronaldsay the "Muckle Gairsty Dyke" divides the Ness township into two unequal portions. Where such circumstances occur, for the purposes of this thesis, townships were combined until reasonably accurate boundaries could be established. The same procedure was carried out when townships ran into one another, there being no mapped dividing dyke between them. These large units often represent the original Landnam (Old Norse - Landtake) by an individual during the initial phase of Norse settlement. Division of such areas into townships came later. One remaining consideration in delimiting townships area is the accuracy of McKenzie's 1750 maps. Examination of pre-1750 maps of Orkney clearly demonstrate the terrible inaccuracies of some of these early maps (Fig10:2). However McKenzie's maps of 1750 were the first of Orkney to be based on triangulation points and are widely recognised to be a reasonably accurate representation of Orkney. Nevertheless, when compared with the equivalent contemporary Ordnance Survey maps there are still inaccuracies. If however we assume that the slight inaccuracies of McKenzie's maps are consistent then it is still valid to compare township

Figure 10:2 Outlines of the Orkney Islands, 1558-1877. (From Inglis, 1918).



areas obtained from these maps.

The second problem is to identify the actual population size (not density) of the townships. This was achieved by the use of skat (tax) values which were recorded in pennylands in Orkney, with eighteen pennylands representing one urisland. Skat values are compiled in "Rentals of the Ancient Earldom and Bishopric of Orkney" (Peterkin, 1820). The significance of skat values in working out population sizes in Orkney lies in the thesis presented by Marwick (1935; 1949; 1952) that skat values originated with Leding, the Norse system of national defence. Marwick established that 4½ pennyland (¼ urisland) was required to provide one man for the earl's vessels and probably food and stores to support that man. This "tax" system, which was laid down probably in the 10th or 11th Centuries, later developed into the land tax system of Orkney and was applied to the arable land. Skat was levied annually on these land units. Thus the skat value of the different townships in Orkney may give an indication of how the population was distributed in Orkney right back into the Norse period (Steinnes, 1959). The rentals of Orkney are written in the Old Scots/Latin legal language making them difficult to understand for those that are not trained in Scottish medieval history. Fortunately Marwick (1952) has already worked out as far as is possible the rental values for the townships, farms and areas of Orkney from the rentals. In some parishes it is now no longer possible to ascertain with complete certainty the exact skat values of some townships. This is particularly so in Westray, Shapinsay and St Andrews Parish, Mainland. In the Paplay district it is even uncertain as to whether the skat values are representative of farm size. There is however no alternative but to pursue the use of skat values as indicators of population density, with appropriate caution.

The two elements required to produce a figure for population density, township area and skat value, are tabulated in Table 10:1. Farmland areas of the townships in Orkney were calculated from McKenzie's 1750 maps using a compensating polar planimeter. Pennyland values for the townships were based on Marwick (1952) and location of townships and farms within townships was aided by

TABLE 10:1

A POPULATION DENSITY INDEX OF THE EARLY ORCADIAN TOWNSHIPS

Township(s) Name (By Parish)	Farmland Area (Acres)	Pennyland Value (d)	Pennyland/ Acre($x10^2$)
North Ronaldsay			
Sailness & Sand	700	24	3.4
Linklet/Ness/Busta Sand Be-South	1180	48¾	4.1
Sanday			
Arstas	160	18	11.2
Brabustir	300	9	3.0
Brough	140	-	-
Cleat	150	18	12.0
Elsness	170	36	21.2
Tafts	20	18	90.0
How (Be-North)	20	16¼	81.2
Walls	250	36	14.4
Lopness	240	18	7.5
Stove + Area	500	46½	9.3
Langtas + Houstas	200	54	27.0
Voy	140	36	25.7
Sellibister	480	18	3.7
Hobister	50	12	24.0
Warsetter + Area	270	45	16.7 (est boundary)
Housegarth (How)	110	27	24.5
Noltland	230	18	7.8
Hellyhowe	80	18	22.5
Skelbrae	50	18	36.0
Stangasetter	30	18	60.0
Simbuster	60	18	30.0
Tresness	80	18	22.5
Sutherbie + Leyland	110	36	32.7 (est boundary)
Colligar	20	9	4.5
Bressigar & Cleavisgarth :	Boundary no longer evident.		
Stronsay			
Evirby	990	18	1.8
Rothisholm	630	36	5.7
Strenzie + Area	1810	60	3.3
Aith, Howard + District	1810	95.5	5.3
Papa Stronsay	140	12	8.6
Eday			
Skail + Backaland	320	11	3.4
Sealskerry + Carpaquoy	30	2	6.7
Ferness	50	1	2.0
Gusry :	Not mentioned.		
Carrick/Nupe :	No skat value given.		
Faray :	Skat value unknown.		

Township(s) Name (By Parish)	Farmland Area (Acres)	Pennyland Value (d)	Pennyland Acre(x10^2)
Westray			
Aikerness	500	27	5.4
Musland	70	1	1.4
Midby/Tuquoy + Area	1560	85.5	5.5
Noltland + Area	1820	105	5.8
Skelwick	580	3	0.5
Rapness	1090	c 10.5	0.96
Papa Westray	540	72	13.3
Egilsay	1250	72	5.8
Wyre	240	12	5.0
Gairsay	320	13	4.1
Rousay			
Trumland	80	2	2.5
Knarston/Sourin	830	46.5	5.6
Wasbuster	600	27	4.5
Westness, Frotoft, Hunclett	1030	43	4.2
Shapinsay			
Sands/Kirkuster/Sound	1513	61(?)	4.9
Waltness	250	9	3.6
Weland	580	8	1.4
Holland	550	18	3.3
Menis	470	9	1.9
Burrows	160	3	1.9
Birsay			
Marwick	600	36	6.0
Hundland	110	3	2.7
Swannay	470	7	1.5
Ingsay	300	12½	4.2
Barony	1540	171¾	11.1
Kirkbuster	100	3	3.0
Folsetter/Isbuster	230	12	5.2
Twatt	160	3	1.9
Beaquoy	170	5¼	3.1
Hillside + Durkadale	350	5½	1.6
Birsay/Sandwick			
Greeny/Sabiston/ Lealy/Skeabrae	1830	60	3.3

Township(s) Name (By Parish)	Farmland Area (Acres)	Pennyland Value (d)	Pennyland Acre(x10^2)
Sandwick			
Tenston	210	18	8.6
Voy	230	6	2.6
Yesnaby	310	9	2.9
Lyking	220	12	5.4
Wasbistur	340	9	2.6
Northdyke/Southequoy	2700	201	7.4
Stromness			
Whom	550	4	0.7
Redland/Kirkbuster	720	9	1.2
Mousland	110	1½	1.4
Seatter	70	1	1.4
Cairston	710	14	2.0
Hamigar	50	½	1.0
Inner + Outer Town	100	72	10.3
	(Taken as one unit - no obvious township divisions)		
Evie	3220	144	4.5
Rendall			
Ellibister	100	5	4.5
Rendall/Gorseness/ Queenamuckle	1430	54	3.8
Cottascarth	260	3	1.1
Hackland/Isbuster	550	18	3.3
Harray			
Knarston	180	4½	2.5
Grimeston	380	18	4.7
West Stennes Townships	1330	51.5	3.9
Firth			
Seater/Wasdale	240	2	0.8
Hedal	120	3	2.5
Coastal Townships	1430	37	2.6
Binscarth	200	4½	2.2
Rennibister :	No boundary shown.		
Settiscarth :	No boundary shown.		
Stennes			
Bigswell	110	3	2.7
Stennes/Clouston	850	30	3.5
Ireland	360	18	5.0
Germiston	10	6	3.5
Ottergill :	No boundary shown.		
Anderswick :	No skat value given.		
Dowscarth :	No boundary shown.		

Township(s) Name (By Parish)	Farmland Area (Acres)	Pennyland Value (d)	Pennyland Acre(x10^2)
Orphir			
Clestran/Coubister	1260	14	1.1
Swanbister	710	9	1.3
Orphir/Midland/Houth	620	27	4.3
Groundwater	190	9	4.7
Hobbister	130	6	4.6
Kirbister	100	3	3.0
Tuskerbister	200	9	4.5
Naversdale	60	Unskatted	
St Ola			
Caldale	160	3	1.9
Crowness + Area	750	26	3.5
Gratnip	60	3	5.0
Scapa + Area	920	38	4.1
Papdale	230	9	3.9
Weyland	190	6	3.2
Wideford	320	9	2.8
Inganess Townships	830	27¾	3.3
St Andrews			
Deer Sound Townships	1980	63	3.2
Stembister	210	4½	2.1
Yenstay/Essenquoy	720	16	2.2
Linksness	230	3	1.3
Tankerness	480	15	3.1
Holm			
Hunclett	70	3	4.3
Easterbister	500	9	1.8
Henbister	410	18	4.4
Westerbister	360	9	2.5
Paplay/Aikerbister + Area	1160	72.25	6.2
Deerness :	No township divisions given.		
	2920	108	3.7
Burray			
Bu/South + North Town	1250	36	2.9
South Ronaldsay			
Hoxa	300	6¼	2.1
Mid-East Coast Townships	1030	30	2.9
Barswick	210	6	2.9
Southend	1070	31¾	3.0
Burrowell/Holland	970	25½	2.6
Ronsvoe	680	16	2.3
Herston	150	3	2.0
Grimness	750	10	1.3
Sandwick	430	12¼	2.8
Widewall	350	12	3.4

Township(s) Name (By Parish)	Farmland Area (Acres)	Pennyland Value (d)	Pennyland Acre(x10²)
<u>Graesay</u>			
Corrigal/Suthergarth	270	18½	6.8
Outerile/Sandisend	300	16	5.3
<u>Fara</u>	130	3	2.3
<u>Flotta</u>	400	9	2.25
<u>Hoy</u>			
Rackwick	150	3	2.0
North West Coast Townships	980	48	4.9
<u>Walls</u>			
Rysa	340	½	0.2
Aith	340	18	5.6
Brims/Manclett Millsetter	790	9½	1.2
Fea/Kirbister/ Walds	730	27	4.0
Thurvo	210	3	1.9
Osmundwall	430	18	4.4
Seater	160	3	2.0

the Ordnance Survey 1:10,000 map series of Orkney. Values for pennyland per acre for the individual townships or areas could then be calculated and presented in the map form of Figure10:3.

This map can validly be taken as representing the relative population density in Orkney prior to the agricultural improvements. The usefulness of the map depends on how representative it is of population density over the period of deep top soil and farm mound evolution (See Chapter 5). It is possible to assume that relative farm sizes remained much the same throughout the major anthropogenic sedimentation period. The only check that can be made on this assumption is to compare the parish population figures given in the Old Statistical Account (1791-1799) with the total skat values for the parishes (Table10:2). Population figures were available for 1755, 1790 and 1801, towards the end of the period of anthropogenic sedimentation in Orkney. Comparison of these three years population figures with the total skat values for the parish by Spearmans Rank Correlation gave r_s coefficients of 0.79, 0.77 and 0.78 respectively. In each case it was possible to reject the null hypothesis that there was no correlation between the population figures and the skat values at the 99% confidence level. These results go some way towards alleviating the fears that the township skat values were unrepresentative of population density over the time period under consideration despite the fact that the Kelp boom may have slightly affected the 18th Century figures (Thomson, 1983).

Skat values may also be indicative of relative population densities prior to the Norse settlement. Marwick (1952) in noting the high scale of taxation in Sanday attributes this to the possibility that the island was already extensively cultivated prior to Norse immigration. This suggests that the pre-Norse,Pictish, landscape carrying capacity is reflected in the skat values.

From the above discussion it is possible to state that relative population density in Orkney did not alter greatly over the period of anthropogenic sedimentation. Thus it is valid to take one map as representative of this whole period. Township skat

Figure 10:3 Pennyland/Acre values plotted for early Townships in Orkney. (Base map after McKenzie, 1750).

TABLE 10:2

PARISH POPULATION AND SKAT VALUE FIGURES

(From the Old Statistical Account, 1791-1799, Marwick 1952)

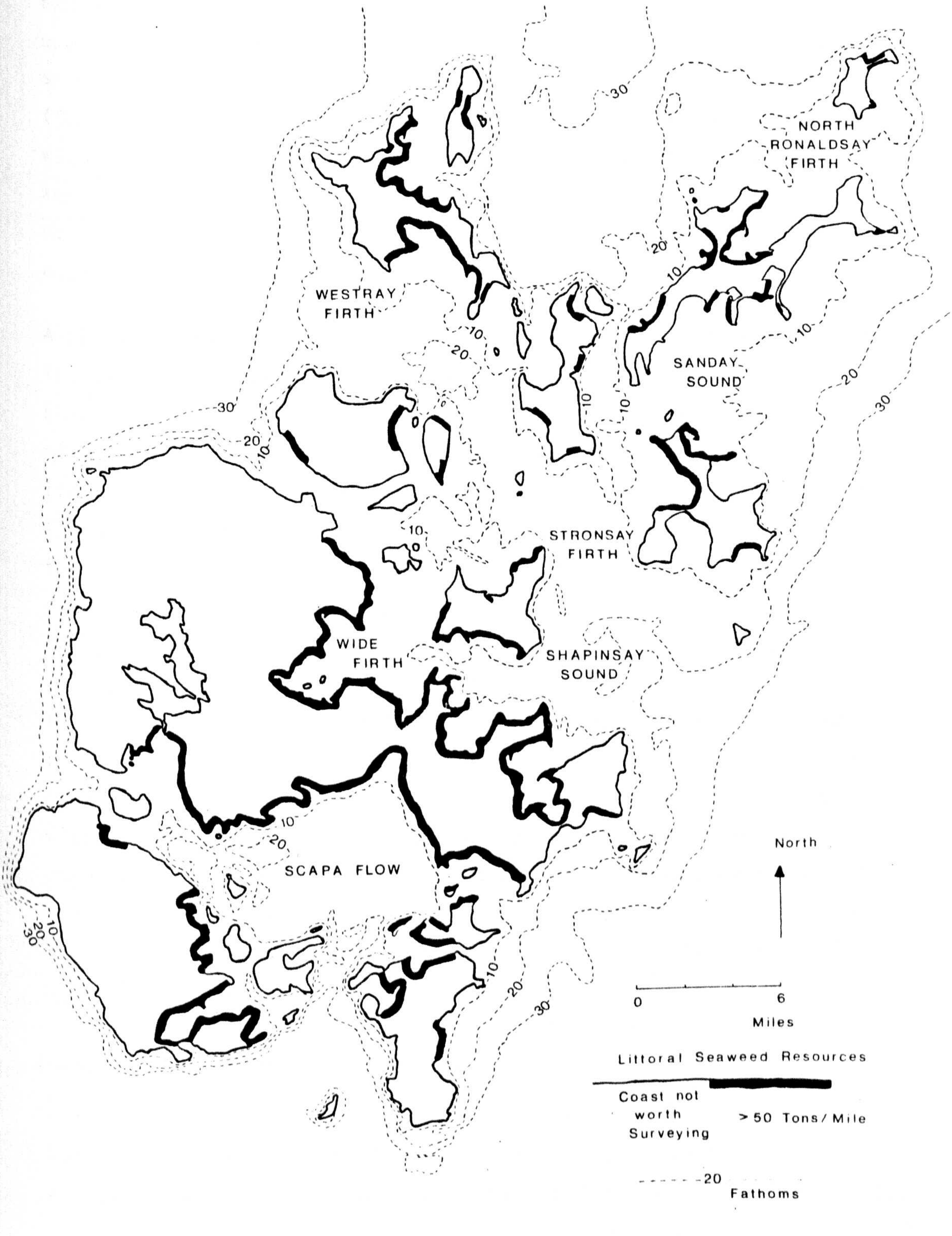
PARISH	TOTAL POPULATION IN 1755	1790	1801	TOTAL SKAT VALUE
North Isles				
Rousay & Egilsay	978	1072	1061	190.5
Sanday & North Ronaldsay	2000	2192	2148	633.5
Shapinsay	642	730	744	108
Stronsay & Eday	1493	1389	1642	235.5
Westray & Papa Westray	1290	1629	1624	304
Mainland				
Birsay & Harray	2200	2013	2176	351.5
Evie & Rendall	1789	1564	1416	224
Firth & Stennes	1108	1186	1272	103.5
Holm	1185	702	871	111.25
Kirkwall & St Ola	1989	2550	2621	121.75
Orphir	855	826	864	77
St Andrews & Deerness	1650	1335	1517	209.5
Sandwick & Stromness	2677	3012	3193	357
South Isles				
Hoy & Graemsay	680	410	423	85.5
South Ronaldsay & Burray	1996	1954	1881	188.75
Walls & Flotta	1000	991	993	88

values are considered to provide a good indication of relative population density in Orkney for this period. Accordingly Figure 10:3 can be used as the basis for the comparison of population density with anthropogenic sedimentation distribution.

10:3:2 Mapping Seaweed Availability

Several studies of seaweed distribution in Orkney have been carried out over the last three or four decades, (Chapman, 1948; Walker, 1947; Jackson, 1958). There is considerable disagreement on the precise volume of the seaweed resources but general trends of distribution are apparent. The quantity of tang (rock weed) is closely related to the exposure of the coast. Sheltered inner coastlines, such as the inner part of Deer Sound may yield as much as 360 tons/mile of coastline. The weight of rock weed drops dramatically even with a moderate degree of exposure. On open coasts rock weeds are absent; there is little development of rock weeds on the western coasts of Mainland, Hoy, Westray, Rousay and Eday. Sunlight also influences seaweed amounts, with greater amounts found on coasts with a southerly aspect. Sandy coasts lack rock weeds because of the lack of anything for the weed to attach to. These observations are borne out by the littoral seaweed surveys of Orkney (Fig 10:4). Sublittoral seaweed, of which Laminarea hyperborea is the most abundant in Orkney, grow in waters up to ten fathoms in depth and occasionally at greater depths. Because the islands rise from a submarine platform (Flett, 1920), there are considerable areas of appropriate depth for sublittoral seaweed growth. Such areas are the North Ronaldsay Firth, Sanday Sound, Wide Firth and Scapa Flow, ie areas to the north and east of the islands. Off the west coast the submarine contours drop rapidly restricting the zone where sub-littoral seaweeds can develop (Fig10:4). It is possible to conclude therefore that sublittoral seaweed resources were, like the littoral resources, relatively abundant in the north and east while in short supply down the west coast of Orkney. This shortage is further accentuated by the inaccessibility of much of this coastline with extensive lengths of cliff greater than 15m (Mather et al, 1975). Coastlines to the north and east of the island group are more readily accessible. Orkney can thus be divided into two broad categories

Figure 10:4 The littoral seaweed resources and submarine contour pattern of Orkney.



in terms of seaweed resources (Fig10:5). There is a zone of seaweed abundance which includes the North Isles, the South Isles (with the exception of West Hoy) and much of East Mainland. The major zones of seaweed shortage are to be found in West Mainland and West Hoy. This is not to say that seaweed was unavailable for use in deep top soil formation within zones of seaweed shortage as the seaweed traces in the West Howe deep top soil indicate (Chapter 8). Furthermore there are records for example in Sandwick, within the seaweed shortage zone, of seaweed being subdivided amongst the different landholders (Fenton, 1978). The above discussion simply points out that certain areas of Orkney had access to greater abundances of seaweed than others.

A check on the validity of Figure 10:5 is possible by considering the amount of kelp production per head of population during the kelp-making years of the 18th and 19th Century. The production of kelp uses seaweed as its raw material and so if seaweed was limited in any area kelp production would be restricted. Thomson (1983) has produced a table of kelp production per head of population for the different parishes and islands of Orkney (Table10:3). This demonstrates the minor importance of kelp in West Mainland parishes (Fig10:6) which must be attributed in part to the lack of seaweed availability as outlined above. The northern isles with their abundant seaweed supply allowed for large kelp production figures. It is possible then to have reasonable confidence in Figure 10:5 when compared statistically with deep top soil and farm mound distribution. Also, given that environmental conditions have changed little over the past few millenia it is unlikely that the broad pattern of seaweed availability as presented in Figure10:5 will have altered over the period when deep top soils and farm mounds were forming.

10:3:3 Mapping Major Soil Groups

Fortunately the soils of Orkney have already been mapped by the Soil Survey for Scotland (1981). A map of the major soil groups in Orkney was derived from the published 1:50,000 soil maps(see Fig 2:6). Because of the stability of the Orcadian environment (See Chapter 2) this map is considered representative of soil conditions over the

Figure 10:5 Estimated seaweed availability in Orkney.

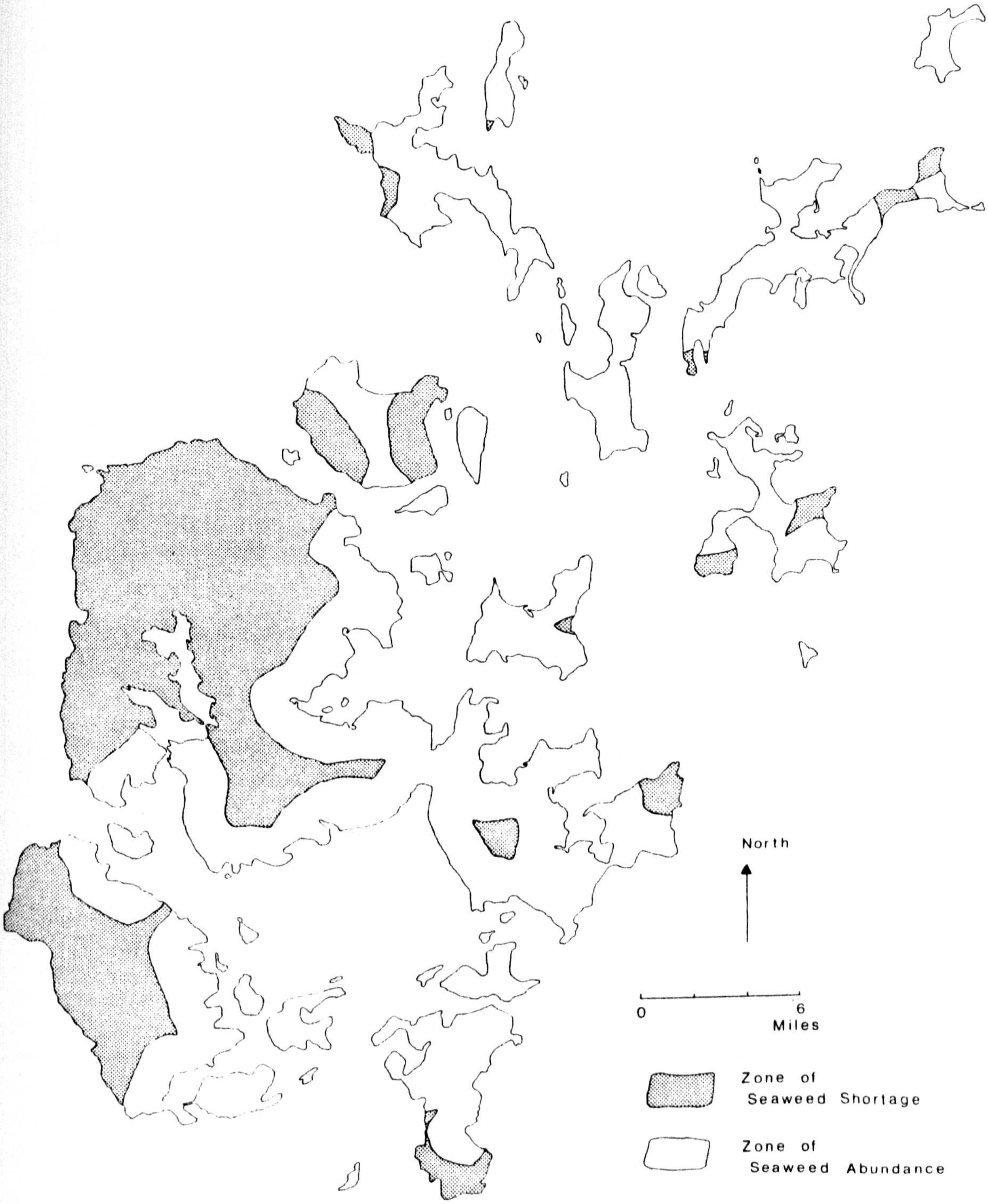


Figure 10:6 Intensity of kelp making (1790-1800). (after Thomson, 1983).

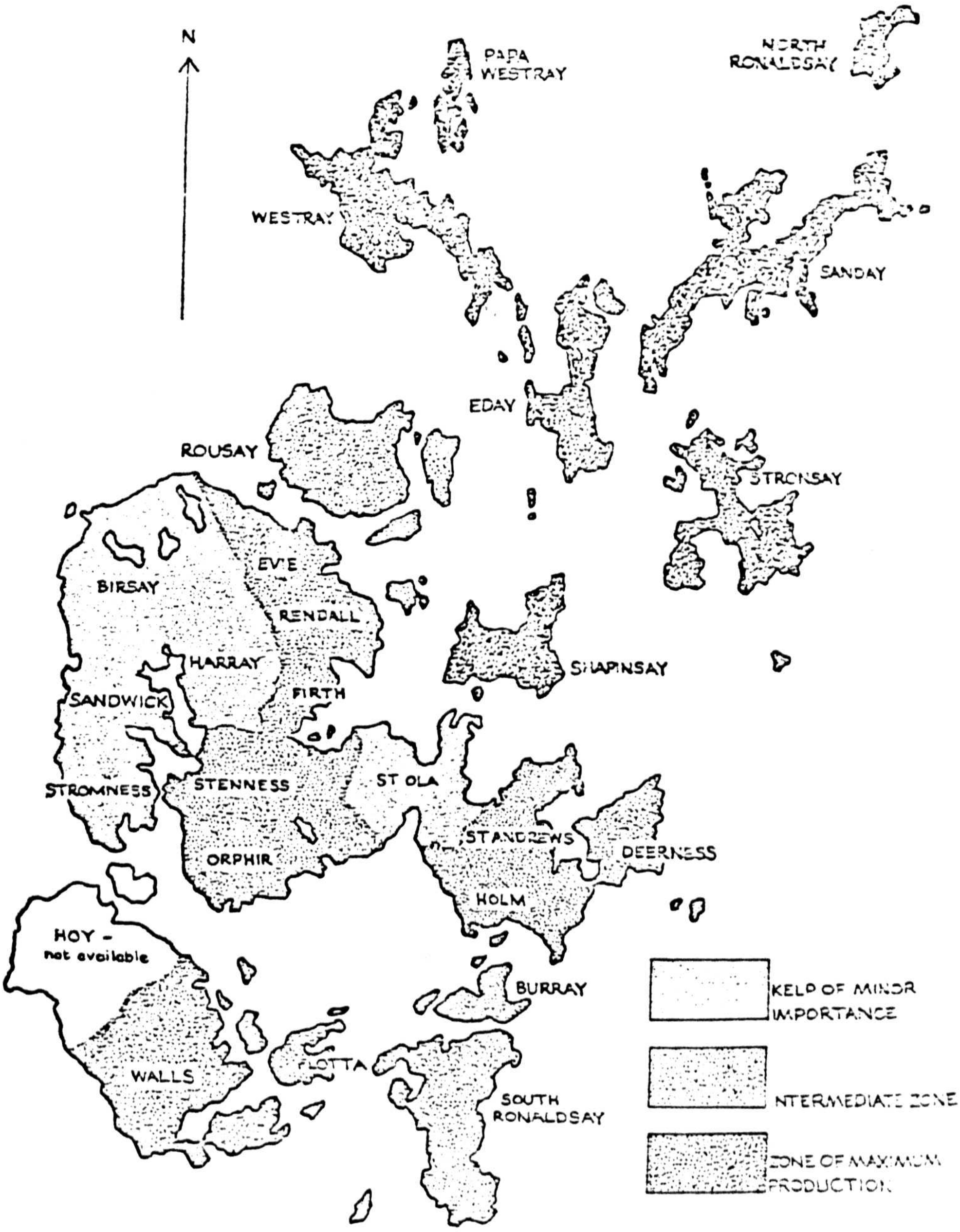


TABLE 10:3

INTENSITY OF KELP PRODUCTION, 1790-1800
(Tons per Head of Population per Year)

Papa Westray	0.35
Stronsay	0.34
Sanday	0.30
North Ronaldsay	0.24
Westray	0.20
Eday	0.17
Shapinsay	0.14
Walls & Flotta	0.09
St Andrews & Deerness	0.08
Firth & Stennes	0.07
Holm	0.07
South Ronaldsay & Burray	0.06
Orphir	0.06
Evie & Rendall	0.04
Rousay	0.04
Kirkwall & St Ola	0.02
Strømness	0.02
Birsay	0.01
Sandwick	0.01

(from Thomson, 1983)

period of deep top soil and farm mound evolution.

10:4 Factor Analysis of Population Density, Seaweed Availability and Soil Type in Relation to Anthropogenic Sedimentation

10:4:1 Methods

Comparison of anthropogenic sediment distribution with the spatial variability of the hypothesised controlling factors (Figs 10:3, 10:5 and 2:6) was based on the township areas. Deep top soils were considered as a percentage of the township areas while farm mounds were examined as a ratio of the mound size index (obtained from the slope diagrams of Chapter 3) to township area. This provided standardised values which could be subject to non-parametric statistical procedures. Population densities for the different townships were already calculated (Table 10:1) and these were sub-divided into the three categories of 0-6.0, 6.01-12.0 and 12.01 pennylands/acre x 10^2, a sufficient generalization for the task in hand. Seaweed availability, based on the categories of abundance and shortage, were assessed for each township area from Figure 10:5. The dominant major soil group in each township was identified from Figure 2:6 by point-counting. There were a total of 154 township areas in Orkney based on McKenzie's 1750 maps. Of this total full information was available for 143 and these formed the sample for analysis. Data for the township areas is tabulated in Table 10:4.

The statistical analysis was based on the factor analysis of Haggett (1964 et al, 1977). Ranking of deep top soil percentages and farm mound size indexes was carried out within the categories of the different factors. Where they were only two categories of a factor (ie seaweed availability), the Mann-Whitney U Test was used to identify differences between the deep top soil and farm mound occurrences in the two categories (Hammond and McCullagh, 1978). If more than two categories were involved in the analysis the non-parametric Kruskall-Wallis Analysis of Variance was used. Only an underlying continuous distribution is assumed by this test (Hammond and McCullagh, 1978). The results of the statistical analysis are presented in Tables 10:5 and 10:6.

TABLE10:4

DATA BASE FOR FACTOR ANALYSIS

Key: A = Abundance B = Blown sands
S = Shortage G = Gley soil
P = Podzol

Township Name (By Parish)	% deep top soil in farm land	Farm mound size/town-ship area ratio	Popul-:ation density (d/acre x 10^2) farmland	Seaweed availa-:bility	Dominant major soil group
North Ronaldsay					
Sailness & Sand	0	1.86	3.4	A	S
Linklet/Ness/Busta Sand Be-South	0	1.16	4.1	A	G
Sanday					
Artas	0	0	11.2	A	P
Brabustir	0	0	3.0	A	S
Brough	-	-	-	-	-
Cleat	0	9.35	12.0	A	P
Elsness	0	0	21.2	A	P
Tafts	0	25.6	90.0	A	S
How (Be-North)	0	33.1	81.2	A	S
Walls	0	0	14.4	A	S
Lopness	0	0.5	7.5	A	P
Stove + area	0	0	9.3	A	G
Langtas + Houstas	0	0	27.0	A	S
Voy	0	0	25.7	A	P
Sellibister	0	1.89	3.7	A	S
Hobister	0	6.56	24.0	A	P
Warsetter + area	0	0	16.7	A	S
Housegarth (How)	0	2.13	24.5	A	P
Noltland	0	2.32	7.8	A	S
Hellyhowe	0	0	22.5	A	S
Skelbrae	0	2.32	36.0	A	P
Stangasetter	0	0	60.0	A	S
Simbuster	0	0	30.0	A	P
Tresness	0	0	22.5	A	P
Sutherbie + Leyland	0	0	32.7	A	S
Colligar	0	0	4.5	A	P
Bressigar & Cleavisgarth	-	-	-	-	-

TABLE10:4 Cont'd

Township Name (By Parish)	% deep top soil in farm land	Farm mound size/township area ratio	Popul-:ation density (d/acre x 10^2) farmland	Seaweed availa-:bility	Dominant major soil group
Stronsay					
Evirby	0	0	1.8	S	G
Rothisholm	0	0	5.7	A	G
Strenzie + area	4.76	0	3.3	A	P
Aith, Howard + district	0	0	5.3	A	G
Papa Stronsay	0	0	8.6	A	G
Eday					
Skail + Backaland	0	0	3.4	A	G
Sealskerry + Carpaquoy	0	0	6.7	A	S
Ferness	0	0	2.0	A	G
Gusry	0	0	-	A	-
Carrick/Nupe	0	0	-	A	-
Faray	-	-	-	-	-
Westray					
Aikerness	0	0	5.4	A	P/S
Musland	0	0	1.4	A	G
Midby/Tuquoy + area	0	0	5.5	A	P/S
Noltland + area	0	0	5.8	A	G/S
Skelwick	0	0	0.5	A	G
Rapness	0	0	0.96	A	G
Papa Westray	0	0	13.3	A	P
Egilsay	0	0	5.8	A	P
Wyre	0	0	5.0	A	P/G
Gairsay	0	0	4.1	A	G
Rousay					
Trumland	0	0	2.5	A	P
Knarston/Sourin	0	0	5.6	S	P
Wasbuster	0	0	4.5	A	P
Westness, Frotoft, Hunclett	0	0	4.2	S	P

TABLE10:4 Cont'd

Township Name (By Parish)	% deep top soil in farm land	Farm mound size/township area ratio	Popul-:ation density (d/acre x 10^2) farmland	Seaweed availa-:bility	Dominant major soil group
Shapinsay					
Sands/Kirbuster/Sound	0	0	4.0	A	P
Waltness	0	0	3.6	A	G
Weland	0	0	1.4	A	G
Holland	0	0	3.3	A	P
Menis	0	0	1.9	A	P
Burrows	0	0	1.9	A	G
Birsay					
Marwick	41.67	0	6.0	S	P
Hundland	9.09	0	2.7	S	P
Swannay	0	0	1.5	S	G
Ingsay	10.00	0	4.2	S	P
Barony	14.93	0	11.1	S	S/P
Kirkbuster	0	0	3.0	S	P
Folsetter/Isbuster	4.35	0	5.2	S	P
Twatt	0	0	1.9	S	G
Beaquoy	0	0	1.6	S	P
Hillside + Durkadale	0	0	1.6	S	G
Birsay/Sandwick					
Greeny/Sabiston/Lealy/Skeabrae	12.57	0	3.3	S	P
Sandwick					
Tenston	28.57	0	8.6	S	P
Voy	17.39	0	2.6	S	P
Yesnaby	0	0	2.9	S	p
Lyking	0	0	5.4	S	P
Wasbistur	0	0	7.4	S	P
Northdyke/Southequoy	16.67	0	7.4	S	P/S
Stromness					
Whom	0	0	0.7	S	G
Redland/Kirkbuster	0	0	1.2	S	G/P
Mousland	0	0	1.4	A	P
Seatter	0	0	1.4	S	P
Cairston	0	0	2.0	A	G
Hamigar	0	0	1.0	A	P
Inner + outer town	0	0	10.3	A	G

TABLE 10:4 Cont'd

Township Name (By Parish)	% deep top soil in farm land	Farm mound size/township area ratio	Popul-:ation density (d/acre x 10^2) farmland	Seaweed availa-:bility	Dominant major soil group
Evie	2.79	0	4.5	S	P
Rendall					
Ellibister	0	0	4.5	S	G
Rendall/Gorseness/ Queenamuckle	0	0	3.8	A	P
Cottascarth	0	0	1.1	A	G
Hackland/ Isbuster	3.64	0	3.3	A	P
Harray					
Knarston	0	0	2.5	S	P
Grimeston	15.79	0	4.7	S	P
West Stennes Townships	12.41	0	3.9	S	P
Firth					
Seater/Wasdale	4.17	0	0.8	S	P
Hedal	0	0	2.5	A	P
Coastal Townships	0	0	2.6	A	G/P
Binscarth	0	0	2.2	A	P
Rennibister	-	-	-	-	-
Settiscarth	-	-	-	-	-
Stennes					
Bigswell	0	0	2.7	S	P
Stennes/Clouston	0	0	3.5	A	G
Ireland	0	0	5.0	A	G
Germiston	0	0	3 5	S	P
Ottergill	-	-	-	-	-
Anderswick	-	-	-	-	-
Dowscarth	-	-	-	-	-
Orphir					
Clestran/ Coubister	0	0	1.1	A	G
Swanbister	0	0	1.3	A	G
Orphir/Midland/ Houth	0	0	4.3	A	G
Groundwater	0	0	4.7	S	P
Hobbister	0	0	4.6	A	G
Kirbister	0	0	3.0	A	P
Tuskerbister	0	0	4.5	S	G
Naversdale	-	-	-	-	-

TABLE10:4 Cont'd

Township Name (By Parish)	% deep top soil in farm land	Farm mound size/township area ratio	Popul:ation density (d/acre x 10^2) farmland	Seaweed availa:bility	Dominant major soil group
St Ola					
Caldale	00	0	1.9	S	P
Crowness + area	0	0	3.5	A	G
Gratnip	0	0	5.0	A	G
Scapa + area	0	0	4.1	A	G
Papdale	0	0	3.9	A	G
Weyland	0	0	3.2	A	G
Wideford	0	0	2.8	A	G
Inganess Townships	0	0	3.3	A	G
St Andrews					
Deer Sound Townships	0	0	3.2	A	G
Stembister	0	0	2.1	A	G
Yenstay/ Essenquoy	0	0	2.2	A	G
Linksness	0	0	1.3	A	G
Tankerness	0	0	3.1	A	G
Holm					
Hunclett	0	0	4.3	S	P
Easterbister	0	0	1.8	A	P
Henbister	0	0	4.4	A	P
Westbister	0	0	2.5	A	P
Paplay/Aikerbister + area	0	0	6.2	A	P
Deerness	0	0	3.7	A	G
Burray					
Bu/South + North Town	0	0	2.9	A	G
South Ronaldsay					
Hoxa	0	0	2.1	A	P
Mid-east Coast Townships	0	0	2.9	A	G
Barswick	0	0	2.9	S	G
Southend	0	0	3.0	S	G
Burrowell/ Holland	0	0	2.6	A	G
Ronsvoe	0	0	2.3	A	G

TABLE10:4 Cont'd

Township Name (By Parish)	% deep top soil in farm land	Farm mound size/township area ratio	Popul-:ation density (d/acre x 10^2) farmland	Seaweed availa-:bility	Dominant major soil group
South Ronaldsay Cont'd					
Herston	0	0	2.0	A	P
Grimness	0	0	1.3	A	G
Sandwick	0	0	2.8	A	G
Widewall	0	0	3.4	A	P
Graesay					
Corrigal/ Suthergarth	0	0	6.8	A	P
Outerile/ Sandisend	0	0	5.3	A	G
Fara	0	0	2.3	A	P
Flotta	0	0	2.25	A	G
Hoy					
Rackwick	0	0	2.0	S	P
North West Coast Townships	0	0	4.9	A	G
Walls					
Rysa	0	0	0.2	A	G
Aith	0	0	5.6	A	G
Brims/Manclett Millsetter	0	0	1.2	A	P
Fea/Kirbister/ Walds	0	0	4.0	A	G
Thurvo	0	0	1.9	A	G
Osmundwall	0	0	4.4	A	G
Seater	0	0	2.0	A	P/G

TABLE 10:5

RESULTS OF FACTOR ANALYSIS ON SUSPECTED DEEP TOP SOIL CONSTRAINTS

Significance Level = 95%

Main Effects

Population density	H = 1.771(df=2)	Not significant	
Soil Type	H = 24.436(df=3)	Significant	p = >0.001
Seaweed availability	z = 1.5	Not significant	

Interactions

Population density/ soil type	H = 8.828	Not significant	
Population density/ seaweed availability	H = 23.037(df=5)	Significant	p = >0.001
Soil type/seaweed availability	H = 19.362(df=6)	Significant	p = >0.01
Population density/ soil type/ seaweed availability	--	--	

10:4:2 Results and Discussion : Deep Top Soils

Of the three single factors under consideration (viz population density, seaweed availability and soil type) only one, soil type, demonstrates any degree of constraint on deep top soil distribution. Deep top soil distribution is confined, as already pointed out, to the podzol soil group. Despite other early townships in Orkney having a dominance of podzol soils within their confines, deep top soils are suffiently concentrated on this soil group to yield this result. The general hypothesis that deep top soils are to be found in townships with soils of poorer inherent fertility is upheld and, furthermore, this sets limits on deep top soil distribution. Deep top soils can therefore be considered as a fairly general response by arable farmers, from the Norse to the late Medieval period, to maintain good soil fertility levels in townships where inherent soil fertility was relatively poor, notably West Mainland.

Of themselves, population density and seaweed availability do not exert any constraining influence on deep top soil distribution when Orkney is considered as a whole. Thus it is necessary to reject the hypothesis that in general where population density is high, meaning a greater potential for plaggen manure generation and more potential energy to move that material, deep top soils will most likely be found. Likewise the hypothesis that in areas of seaweed shortage, the alternative soil fertiliser being seaweed, deep top soils are more likely to be found must also be rejected. However when these two factors are combined and statistically analysed by the Kruskall-Wallis Analysis of Variance, they demonstrate an exceptionally good control on deep top soil occurrence ($p= > 0.001$). This suggests the relationship that in those areas where seaweed is in short supply, if population density is relatively high, then deep top soils will be found. This relationship is further explored in Figure10:7. Here it is evident that by far the major proportion of deep top soils occur within zones of seaweed shortage, although as stated above, this is not sufficient to be a significant constraint on deep top soil occurrence on its own. Furthermore, Figure10:7 shows that there are no

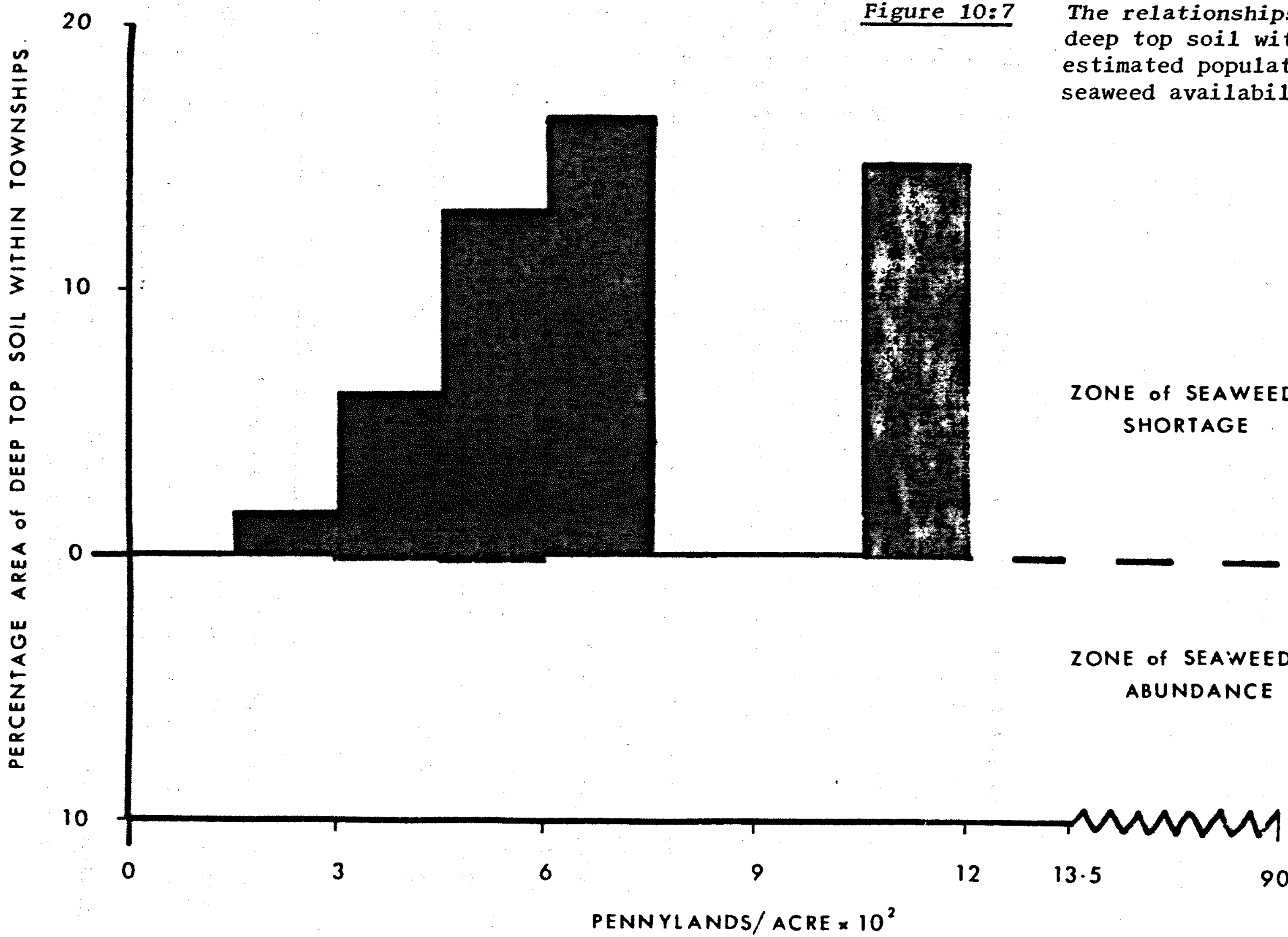


Figure 10:7 *The relationships between area of deep top soil within Townships, estimated population density and seaweed availability.*

townships in the seaweed shortage zone with a population density index value greater than 12.00 pennylands/acre x10^2. The population density range is therefore restricted within the zone of seaweed shortage and within this restricted range it is evident that as population density increases the area of deep top soils increases. An r_s value of +0.943 (significant at the p = 0.01 level) testifies to the reality of this positive correlation. It can thus be concluded that a shortage of seaweed promotes deep top soil formation partly by defining the area of Orkney within which the degree of deep top soil occurrence is directly related to population density.

Soil type and seaweed availability together combine to yield a significant relationship to deep top soil intensity of occurrence ($p = > 0.01$). It has already been established that soil type, the podzols, exert a dominant influence on whether deep top soils are featured on the landscape or not. Although the probability value is lowered when soil type is considered together with seaweed availability the H result is still suggestive of the lack of seaweed being a constraining factor on deep top soil formation. Townships that have deep top soils are those that lack seaweed resources and are, in general, also townships with soils of poorer inherent soil fertility, the podzols. It is possible to conclude from the above discussion that deep top soils are confined to early townships of poorer inherent soil fertility generally lacking seaweed to maintain or increase soil fertility under arable activity. Within these townships the percentage of farm land which is deep top soil increases as population density increases.

10:5:2 <u>Results and Discussion : Farm Mounds</u>

The spatial constraints on farm mound formation are, compared with the deep top soils, more straightforward. Major constraining factors are population density and seaweed availability. Soil type within the townships plays little or no part in constraining farm mound formation either as a factor within its own right or in combination with other factors (Table 10:6). However χ^2 analysis of the farm

TABLE10:6

RESULTS OF FACTOR ANALYSIS ON SUSPECTED FARM MOUND CONSTRAINTS

Significance Level : 95%

Main Effects

Population density	H = 6.159(df=2)	Significant	p = >0.05
Soil type	H = 5.843(df=3)	Not significant	
Seaweed availability	z = 5.89	Significant	p = 0.000

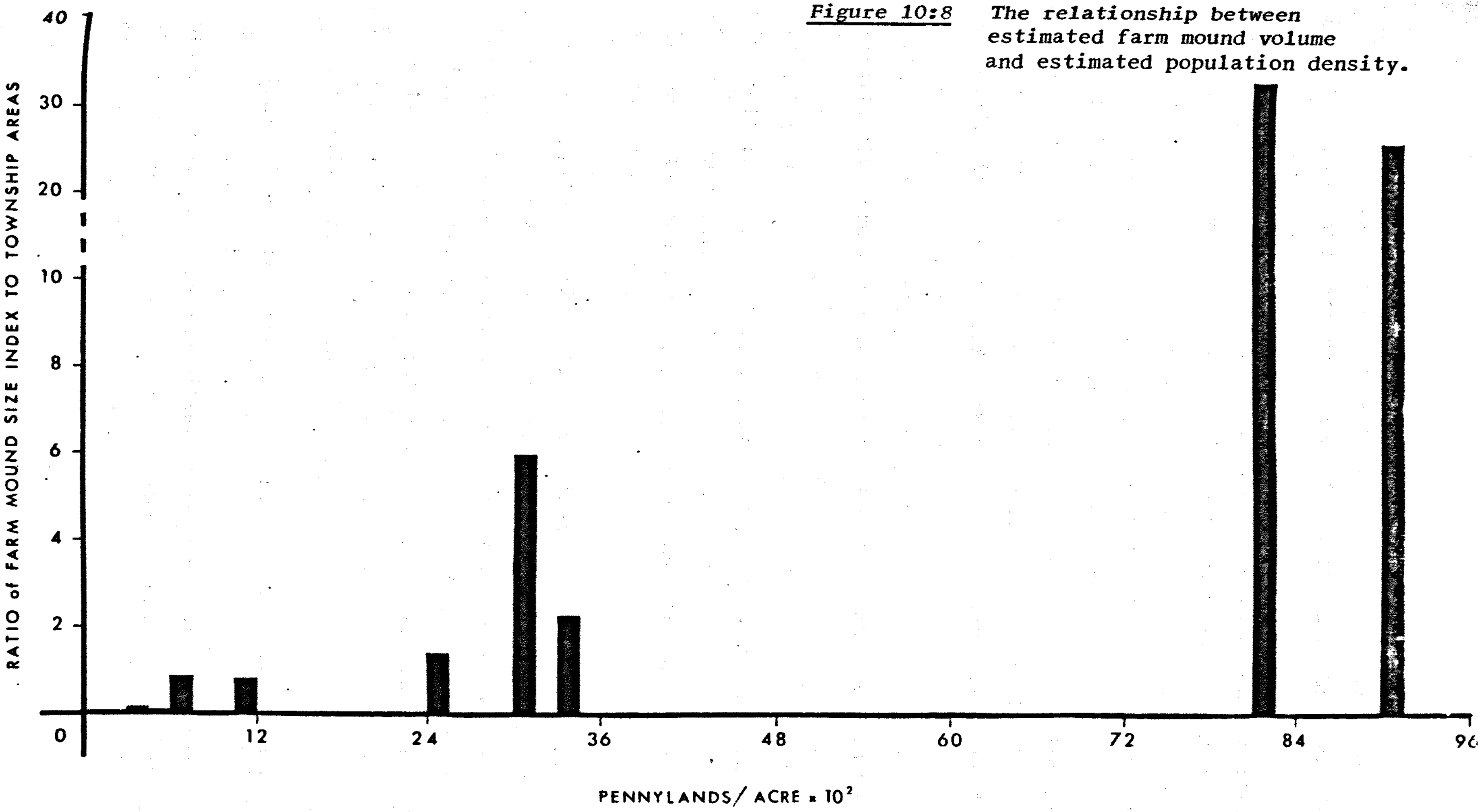
Interactions

Population density/ soil type	H = 11.755(df=7)	Not significant
Population density/ seaweed availability	H = 6.931(df=4)	Not significant
Soil type/seaweed availability	H = 6.954(df=6)	Not significant
Population density/ soil type/seaweed availability	--	--

mounds in relation to the soils upon which they actually stand on Sanday and North Ronaldsay yielded a highly significant (p = 0.01) value of 10.04. In this case it is possible to reject the null hypothesis that there is no significant relationship between farm mounds and soil type. At this local level farm mounds are concentrated on sandy soils, with only one farm mound found on gley or poorly drained soils. It seems most unlikely therefore that mounds were deliberately constructed as a living platform to alleviate poor drainage. They may however have been deliberately constructed to create a gradient thus counteracting sand blow. What seems more likely though is that the mound dwellers tended to populate areas of calcareous sand because of their good fertility and easily tilled nature.

Because soil type appears not to influence farm mound formation when the entire region of Orkney is taken into consideration, other factors must define the occurrence of farm mounds on Sanday and North Ronaldsay. One such factor is population density (Table 10:6). In general farm mound size within a township increases with population density (Fig 10:8). Rs ignoring gaps, is 0.933, significant to the 99% level. It seems reasonably straightforward that this is the result of the increased capacity of the populations associated with the mounds to generate settlement waste materials. There are though major gaps in the distribution as illustrated by Figure 10:8. This could be in part due to the removal of materials from the vicinity of the settlement by the populace. Conceivably waste materials may well have been dumped on the shore to be removed by the tide and Fenton (1978) quotes evidence of this happening on Sanday. The major reason why waste material generated by the settlement was not applied to the arable land was probably because of the abundance of seaweed available on Sanday and North Ronaldsay. Seaweed would be used to maintain soil fertility rather than animal manures or house wastes and the results of examining seaweed availability in relation to farm mound distribution does give a statistical result which supports this hypothesis. Farm mounds are found in zones of ample supply of seaweed (Table 10:6). From the above discussion it is possible to conclude that the two major constraints on farm mound formation is population density, possibly because of the high fertility of the islands, and seaweed availability.

<u>Figure 10:8</u> *The relationship between estimated farm mound volume and estimated population density.*



To conclude this chapter it is of interest to compare the two anthropogenic sedimentary systems to be found in Orkney. Both are constrained by population density although in different ways. Farm mounds are more directly related to population density, increasing in size per townsland area as population density is increasing. The deep top soils are also found to increase in area as population density increases but only within those townships that lack seaweed to sustain soil fertility. Both sedimentary systems are controlled by the availability of seaweed but again in different ways. Farm mounds are found where there is abundant seaweed. It is suggested that this meant there was no need to apply settlement waste to the arable land. When considered together with population density, seaweed availability is demonstrated to dictate the occurrence of deep top soils. Dominantly in those townships with a population density index of between 7.5 and 12.0 pennylands/acre x 10^2, the lack of available seaweed results in deep top soil formation. This is, it is suggested, because an alternative means of sustaining soil fertility was required in the absence of seaweed. Plaggen manure, resulting in deep top soil formation, was that alternative.

Soil type plays little role in constraining farm mound formation although detailed analysis of Sanday and North Ronaldsay confirms that the mounds as a group were unlikely to be raised to alleviate poor drainage. In contrast deep top soils are found in townships with podzolic soils, soils of poorer inherent fertility. Thus, where there was less seaweed, plaggen manure was essential to maintain soil fertility in these townships.

One final observation that must be made is that although the factors involved in constraining the two sedimentary systems are often the same, it is the different combinations and levels of these factors that result in the two expressions of anthropogenic sedimentation evident in Orkney.

CHAPTER 11

SUMMARY: THE FORMATION OF DEEP TOP SOILS AND FARM MOUNDS IN ORKNEY

11:1 Introduction

From the outset it was quite obvious that deep top soils and farm mounds in Orkney are two quite separate landscape features. Their differences were sufficient to warrant two distinct investigations. Thus although similar methodologies and techniques could be applied to both the deep top soils and farm mounds, they are considered separately in this work. Separation of the two features under investigation is maintained in this chapter.

11:1:1 The Formation of Deep Top Soils in Orkney

The identification of distinctive field and laboratory derived properties demonstrates that the deep top soils have formed dominantly as a result of anthropogenic sedimentary processes. That is man has by his own efforts transported sedimentary material, both inorganic and organic, from one part of the landscape and deposited it in another thus forming an anthropogenic sediment. Under the natural pedogenic and/or sedimentary regime found in Orkney soils, the podzolic Bilbster Series would normally be found in areas of deep top soil. Thus it is valid to compare Bilbster Series soils and deep top soils in the effort to identify any differences between the two soil types. Such a comparison revealed that deep top soils have a thickened top soil around farmsteads, a heavier texture, greater exchangeable magnesium levels and greater total phosphate levels relative to the Bilbster Series. Each of these properties is indicative of anthropogenic sedimentation in the Orcadian context, suggesting deposition of an abnormal inorganic material which had been heavily amended with organic materials. Other differences between the deep top soils and soils of the Bilbster Series are found in exchangeable calcium and loss on ignition values. Both these properties have lower values in deep top soils suggesting that areas of deep top soil have been more intensively cultivated than soils of the Bilbster Series. Thus it would appear that the reason for deposition of anthropogenic sediments is to aid an intensive form of cultivation. Deep top soils can therefore be classified as plaggen soils and are closest in character to the classic Dutch brown plaggen soils.

Despite the potential for plaggen manuring (and therefore for deep top soil formation) being present in Orkney since the early Norse period (commencing AD800), it was not until the late 12th or early 13th Centuries that deep top soil formation in Orkney commenced. Two theories for deep top soil initiation are presented as it is not presently possible to refute one or the other. One theory is that the introduction of plaggen manuring to Orkney was a spontaneous innovation by the local populace. This theory is particularly attractive in view of the long arable tradition in Orkney extending back to the Neolithic. A second theory is that plaggen manuring techniques were introduced with 12th Century monastic settlements in Orkney. Elsewhere in Scotland deep top soils have been found associated with monastic settlements. Whichever theory is correct for the deep top soils of Orkney (indeed both may ultimately be proved correct) the technique of plaggen manuring would have been quickly adopted by the late Norse inhabitants of Orkney. This is in view of the increasing population density and the optimisation of agricultural resources that occurred at the same time as deep top soil initiation. Cessation of deep top soil formation is considered to have been in the late 19th Century. This coincides with the introduction to Orkney of more convenient chemical forms of fertilizing arable land. Consequently the need for plaggen manure ceased and so therefore did deep top soil formation.

The process of deep top soil formation is considered to be controlled by the interaction of land use in areas of deep top soil and the selection, transportation and deposition of sedimentary materials that allow, sustain or enhance that land use. Deep top soil formation processes can therefore be thought of in terms of a simple gravity model. Land use associated with deep top soils has already been identified as arable but more detailed analysis of one deep top soil unit, at West Howe in Marwick, developed this theme further. The deep top soil at West Howe can be defined as the Tunmal arable land within the early Township. That is, this portion of the landscape was the most intensively cultivated throughout the late Norse and Medieval period and was owned in a permanent or semi-permanent way. This land was quite distinct from the Townsland and Backs arable land which were less intensively cultivated. Within the deep top soil (or Tunmal) there was some degree of variation in arable intensity. Generally as the deep top soil formed with time and as proximity to the farmstead became closer,arable intensity became greater. There are however slight variations within this general trend notably in the upper portion of this deep top soil. Between c15 and 25cm depth throughout the deep top soil a decline in arable activity relative to the general trend is observed. Above this zone in the most recent portion of the deep top soil arable activity is greater in comparison with the general trend.

The subtle differences in arable activity within the Tunmal did not influence the types of material used in deep top soil formation. However the more general early arable intensity trends within the Tunmal did have this influence. Closest to the farm steading where arable activity was always the most intense, turf material came from portions of the hill land that had not previously been cut over. What influence this had on soil fertility levels is not clear. All available manure material during the early stages of the deep top soil formation was applied to this part of the Tunmal closest to the farmstead, an action that would contribute to enhanced soil fertility levels. Manure was not however always available in the early stzges of formation and under these circumstances turf material on its own was deposited. Further away from the farmstead where arable intensity was less, turf material from previously cut over areas was used together with

with a little seaweed during the early stages of deep top soil formation. In later stages manure became more plentiful. It was used together with turf material, both materials having been mixed in the byre where the turf acted as bedding. This mixed material was then used to sustain or enhance soil fertility levels across the whole Tunmal, coinciding as it did with increased levels of arable intensity. If it is accepted that the general process of deep top soil formation outlined in the paragraphs above can be applied to other deep top soils in Orkney,then examination of their distribution makes it clear that this process only operates in certain parts of the landscape. Spatial constraints operating upon deep top soil formation are proposed as being the interacting of inherent soil type, population density and seaweed availability. Deep top soils are found only upon soils of poorer inherent soil fertility which in Orkney are the podzolic soils. This factor is dominant in dictating deep top soil distribution in Orkney, reflecting the need for the early Orcadians to fertilize this land to enable, maintain or enhance the cultivation of food crops. The other two spatial factors, population density and seaweed availability, interact to dictate deep top soil distribution. In those areas where seaweed was in short supply and population density was comparatively high, deep top soils are in evidence. This observation indicates that the plaggen manuring technique was used as an alternative land fertilizer to seaweed. However within the areas of seaweed shortage in Orkney it was only where population density was high that deep top soils are to be found. A high population density was needed to generate plaggen manure and to provide the energy to shift that material to the arable land.

11:1:2 The Formation of Farm Mounds in Orkney

The anthropogenic origins of farm mounds in Orkney have been known at least since the observations of Grant in 1843. Slope morphology and the stratigraphic properties of the farm mounds confirm their anthropogenic sedimentary status associated with habitation activity. Such characteristics also serve to emphasise the diverse nature of the farm mounds.

No single point in time can be assigned to the commencement of farm mound formation in Orkney. Instead individual mounds commenced formation over anything up to a thousand year period. The later Iron Age is the earliest likely date of farm mound formation commencement, while the latest most likely commencement date is in the late Norse period, c AD1300s. Norse colonization of Orkney began c AD800 is considered as giving the major impetus towards farm mound formation. With the preference of Norse settlers to construct their settlements on existing or recently abandoned habitation sites a mound would evolve whose basal layers would be dated to the late Iron Age, or indeed earlier. Immigration of Norse settlers to Orkney and particularly Sanday and North Ronaldsay was possibly of greater volume than could have been accommodated by available pre-existing settlement sites. Consequently new settlement sites were required and in some cases land was reclaimed for this purpose. These new settlement sites on Sanday and North Ronaldsay are represented by the later farm mounds. Some came into being with the initial phase of Norse settlement, others for example at Langskail, are associated with the increasing population density of the late Norse period. The time period and causes of farm mound formation cessation cannot on the basis of the available data be discerned. For the moment it is tentatively suggested that the cessation of farm mound formation was around the end of the 15th Century. Reasons for cessation are quite uncertain.

To examine the processes of farm mound formation on Orkney two farm mounds were selected for detailed analysis, Westbrough and Skelbrae, both on Sanday. These two farm mounds exhibit similar formation processes but it should be emphasised that the following conclusions are based only on one profile from each farm mound. The lower portion of these mounds forms the core of a raised living platform. This core material is composed dominantly of a turf/manure mixture. In all probability this material came from the farmstead byre with turf having first been used as animal bedding. Such a use for the byre waste material was also useful as a means of waste disposal. At Westbrough the byre waste materials deposited as the mound core were placed almost simultaneously in an area of waterlogged soils and form a thickness of at least 75cm, probably considerably thicker. Clearly the deposition of midden material permitted some useful purpose for an area which could not otherwise be utilised. Thus this site is analagous to the terpen or wurt sites of north west Europe. Reasons for the deposition of byre waste material to form the core of the Skelbrae farm mound are less clear. Underlying the Skelbrae farm mound are soils of the Bilbster Series, soils which have no serious waterlogging problem and indeed prior to the deposition of mound material were probably cultivated. Perhaps the reason was the desire of the Norse colonizers to live on slightly elevated sites and if no such conditions were provided naturally or by building on top of earlier settlements then raised sites were constructed. This however is purely conjecture.

Whatever the precise reasons for deposition of a core material at both these farm mounds this core was "capped" with 30cm of turf material at Skelbrae and a highly organic peaty material c40cm thick at Westbrough. The capping provided a suitable surface for habitation activities. Activities upon this new surface at Skelbrae cannot be ascertained with any certainty on the basis of the available data. At Westbrough however there are good grounds for suggesting gardening activity upon the raised surface with seaweed deposited to aid soil fertility levels.

At some undetermined point in time and for as yet unknown reason the raised surfaces at both Westbrough and Skelbrae fell into disuse. The latter phase of farm mound formation processes at both these sites saw their use as middens serving gradually diminishing populations. Here the wastes of the Toft were deposited, wastes which were dominantly ash material from the hearth. The nature of the fuel material prior to its combustion in the hearth was turf and manure with a little seaweed. These are the sorts of materials expected to be used as a fuel source in Sanday because of the absence of peat on this island. The thickness of this ash material is some 120cm at Skelbrae and 110cm at Westbrough. Finally, at Westbrough excavation material from the construction of a new cattle court was recently deposited upon this farm mound thus contributing to its formation.

Farm mound formation processes were generally restricted to certain parts of the Orcadian landscape, notably Sanday and North Ronaldsay. Two spatial constraints control this distribution pattern, population density and seaweed availability. In areas of high population density it may be argued that there was a greater need to reclaim land for habitation purposes. Furthermore there would also be a greater potential for generating large quantities of Toft waste materials that were involved in the formation of farm mounds. Thus farm mounds in Orkney are found in areas of the highest early population density. Seaweed availability also exerts a control on the occurrence of farm mounds. Generally where there was an abundant seaweed supply farm mounds were more likely to be found. This was most likely because seaweed was prefered in sustaining arable land fertility to Toft waste materials such as manure. Thus the Toft wastes generated by a relatively large population at a farmstead might be expected to accumulate at the habitation site thus contributing to farm mound formation.

The above summary statement on farm mound formation in Orkney represents only a first approximation. Nevertheless the beginnings of a farm mound temporal categorization is beginning to emerge as is a pattern of formation process. The detail of these emerging characteristics can only be resolved by further careful research.

The above statements only represent the first approximation of deep top soil and farm mound formation in Orkney. Future study of these features may proceed in two directions. Further refining and testing of the analytical methods and conceptual model resolution limits as presented by the thesis should be the first direction. This would provide evaluation and development of the conclusions on deep top soil and farm mound formation so far reached. Such possible refinements were elaborated upon as the thesis developed. A second direction for future research comes with the recognition that deep top soils and farm mound formation represents an attempt by Norse and Medieval Orcadians to 'develop' and order the landscape. The relative benefits and costs of these arable and habitation practices within the context of Norse and Medieval society are questions of some importance to the elucidation of Orkney's social history. It is hoped that this thesis may provide the groundwork for such study. The above sentences have drawn attention to ways in which study of Orcadian anthropogenic sediments could develop. It is worth noting in conclusion that the point so far reached in our understanding of deep top soils and farm mounds in Orkney is not without considerable significance. Norse and Medieval Orcadians are clearly of major importance in the recent sedimentary history of Orkney, creating two quite distinctive land forms as a response to fulfill certain arable and habitation requirements.

LABORATORY ANALYTICAL METHODS USED IN CHAPTER 3

1. Determination of Percentage Sand, Silt and Clay (<2mm Fraction)

Pre-Treatment - Removal of Organic Material 25g of sub sampled soil was accurately weighed on a digital balance and placed in a 600ml tall form beaker with a glass stirring rod. 50ml of 30 volume H_2O_2 was added to this beaker, stirred and allowed to stand for one hour. A further 50ml of H_2O_2 was added to the beaker containing the sample and heated gently on a hot plate. This produces a frothing reaction between the H_2O_2 and organic material in the sample. As the reaction proceeded further aliquots of H_2O_2 were added by washing down the sides of the beaker. Once the reaction ceased the H_2O_2 is diluted down by adding deionised H_2O and the H_2O_2 evaporated off until the bubbles associated with H_2O_2 boiling are no longer evident. Evaporation of H_2O continued until approximately 50ml of liquid remained in the beaker. This is left to cool and then the contents quantitatively transferred to a glass shaking bottle.

Dispersal of Sample 50ml of Calgon (Sodium Hexametaphosphate) solution is added to the glass shaking bottle containing the sample and the contents of this bottle shaken for eight hours on a mechanical shaker. The suspension is then quantitatively transferred to a 500ml glass measuring cylinder.

Determination of Sand, Silt and Clay The 500ml measuring cylinder is made up to the mark with deionised water, the temperature of the liquid taken and the time of settling for international standard silt and clay sizes required at a depth of 10cm obtained from the tables in Smith and Atkinson (1975). The cylinder is stoppered and shaken end over end for one minute ensuring that all sediment is re-suspended. The cylinder is stood on the laboratory bench and the Andreason pippette inserted to the sample thirty seconds before sampling at the appropriate time. 9.8127ml is sucked smoothly from the suspension and released into a 50ml beaker previously oven dried and weighed. The aliquot is evaporated to dryness in an oven at 105°C, cooled in a desiccator, weighed, and percentages of silt and clay calculated on an oven dry basis. To determine the amount of sand the supernatent liquid is decanted and discarded and the sediment washed into a tall form 600ml glass beaker. A mark is made 10cm from the bottom of the beaker and the beaker is filled to the mark with deionised water. The suspension is stirred and allowed to stand for the appropriate time according to temperature for the sand to settle out. The turbid supernatent is poured off, care being taken not to disturb the sand sediment. The process is repeated until the liquid poured off is clear at the appropriate time interval. The sand residue is transferred to an evaporating dish and dried at 105°C, weighed and its percentage of the sample calculated.

2. Determination of Percentage Loss on Ignition

A clean dry crucible is weighed and the weight recorded. A sub sample of $<$ 2mm soil is placed in the crucible and the crucible again weighed. The crucible is placed in an oven at 105°C overnight, after which it is removed from the oven and allowed to cool in a desiccator and weighed. The crucible is then placed in a furnace at 425°C overnight, then allowed to cool in a desiccator and weighed. Calculation of the Loss on Ignition percentage can then be made.

3. Determination of Soil pH (H_2O)

The pH meter is switched on one hour before the commencement of measurement. It is then calibrated with standard solutions of pH 4.0, 7.0 and 9.0. 25 - 30ml of sub sampled $<$ 2mm soil is placed in a clean 50ml glass beaker. Enough deionised water is added to the beaker to form a thin paste when stirred with a glass rod. Thus the sample is at saturation. The sample is then allowed to stand for one hour after which pH determinations are made with the calibrated pH meter. Repeat measurements are always made for each sample.

4. Determination of Exchangeable Bases (Na, K, Mg, Ca)

5g of air dried, < 2mm sub sampled soil is shaken with 100ml N. Ammonium acetate solution for 15 minutes in a screw capped bottle. The liquid suspension is then centrifuged for 10 minutes at 2,500 rpm. The supernatent is filtered with Whatman's No 1 filter paper to ensure a completely clear liquid for input to the Atomic Absorption Spectrophotometer (AAS). A calibration curve is plotted for AAS machine readings against ppm standard of a particular element from which amounts of Na, K, Mg and Ca in samples can be determined. Results are expressed in meq/100g on an oven dry basis. (N.Ammonium acetate solution is 50ml ammonia and 57.5ml acetic acid made up to 1 litre with deionised water and neutralized to pH7).

5. Total Phosphate Analysis

Extraction of total phosphate from soil samples was achieved by Na_2CO_3 fusion (Jackson, 1958). A sub sample of the soil was ground to 180um. 4g of Na_2CO_3 was weighed and c 1g of this placed in a platinum crucible. 0.5g of 180um soil was placed in the crucible and mixed with a further c 2g $Na\ CO_3$. The remaining 1g of Na_2CO_3 covered the mixture. The crucible was heated over a bunsen burner (propane gas) to drive off excess moisture, the lid placed on the crucible, the mass gently fused and then heated at full blast for ten minutes. After this period the crucible was removed from the heat and rotated using platinum tipped tongs so that the melt was deposited in a thin layer on the side of the crucible. This was then left to cool. Once cool the crucible was placed in a 400ml beaker (rendered phosphate free by soaking in concentrated H_2SO_4) with c 125ml deionised water and digested on a hot plate for two hours. The melt was then removed from the crucible using a rubber tipped glass rod and deionised water. Crucible and lid were then placed in boiling 6N HCl to clean them while the sample digested for a further thirty minutes whereafter it was cooled and washed into a 250ml volumetric flask and made up to the mark. The suspension was then filtered through No 41 ashless filter paper (Whatmans) into a clean polythene bottle. Colorometric determination was carried out against a blank determination using a WPA S107 spectrophotometer at 640nm by the Ammonium molybdate/ Stannous chloride procedure. The amount of phosphate in solution was calculated from a calibrated curve and expressed in terms of $mgP_2O_5/100g$.

GRID REFERENCES OF ORCADIAN SOIL PROFILES EXAMINED IN DIFFERENT SEDIMENT PARENT MATERIALS BY THE SOIL SURVEY FOR SCOTLAND

Parent Material	Soil Series	Grid Reference
Glacial Drift	Bilbster	HY 254 259
		HY 303 201
		HY 415 131
		HY 416 133
		HY 420 098
		HY 437 098
		HY 325 187
		HY 389 159
		HY 370 172
		HY 400 195
		HY 348 058
		HY 527 008
		HY 468 108
		HY 254 257
		HY 339 168
		HY 471 096
		HY 387 186
		HY 485 013
		HY 332 169
		HY 408 109
Glacial Drift	Bilbster Complex	HY 475 031
		HY 405 221
		HY 507 062
		HY 496 201
		HY 519 003
		HY 427 098
		HY 471 028
		HY 332 133
		HY 472 027
Calcareous Blown Sand	Fraserburgh	ND 487 976
		HY 552 034
Calcareous Blown Sand	Whitelinks	HY 552 034
		ND 487 975
		HY 590 070
Alluvium	-	HY 310 058
		HY 303 053
		HY 248 205
Fluvioglacial Sands	Boyndie	HY 247 093
	Rackwick	HY 228 004
Colluvium	-	HY 496 021
		HY 519 002
		HY 508 061

PROFILE DESCRIPTION AND LABORATORY DATA OF DEEP TOP SOILS IN ORKNEY

SITE INFORMATION

Soil Type:
Bilbster Series Deep Top Soil.

Locality:
Netherskail

Grid Ref:
HY 234246

Observer:
Ian A Simpson

Date:
31/3/82

Rock Outcrops:
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Relief:

Local:	Valley side-midslope
Micro:	Flat
Slope$^{(o)}$:	2-3^{o}
Aspect:	230^{o}
Slope Form:	Straight
Altitude:	20m

Land Use & Vegetation:
Permanent or long term grassland.

Soil Surface:
Flat.

FIELD DESCRIPTION

Horizon	Depth (cm)	
S1	0-21	Very dark greyish brown (10YR 3/2), silty clay loam, no mottles, moderate organic matter, few fine black (10YR 2.5/1) charcoal flecks, few very small subangular stones, strongly developed medium granular peds, very fine frequent roots, clear smooth boundary to
S2	21-73	Dark brown (10YR 3/3) silty clay loam, no mottles, moderate organic matter, few fine black (10YR 2 5/1) charcoal flecks, few medium angular stones, strongly developed medium granular peds, very fine frequent roots, abrupt smooth boundary to
B2	73-92+	Yellowish brown (10YR 5/6) loam, no mottles, no organic matter, large frequent subangular stones, moderately developed fine subangular blocky peds, no roots.

LABORATORY DATA

Horizon Depth (m)	S1 0.2	S2 0.4	S2 0.6	B2 0.8
Loss on ignition	6.6	5.1	5.1	2.0
% sand	40.5	43.4	37.5	42.2
% silt	30.5	32.1	38.7	35.5
% clay	29.0	24.5	23.8	22.3
Ca (exchangeable me/100g)	5.96	4.43	4.27	1.65
Mg (exchangeable me/100g)	1.81	1.58	1.99	1.73
Na (exchangeable me/100g)	0.28	0.36	0.35	0.27
K (exchangeable me/100g)	0.2	0.19	0.1	0.06
pH (H_2O)	5.99	6.05	6.0	5.89
Phosphorous (total mg P_2O_5/100g)	1116	747	841	359

SITE INFORMATION

Soil Type:
Bilbster Series Deep Top Soil.

Locality:
Muce

Grid Ref:
HY 241236

Observer:
Ian A Simpson

Date:
1/4/82

Rock Outcrops:
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Relief:

Local:	Midslope
Micro:	Flat
Slope (o):	2-3°
Aspect:	310°
Slope Form:	Straight
Altitude:	25m

Land Use & Vegetation:
Long term grassland.

Soil Surface:
Flat.

FIELD DESCRIPTION

Horizon	Depth (cm)	
S1	0-21	Dark brown (10YR 3/3) silty clay loam, no mottles, moderate organic matter, few small angular stones, strongly developed medium granular peds, very fine, frequent roots, clear smooth boundary to
S2	21-63	Very dark greyish brown (10YR 3/2) silty clay loam, no mottles, moderate organic matter, few small angular stones, strongly developed medium granular peds, very fine, frequent roots, abrupt smooth boundary to
B2g	63-76	Brown (10YR 4/3) loamy sand, few fine distinct mottles (10YR 6/2), no organic matter, many very small subangular stones, moderately well developed medium angular blockly peds, no roots, sharp smooth boundary to bedrock (76 cm +).

LABORATORY DATA

Horizon Depth (m)	S1 0.15	S1 0.3	S1 0.5	B2g 0.7
Loss on ignition	7.4	6.6	6.3	1.8
% sand	43.2	48.0	41.0	63.5
% silt	38.5	29.4	33.7	23.6
% clay	18.3	22.6	25.3	12.9
Ca (exchangeable me/100g)	3.75	2.75	4.17	2.55
Mg (exchangeable me/100g)	2.22	1.89	3.00	2.20
Na (exchangeable me/100g)	0.49	0.27	0.35	0.23
K (exchangeable me/100g)	0.15	0.18	0.23	0.16
pH (H_2O)	5.5	5.11	5.4	5.95
Phosphorous (total mg P_2O_5/100g)	750	796	1148	451

SITE INFORMATION

Soil Type:
Bilbster Series Deep Top Soil.

Locality:
Howe

Grid Ref:
HY 231236

Observer:
Ian A Simpson

Date:
1/7/82

Rock Outcrops:
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Relief:

Local:	Valley side midslope
Micro:	Flat
Slope$^{(o)}$:	4^o
Aspect:	338^o
Slope Form:	Straight
Altitude:	26m

Land Use & Vegetation:
Long term or permanent grassland.

Soil Surface:
Flat.

FIELD DESCRIPTION

Horizon	Depth (cm)	
S1	0-19	Very dark greyish brown (10YR 3/2) silty loam, no mottles, moderate organic matter, small common subangular stones, strongly developed fine subangular blocky peds, very fine frequent roots, clear smooth boundary to
S2	19-75	Dark brown (10YR 3/3) silty loam, no mottles, moderate organic matter, few fine distinct black (10YR 2.5/1) charcoal flecks, medium common subangular stones, strongly developed medium subangular blocky peds, very fine frequent roots, abrupt smooth boundary to
B3	75-81	Yellowish brown (10YR 5/6) loam, no mottles, no organic matter, many large subangular stones, massive structure, weakly indurated, no roots, sharp smooth boundary to bedrock.

LABORATORY DATA

Horizon Depth (m)	S1 0.1	S2 0.2	S2 0.3	S2 0.4	S2 0.5	S2 0.6	S2 0.7	B3 0.8
Loss on ignition	6.7	4.9	3.9	3.5	3.3	3.0	2.3	2.2
% sand	43.1	34.5	38.25	34.6	41.6	37.2	32.0	37.3
% silt	37.2	41.4	38.1	40.4	40.9	42.7	43.9	34.0
% clay	19.7	24.1	23.65	25.0	17.5	20.1	24.1	28.7
Ca (exchangeable me/100g)	5.48	5.49	6.31	6.11	5.43	4.80	3.36	3.76
Mg " "	3.45	2.88	2.80	2.79	3.09	3.40	3.75	4.65
Na " "	0.72	0.67	0.72	0.78	0.71	0.73	0.71	0.78
K " "	0.32	0.36	0.29	0.22	0.19	0.17	0.17	0.12
pH (H_2O)	5.6	5.8	6.0	6.1	6.1	6.2	6.2	6.2
Phosphorous (total mg P_2O_5/100g)	768	430	558	522	441	429	394	197

SITE INFORMATION

Soil Type:
Bilbster Series Deep Top Phase

Locality:
Keirfiold

Grid Ref:
HY 248186

Observer:
Ian A Simpson

Date:
27/3/82

Rock Outcrops:
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Relief:

Local:	Valleyside - midslope
Micro:	Ridge furrow
Slope$^{(o)}$:	7^{o}
Aspect:	098^{0}
Slope Form:	3 (concave)
Altitude:	43m

Land Use & Vegetation:
Tillage - fallow

Soil Surface:
Mounded uneven surface.

FIELD DESCRIPTION

Horizon	Depth (cm)	
S1	0-36	Dark brown (10YR 3/3) sandy loam, no mottles, low organic matter, no stones, moderately developed medium granular peds, no roots but some incorporated into the horizon, clear smooth boundary to
A1	36-56	Dark yellowish brown (10YR 4/4) sandy loam, no mottles, low organic matter, no stones, moderately developed coarse granular peds, no roots, abrupt smooth boundary to.
B2	56-81	Brown (10YR 5/3), silt loam, many linear (3-4mm) parallel to the surface yellowish brown (10YR 5/6) mottles, no organic matter, small abundant angular stones, strongly developed fine platy peds, no roots, abrupt smooth boundary to
C	81-89	Parent material.

LABORATORY DATA

Horizon Depth (m)	S1 0.2	S1 0.45	B2 0.6	B2 0.8
Loss on ignition	6.1	3.4	2.5	1.5
% sand	54.6	39.7	32.1	40.0
% silt	21.6	33.2	47.3	41.6
% clay	23.8	27.1	22.6	18.4
Ca (exchangeable me/100g)	26.32	22.27	5.66	3.81
Mg (exchangeable me/100g)	1.50	1.71	tr	tr
Na (exchangeable me/100g)	0.35	0.37	0.21	0.22
K (exchangeable me/100g)	0.12	0.07	tr	tr
pH (H_2O)	7.76	7.65	7.43	7.40
Phosphorous (total mg P_2O_5/100g)	233	220	140	92

tr = trace

SITE INFORMATION

Soil Type:
Bilbster Series Deep Top Soil.

Locality:
Skail

Grid Ref:
HY 234184

Observer:
Ian A Simpson

Date:
26/3/82

Rock Outcrops:
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Relief:

Local:	Valley/basin floor
Micro:	Flat
Slope$^{(o)}$:	Level
Aspect:	N/A
Slope Form:	N/A
Altitude:	12m

Land Use & Vegetation:
Grassland (Ley).

Soil Surface:
Flat

FIELD DESCRIPTION

Horizon	Depth (cm)	
S1	0-115	Dark brown (7.5YR 3/2) sandy clay loam, no mottles, moderate organic matter, few fine to medium black (10YR 2.5/1) charcoal flecks, few small subangular stones, weakly developed medium granular peds, few very fine fibrous roots, clear smooth change to
B2	115-150	Dark yellowish brown (10YR 4/4) silty clay loam, frequent fine reddish brown (5YR 5/3) mottles, no organic matter, frequent medium subangular stones, weakly developed medium granular peds, no roots.

LABORATORY DATA

Horizon Depth (m)	S1 0.2	S1 0.4	S1 0.6	S1 0.8	S1 1.0	S1 1.2	B2 1.4
Loss on ignition	4.2	3.6	4.1	4.0	3.3	3.5	2.5
% sand	53.0	52.9	57.0	46.0	39.1	36.8	31.6
% silt	23.0	21.6	19.8	28.3	34.0	33.2	38.6
% clay	24.0	25.5	23.2	25.7	26.9	30.0	29.8
Ca (exchangeable me/100g)	23.32	24.19	20.08	27.45	8.18	7.71	6.23
Mg " " "	2.24	2.38	2.39	2.68	2.29	2.30	1.70
Na " " "	0.36	0.43	0.45	0.34	0.39	0.28	0.34
K " " "	0.13	0.13	0.12	0.17	0.21	0.22	0.14
pH (H_2O)	7.79	7.89	7.80	7.88	7.62	7.60	7.45
Phosphorous (total mg $P_2 O_5$/100g)	462	717	775	684	498	556	289

SITE INFORMATION

Soil Type:

Bilbster Series Deep Top Soil.

Locality:

Hybreck

Grid Ref:

HY 317149

Observer:

Ian A Simpson

Date:

29/3/82

Rock Outcrops:

Relief:

Local:	Valley floor undifferentiated
Micro:	Mounds
Slope$^{(o)}$:	3^o
Aspect:	230^o
Slope Form:	S
Altitude:	15m

Land Use & Vegetation:

Permanent/long term grassland.

Soil Surface:

Mounded.

FIELD DESCRIPTION

Horizon	Depth (cm)	
S1	0-40	Very dark greyish brown (10YR 3/2), silty clay loam, no mottles, moderate organic matter, few small subangular stones, moderately developed medium granular peds, many fine fibrous roots, clear smooth change to
A1	40-50	Dark brown (10YR 3/3) silty clay loam, no mottles, low organic matter, few small subangular stones, very weakly developed medium granular peds, many fine fibrous roots, clear smooth change to
B2	50-65	Yellowish brown (10YR 5/4) silty clay loam, no mottles, no organic matter, many large subrounded stones, massive structure indurated, no roots.

LABORATORY DATA

Horizon Depth (cm)	S1 0.15	S1 0.25	A1 0.4	B2 0.6
Loss on ignition	8.7	6.4	6.6	3.1
% sand	37.8	39.0	32.0	35.0
% silt	35.9	38.3	39.9	49.7
% clay	26.3	22.7	28.1	15.3
Ca (exchangeable me/100g)	8.96	5.94	4.86	1.98
Mg (exchangeable me/100g)	1.54	0.97	1.52	1.21
Na (exchangeable me/100g)	0.28	0.39	0.36	0.26
K (exchangeable me/100g)	0.12	0.13	0.12	0.08
pH (H_2O)	6.20	6.38	6.25	5.95
Phosphorous (total mg P_2O_5 /100g)	871	1048	966	163

SITE INFORMATION

Soil Type:

Bilbster Series Deep Top Soil.

Locality:

Tenston

Grid Ref:

HY 276172

Observer:

Ian A Simpson

Date:

29/3/82

Rock Outcrops:

Relief:

Local: Middle slope
Micro: Flat
Slope$^{(o)}$: $2/3^o$
Aspect: 130^o
Slope Form: Concave
Altitude: 7m

Land Use & Vegetation:

Permanent or long term grassland.

Soil Surface:

Flat

FIELD DESCRIPTION

Horizon	Depth (cm)	
S1	0-42	Very dark greyish brown (10YR 3/2) silty clay loam, no mottles, moderate organic matter, few very fine black charcoal flecks (10YR 2.5/1), few small subangular stones, moderately developed fine granular peds, many very fine fibrous roots, clear smooth boundary to
S2	42-63	Dark yellowish brown (10YR 4/4) silty clay loam, no mottles, low organic matter, few very fine black charcoal flecks (10YR 2.5/1), few small subangular stones, moderately developed medium granular peds, many very fine fibrous roots, abrupt smooth boundary to
B2	63-73+	Yellowish brown (10YR 5/4), silty clay loam, no mottles, no organic matter, many large subangular stones, very weakly developed medium granular peds, no roots.

LABORATORY DATA

Horizon Depth (cm)	S1 0.15	S1 0.35	S1 0.5	B2 0.7
Loss on ignition	10.5	9.9	7.9	4.5
% sand	34.4	32.6	41.0	35.8
% silt	39.0	39.9	34.4	35.0
% clay	26.6	27.5	24.6	29.2
Ca (exchangeable me/100g)	8.25	6.17	3.87	1.81
Mg (exchangeable me/100g)	2.35	1.73	1.17	0.67
Na (exchangeable me/100g)	0.37	0.28	0.30	0.26
K (exchangeable me/100g)	0.09	0.11	0.07	0.08
pH (H_2O)	6.05	6.25	6.06	5.94
Phosphorous (total mg P_2O_5/100g)	315	724	653	220

SITE INFORMATION

Soil Type:
Bilbster Series Deep Top Soil.

Locality:
Hackland

Grid Ref:
HY 396202

Observer:
Ian A Simpson

Date:
30/3/82

Rock Outcrops:

Relief:

Local:	Valleyside Foot slope
Micro:	Flat
Slope$^{(o)}$:	2^o
Aspect:	220^o
Slope Form:	Concave
Altitude:	30m

Land Use and Vegetation:
Ley grassland.

Soil Surface:
Flat

FIELD DESCRIPTION

Horizon	Depth (cm)	
S1	0-50	Very dark greyish brown (10YR 3/2) silt loam, no mottles, moderate organic matter, few fine black (10YR 2.5/1) charcoal flecks, few small subangular stones, strongly developed medium granular peds, many fine fibrous roots, clear smooth change to
S2/A1	51-58	Dark brown (10YR 3/3), silty clay loam, no mottles, low organic matter, few small subangular stones, strongly developed medium granular peds, frequent very fine fibrous roots, abrupt clear change to
B2	58-78	Dark yellowish brown (10YR 4/4) silty clay loam, no mottles, no organic matter, many large sub-angular stones, strongly developed medium angular blocky peds, no roots.

LABORATORY DATA

Horizon Depth (cm)	S1 0.15	S1 0.25	S1 0.4	S2/A1 0.55	B2 0.7
Loss on ignition	9.6	7.7	6.9	3.6	1.4
% sand	40.7	43.2	37.6	35.1	34.3
% silt	34.3	31.9	36.2	37.3	39.2
% clay	25.0	24.9	26.2	27.6	26.5
Ca (exchangeable me/100g)	7.72	4.84	4.63	3.90	3.64
Mg (exchangeable me/100g)	1.40	1.21	1.04	1.75	2.21
Na (exchangeable me/100g)	0.25	0.19	0.25	0.35	0.23
K (exchangeable me/100g)	0.06	tr	tr	tr	tr
pH (H_2O)	5.92	6.20	6.13	6.15	6.15
Phosphorous (total mg P_2O_5/100g)	472	377	235	93	23

tr = trace

SITE INFORMATION

Soil Type:

Bilbster Series Deep Top Phase.

Locality:

Quinni

Grid Ref:

HY 256231

Observer:

D A Davidson

Date:

Rock Outcrops:

Relief:

Local:
Micro:
Slope $^{(o)}$:
Aspect:
Slope Form:
Alititude:

Land Use & Vegetation:

Soil Surface:

FIELD DESCRIPTION

Horizon	Depth (cm)	
S/A	0-60	Dark brown (7.5YR 3/2) silt loam, no mottles, few small and medium stones, some weathered sandstones, weak fine blocky fragments, roots decreasing with depth, abrupt smooth boundary to
A/B(g)	60-70	Dark greyish brown (10YR 4/2) silt loam with few fine yellowith brown (10YR 5/6) mottles, moderate medium stones, dominantly sandstones, massive, abrupt smooth boundary to
Bx(g)	70-78	Greyish brown (2.5YR5/2)silt loam with many fine yellowish red (5YR 4/6) mottles, moderate medium stones dominantly sandstones, coatings along structural faces, indurated.

LABORATORY DATA

Horizon Depth (m)	S/A 0.12- 0.19	S/A 0.35- 0.43	S/A 0.49- 0.56	A/B(g) 0.62- 0.69	Bx(g) 0.71- 0.78
Loss on ignition	3.1	2.7	2.0	1.6	1.1
% sand	33.1	31.0	31.0	35.5	42.0
% silt	40.9	42.0	41.8	42.1	39.3
% clay	26.0	27.1	27.2	22.4	18.7
Ca (exchangeable me/100g)	6.76	6.00	5.46	3.87	2.42
Mg (exchangeable me/100g)	4.51	3.81	3.38	2.90	2.09
Na (exchangeable me/100g)	0.30	0.22	0.20	0.19	0.21
K (exchangeable me/100g)	0.45	0.76	0.72	0.64	0.48
pH (H_2O)	6.0	6.4	6.5	6.5	6.65
Phosphorous (total mg P_2O_5/100g)	455	588	438	390	202

Profile analysed and described by
D A Davidson.

SOIL PROFILE DESCRIPTIONS FROM MARWICK

CONTROL PROFILE (BILBSTER SERIES)

SITE DESCRIPTION

Relief: Local: Upperslope
Micro: Flat
Angle: 8-11°
Aspect: 110°
Slope Form: Straight
Altitude: 95m

Rock Outcrops: None
Land Use: Rough grazing
Soil Surface: Flat
18th Century land use: Hill land

Horizon	Depth (cm)	
F1H	0-4	Very dark grey (10YR3/1) organic horizon, abundant medium roots, sharp smooth boundary to
A1	4-19	Dark greyish loam (10YR4/2) silt loam, no mottles, no stones, no structure developments, fine common roots becoming few fine roots, clear smooth boundary to
A2	15-31	Brown (7.5YR4/2) silt loam, very few fine distinct yellowish red (5YR5/6) mottles, few small subangular stones, moderately developed medium subangular blocky peds, fine common roots, becoming fine few roots, clear irregular boundary to
B2	31-65	Yellowish brown (10YR5/6) loam, no mottles, abundant medium angular stones with a layer between 40 and 44 cm of extremely abundant large angular stones, massive structure, no roots, sharp smooth boundary to bedrock.

HOWE 31 (ESKISHOLD COMPLEX)

SITE DESCRIPTION

Relief: Local: Midslope/upper slope
Micro: Flat
Angle: 4-7°
Aspect: 338°
Slope Form: Straight
Altitude: 70m

Rock Outcrops: None
Land Use: Permanent/long term grassland
Soil Surface: Flattened.
18th Century land Use: Hill land

Horizon	Depth (cm)	
S1	0-17	Dark yellowish brown (10YR4/4), no mottling, silty clay loam, few very small angular tabular stones, medium subangular blocky peds moderately well developed, common fine fibrous roots, abrupt smooth boundary to
B2	17-30	A composite horizon, dominant part of horizon is yellowish brown (10YR5/8), no mottling, silty clay loam, few very small angular stones, medium sub-angular blocky peds moderately well developed, common fine fibrous roots. Within this horizon is a broken line of organic material at 20cm with abundant roots. Horizon has abrupt smooth boundary to
BX	30-40	Yellowish brown (10YR5/6) massive
C	Bedrock at 40cm	

HOWE PEAT-ALLUVIUM (PEAT-ALLUVIUM SOIL)

SITE DESCRIPTION

Relief:	Local:	Bottom of slope	Rock Outcrops:	None
	Micro:	Flat	Land Use:	Rough grazing/
	Angle:	-		
	Aspect:	-	Soil Surface:	Flat
	Slope Form:	Concave	18th Century Land Use:	Meadowland
	Altitude:	5m		

Horizon	Depth (cm)	
A	0-18	Yellowish brown (10YR 5/4), no mottles, silty clay loam, few small subangular stones, medium subangular blocky weakly developed, common fine fibrous roots, clear smooth boundary to
B	18-65 Water table at 65cm	Olive yellow (2.5YR6/6), medium common distinct yellowish brown (10YR5/8) mottles, silty clay loam, no stones, massive, very few fine fibrous roots.

HOWE 34 (BILBSTER SERIES)

SITE DESCRIPTION

Relief:	Local:	Lower slope	Rock Outcrops:	None
	Micro:	Flat	Land Use:	Permanent/longterm grassland
	Angle:	2-3°		
	Aspect:	355°	Soil Surface:	Flattened
	Slope Form:	Concave	18th Century Land Use:	Grazing land
	Altitude:	12.5m		

Horizon	Depth (cm)	
S1	0-21	Yellowish brown (10YR 5/4) no mottles, silty clay loam, few small subangular tabular stones, medium subangular blocky peds moderately well developed, common fine fibrous roots, clear smooth boundary to
B2	21-49	Yellowish brown (10YR 5/6), no mottles, silty clay loam, few small subangular tabular stones, medium angular blocky peds moderately well developed, common fine fibrous roots, clear smooth boundary to
B2X	at 49cm	Yellowish brown (10YR 5/6) massive.

HOWE 26 (BILBSTER SERIES)

SITE DESCRIPTION

Relief:	Local:	Footslope	Rock Outcrops:	None
	Micro:	Flat	Land Use:	Permanent/longterm grassland.
	Angle:	2-3°		
	Aspect:	338°	Soil Surface:	Flattened.
	Slope Form:	Straight		
	Altitude:	10m	18th Century land use:	Arable

Horizon	Depth (cm)	
S1	0-22	Dark brown (10YR 3/3), no mottles, silty clay loam, few small subangular tabular stones, medium angular blocky peds moderately well developed, common fine fibrous roots, clear smooth boundary to
B2	22-31	Yellowish brown (10YR 5/4), no mottles, silty clay loam, few small subangular tabular stones, medium angular blocky peds moderately well developed, common fine fibrous roots, clear smooth boundary to
B2X	31-42	Light olive brown (2.5YR 5/4) massive.
C	Bedrock at 42cm	

HOWE 26A (BILBSTER SERIES)

SITE DESCRIPTION

Relief:	Local:	Footslope	Rock Outcrops:	None
	Micro:	Flat	Land Use:	Permanent/longterm grassland.
	Angle:	2-3°		
	Aspect:	338°	Soil Surface:	Flattened
	Slope form:	Straight		
	Altitude:	12.5m	18th Century Land Use:	Arable

Horizon	Depth (cm)	
S1	0-21	Dark brown (10YR 3/3), no mottles, silty clay loam few small subangular tabular stones, medium angular blocky peds moderately well developed, common fine fibrous roots, clear smooth boundary to
B2	21-27	Yellowish brown (10YR5/4), no mottles, silty clay loam, few small subangular tabular stones, medium angular blocky peds moderately well developed, common fine fibrous roots, clear smooth boundary to
B2X	27-39	Light olive brown (2.5YR5/4) massive
C	Bedrock at 39cm	

HOWE 23 (BILBSTER SERIES)

SITE DESCRIPTION

Relief:	Local:	Midslope/ footslope	Rock Outcrops:	None
	Micro:	Flat	Land Use:	Permanent/longterm grassland.
	Angle:	4-7°		
	Aspect:	338°	Soil Surface:	Flattened
	Slope Form:	Straight	18th Century Land Use:	Arable
	Altitude:	15m		

Horizon	Depth (cm)	
S1	0-23	Dark brown (10YR3/3), no mottles, silty clay loam, few small subangular tabular stones, medium angular blocky peds moderately well developed, fine fissures, common fine fibrous roots, clear smooth boundary to
S2	23-26	Brown (10YR4/3), no mottles, silty clay loam, few small subangular tabular stones, medium angular blocky peds moderately well developed, few fine fibrous roots, abrupt smooth boundary to
B2X	26-43	Light olive brown (2.5YR5/4), no mottles, silty clay loam, large abundant, angular tabular stones, massive.
C	Bedrock at 43cm	

HOWE 27 (BILBSTER SERIES)

SITE DESCRIPTION

Relief:	Local:	Midslope	Rock Outcrops:	None
	Micro:	Flat	Land Use:	Permanent/longterm grassland.
	Angle:	4-7°		
	Aspect:	338°	Soil Surface:	Flattened
	Slope Form:	Straight	18th Century Land Use:	Arable
	Altitude:	40m		

Horizon	Depth (cm)	
S1	0-11	Dark yellowish brown (10YR 4/4), no mottles, silty clay loam, few fine small subangular stones, medium subangular blocky peds moderately well developed, common fine fibrous roots, abrupt smooth boundary to
B2	11-27	Yellowish brown (10YR5/4), no mottles, silty clay loam, few small subangular stones, coarse subangular blocky peds moderately well developed, no roots, abrupt smooth boundary to
C	Bedrock at 27cm	

HOWE 27A (BILBSTER SERIES)

SITE DESCRIPTION

Relief:	Local:	Midslope	Rock Outcrops:	None
	Micro:	Flat	Land Use:	Permanent/longterm grassland
	Angle:	4-7^{o}		
	Aspect:	338^{0}	Soil Surface:	Flattened
	Slope Form:	Straight		
	Altitude:	37.5m	18th Century Land Use:	Arable

Horizon	Depth (cm)	
S1	0-15	Dark yellowish brown (10YR4/4), no mottles, silty clay loam, few fine small subangular stones, medium subangular blocky peds moderately well developed, common fine fibrous roots, abrupt smooth boundary to
B2	15-27	Yellowish brown (10YR5/4), no mottles, silty clay loam, few small subangular tabular stones, medium angular blocky peds moderately well developed, no roots, abrupt smooth boundary to
C	Bedrock at 27cm	

HOWE 3 (BILBSTER SERIES)

SITE DESCRIPTION

Relief:	Local:	Midslope	Rock Outcrops:	None
	Micro:	Flat	Land Use:	Permanent/longterm grassland
	Angle:	4-7^{o}		
	Aspect:	338^{o}	Soil Surface:	Flattened
	Slope Form:	Straight		
	Altitude:	35m	18th Century land use:	Arable

Horizon	Depth (cm)	
S1	0-24	Dark yellowish brown (10YR4/4), no mottles, silty clay loam few small subangular tabular stones, medium angular blocky peds moderately well developed, common fine fibrous roots, clear smooth boundary to
B2	24-31	Yellowish brown (10YR5/4), no mottles, silty clay loam, few small subangular tabular stones, medium angular blocky peds moderately well developed, no roots, abrupt smooth boundary to
C	Bedrock at 31cm	

HOWE 3A (BILBSTER SERIES)

SITE DESCRIPTION

Relief:

Local:	Midslope	Rock Outcrops:	None
Micro:	Flat	Land Use:	Permanent/longterm grassland.
Angle:	4-7°		
Aspect:	338°	Soil Surface:	Flattened
Slope Form:	Straight		
Altitude:	32.5m	18th Century Land Use:	Arable

Horizon	Depth (cm)	
S1	0-27	Brown (10YR4/3), no mottles, silty clay loam, few small subangular tabular stones, medium angular blocky peds moderately well developed, common fine fibrous roots, clear smooth boundary to
B2	27-35	Yellowish brown (10YR5/4), no mottles, silty clay loam, few small subangular tabular stones, medium angular blocky peds moderately well developed, no roots, abrupt smooth boundary to
C	Bedrock at 35cm	

HOWE - GLEY SOIL (THURSO SERIES)

SITE DESCRIPTION

Relief:

Local:	Footslope	Rock Outcrops:	None
Micro:	Flat	Land Use:	Permanent/Long term grassland
Angle:	0		
Aspect:	0		
Slope Form:	Straight	Soil Surface;	Flattened
Altitude:	7m	18th Century Land Use:	Meadowland

Horizon	Depth (cm)	
S	0-25	Dark greyish brown (10YR 4/2), no mottles, silty clay loam, few small subangular stones, medium subangular blocky peds moderately well developed, common fine fibrous roots, clear smooth boundary to
B_2g	25-50	Greyish brown (10YR5/2), frequent distinct yellowish brown (10YR 5/4) and strong brown 7.5YR 5/8) mottles, silty clay loam, prismatic soil structure well developed, few fine fibrous roots. Parent material at 50cm.

HOWE 23A (BILBSTER SERIES, DEEP TOP PHASE)

SITE DESCRIPTION

Relief:	Local:	Midslope	Rock Outcrops:	None
	Micro:	Flat	Land Use:	Permanent/longterm grassland
	Angle:	4-7^{o}		
	Aspect:	338^{o}	Soil Surface:	Flattened
	Slope Form:	Straight		
	Altitude:	17.5m	18th Century Land Use:	Arable

Horizon	Depth (cm)	
S1	0-12	Dark yellowish brown (10YR4/4), no mottles, silt, no stones, fine subangular blocky peds moderately well developed, fine fissures, fine macropores, few fine fibrous roots, no plant remains, clear smooth boundary to
S2	12-37	Dark brown (10YR3/3), few fine distinct black (10YR2.5/1) charcoal flecks, no mottles, silt, common small subangular tabular stones, medium subangular blocky peds moderately well developed, fine fissures, fine macropores, few fine fibrous roots, no plant remains, clear smooth boundary to
A1	37-45	Dark yellowish brown (10YR4/4), no mottles, sandy clay loam, many small subangular tabular stones, medium subangular blocky peds moderately well developed, abrupt smooth boundary to
B2	45-55	Light yellowish brown (2.5YR6/4), no mottles, sandy clay loam, many medium subangular tabular stones, strongly developed coarse subangular blocky peds.

HOWE 18 (BILBSTER SERIES, DEEP TOP PHASE)

SITE DESCRIPTION

Relief:	Local:	Midslope	Rock Outcrops:	None
	Micro:	Flat	Land Use:	Permanent/longterm grassland
	Angle:	4-7^{o}		
	Aspect:	338^{o}	Soil Surface:	Flattened
	Slope Form:	Straight		
	Altitude:	20m	18th Century Land Use:	Arable

Horizon	Depth (cm)	
S1	0-21	Dark yellowish brown (10YR4/4), no mottles, silt few very small rounded tabular stones, medium subangular blocky peds strongly developed, fine fissures, fine macropores, common fine fibrous roots, no plant remains clear smooth boundary to
S2	21-59	Dark brown (10YR3/3), no mottles, few very fine distinct black (10YR5/1) charcoal flecks with sharp boundaries, silt, few small subangular stones, coarse subangular blocky peds moderately well developed, no fissures, fine macropores, few fine fibrous roots, no plant remains, abrupt smooth boundary to
B2X	59-72	Yellowish brown (10YR5/6), no mottles, silty loam, many very large subrounded tabular stones, massive.

HOWE 18A (BILBSTER SERIES, DEEP TOP PHASE)

SITE DESCRIPTION

Relief:	Local:	Midslope	Rock Outcrops:	None
	Micro:	Flat	Land Use:	Permanent/longterm grassland
	Angle:	4-7^{o}		
	Aspect:	338^{o}	Soil Surface:	Flattened
	Slope Form:	Straight		
	Altitude:	22.5m	18th Century Land Use:	Arable

Horizon Depth (cm)

S1 0-19 Dark greyish brown (10YR 4/2), no mottles, silt, few small subrounded stones, medium subangular blocky peds moderately developed, fine fissures, fine macropores, many fine fibrous roots, no plant remains, clear smooth boundary to

S2 24-77 Brown (10YR4/3), no mottles, few fine distinct black charcoal flecks (10YR5/1) with sharp boundaries, silt, many medium subangular stones, medium subangular peds moderately developed, fine fissures, fine macropores, common fine fibrous roots, no plant remains, clear smooth boundary to

B2 77-100 Dark yellowish brown (10YR4/4), no mottles, loam many medium subangular stones, coarse subangular blocky peds moderately developed, no fissures, no macropores, no roots, no plant remains.

HOWE 13 (BILBSTER SERIES, DEEP TOP PHASE)

SITE DESCRIPTION

Relief:	Local:	Midslope	Rock Outcrops:	None
	Micro:	Flat	Land Use:	Permanent/long term grassland
	Angle:	4-7^{o}		
	Aspect:	338^{o}	Soil Surface:	Flattened
	Slope Form:	Straight		
	Altitude:	25m	18th Century land use:	Arable

Horizon Depth (cm)

S1 0-19 Very dark greyish brown (10YR3/2) silty loam, no mottles, small common subangular stones, strongly developed fine subangular blocky peds, very fine common fibrous roots, clear smooth boundary to

S2 19-75 Dark brown (10YR3/3), silty loam, no mottles, few fine distinct black (10YR5/1) charcoal flecks, medium common subangular stones, strongly developed medium subangular blocky peds, very fine common roots, abrupt smooth boundary to

B2 75-81 Yellowish brown (10YR5/6) loam, no mottles, many large subangular stones, massive structure, no roots, sharp smooth boundary to bedrock.

MUCE (BILBSTER SERIES, DEEP TOP PHASE)

SITE DESCRIPTION

Relief:	Local:	Midslope	Rock Outcrops:	None
	Micro:	Flat	Land Use:	Permanent/longterm grassland
	Angle:	$2-3^{o}$		
	Aspect:	310^{o}		
	Slope Form:	Straight	Soil Surface:	Flattened
	Altitude:	25m	18th Century land use:	Arable

Horizon	Depth (cm)	
S1	0-21	Dark brown (10YR 3/3) silty clay loam, no mottles, few small angular stones, strongly developed medium granular peds, very fine common roots, clear smooth boundary to
S2	21-63	Very dark greyish brown (10YR3/2) silty clay loam, no mottles, few small angular stones, strongly developed medium granular peds, very fine common roots, abrupt smooth boundary to
B2g	63-76	Brown (10YR4/3) loamy sand, few fine distinct mottles (10YR6/2) many very small subangular stones, moderately well developed medium angular blocky peds, no roots, sharp smooth boundary to bedrock (76cm+)

NETHERSKAIL (BILBSTER SERIES, DEEP TOP PHASE)

SITE DESCRIPTION

Relief:	Local:	Midslope	Rock Outcrops:	None
	Micro:	Flat	Land Use:	Permanent/long term grassland
	Angle:	$2-3^{o}$		
	Aspect:	250^{o}		
	Slope Form:	Straight	Soil Surface:	Flattened
	Altitude:	20m	18th Century Land Use :	Arable

Horizon	Depth (cm)	
S1	0-21	Very dark greyish brown (10YR3/2), silty clay loam, no mottles, firm fine black (10YR2.5/2) charcoal flecks, few very small subangular stones, strongly developed medium granular peds, very fine common roots, clear smooth boundary to
S2	21-73	Dark brown (10YR 3/3) silty clay loam, no mottles, few fine black (10YR2.5/1) charcoal flecks, few medium angular stones, strongly developed medium granular peds, very fine common roots, abrupt smooth boundary to
B2	73-92+	Yellowish brown (10YR 5/6) loam, no mottles, large abundant subangular stones, moderately developed fine subangular blocky peds, no roots.

HOWE - FARM YARD

This profile was dug in the old farm yard at West Howe. It can be considered as similar to a farm mound of Sanday or North Ronaldsay.

The profile was dug to a depth of 1.5 metres and was uniform throughout.

Description: Dark greyish brown (10YR 4/3), no mottling, silty clay loam, few very small angular tabular stones, medium subangular blocky peds (?) moderately well developed, few fine fibrous roots in top 25 cm.

Black charcoal flecks and orange peat ash flecks were observed.

FIELD OBSERVATIONS, WESTBROUGH DATA SET

	PROFILE & HORIZON NO	WB2/1	WB2/2	WB2/3	WB2/4	WB2/5	WB2/6	WB2/7	WB2/8	WB2/9
	NUMBER FOR CLUSTER ANALYSIS	30	31	32	33	34	35	36	37	38
HORIZON DISCRIMINATION PROPERTIES	Hue	10	10	10	10	10	10	7.5	10	10
	Value	3	5	3	5	4	5	4	3	4
	Chroma	3	4	3	3	2	4	4	2	3
	Texture	18	9	22	22	22	20	22	22	22
	Mottling	0	0	0	0	0	0	0	0	0
	Organic Matter Status	2	0	1	1	1	1	1	1	1
	Stoniness:									
	Size	2	2	2	2	2	2	2	2	2
	Abundance	1	2	1	1	1	1	1	1	1
	Shape	30	30	30	30	30	40	40	40	30
	Inclusions:									
	Type	0	0	0	0	0	0	0	0	0
	Abundance	0	0	0	0	0	0	0	0	0
	Size	0	0	0	0	0	0	0	0	0
HORIZON ORGANISATION PROPERTIES	Mean Horizon Thickness (cm)	45	4	15	9	16	6	3	11	2
	Mean Horizon Orientation	2	2	3	0	0	0	0	4	0
	Horizon Continuity	5	5	5	5	5	2	3	5	1
	PED shape	4	4	4	4	4	4	4	4	4
	PED size	2	1	2	2	2	2	2	2	2
	PED grade	6	3	6	6	3	3	3	3	3
	Horizon Boundary and Form	5	5	5	5	5	5	5	5	5
	Root Size	0	0	0	0	0	0	0	0	0
	Root Nature	0	0	0	0	0	0	0	0	0
	Root Abundance	0	0	0	0	0	0	0	0	0
	Phosphate Spot Test Value	3	3	3	3	3	3	3	3	3

	PROFILE & HORIZON NO	WB2/10	WB2/11	WB2/12	WB2/13	WB2/14	WB2/15	WB2/16	WB2/17
	NUMBER FOR CLUSTER ANALYSIS	39	40	41	42	43	44	45	46
HORIZON DISCRIMINATION PROPERTIES	Hue	7.5	7.5	5	10	5	10	10	7.5
	Value	4	4	5	3	5	4	3	3
	Chroma	4	4	8	3	6	2	3	2
	Texture	22	22	-	-	-	18	18	18
	Mottling	0	0	-	-	-	0	0	0
	Organic Matter Status	1	1	-	-	-	1	1	2/3
	Stoniness:								
	Size	3	2	-	-	-	3	2	2
	Abundance	1	1	-	-	-	1	1	1
	Shape	30	30	-	-	-	30	30	30
	Inclusions:								
	Type	0	1	-	-	-	1+2	1+2+3	0
	Abundance	0	-	-	-	-	-	-	0
	Size	0	-	-	-	-	-	-	0
HORIZON ORGANISATION PROPERTIES	Mean Horizon Thickness (cm)	8	13	3	2	3	11	19	26
	Mean Horizon Orientation	1	0	3	3	3	0	0	0
	Horizon Continuity	3	5	1	1	4	5	5	5
	PED shape	4	4	-	-	-	4	4	4
	PED size	2	2	-	-	-	2	2	2
	PED grade	3	3	-	-	-	3	3	6
	Horizon Boundary and Form	5	5	-	-	-	5	5	9
	Root Size	0	0	-	-	-	0	0	0
	Root Nature	0	0	-	-	-	0	0	0
	Root Abundance	0	0	-	-	-	0	0	0
	Phosphate Spot Test Value	3	3	-	-	-	3	3	3

PROFILE & HORIZON NO	WB2/18	WB2/19	WB3/1	WB3/2	WB3/3	WB3/4	WB3/5	WB3/6	WB3/7
NUMBER FOR CLUSTER ANALYSIS	47	48	49	50	51	52	53	54	55
HORIZON DISCRIMINATION PROPERTIES									
Hue	7.5	10	7.5	7.5	10	5	10	7.5	7.5
Value	3	3	3	5	3	5	3	4	4
Chroma	2	1	2	4	3	4	3	4	4
Texture	0	20	22	22	22	18	22	22	22
Mottling	0	1	0	0	0	0	0	0	0
Organic Matter Status	3	2	1	1	1	0	1	0	0
Stoniness:									
Size	0	2	2	0	2	1	2	0	0
Abundance	0	1	1	0	1	1	1	0	0
Shape	0	30	30	0	30	30	30	0	0
Inclusions:									
Type	0	2	1	1	1	1	1	1	1
Abundance	0	-	1	1	1	1	1	1	1
Size	0		1	1	1	1	1	2	2
HORIZON ORGANISATION PROPERTIES									
Mean Horizon Thickness (cm)	46	-	97	15	5	20	4	7	7
Mean Horizon Orientation	0	0	0	1	1	1	3	1	4
Horizon Continuity	5	5	5	5	5	5	5	3	3
PED shape	0	4	4	4	4	0	4	5	5
PED size	0	2	2	2	2	0	2	2	2
PED grade	2	7	6	6	6	1	6	3	3
Horizon Boundary and Form	9	-	5	5	5	5	5	5	5
Root Size	0	0	0	0	0	0	0	0	0
Root Nature	0	0	0	0	0	0	0	0	0
Root Abundance	0	0	0	0	0	0	0	0	0
Phosphate Spot Test Value	3	3	3	3	3	3	3	3	3

	PROFILE & HORIZON NO	WB3/8	WB3/9	WB3/10	WB3/11	WB3/12	WB3/13	WB3/14	WB3/15
	NUMBER FOR CLUSTER ANALYSIS	56	57	58	59	60	61	62	63
HORIZON DISCRIMINATION PROPERTIES	Hue	5	7.5	10	7.5	10	7.5	7.5	7.5
	Value	5	4	3	4	3	5	5	4
	Chroma	6	4	3	2	4	4	4	4
	Texture	18	19	19	19	19	19	19	-
	Mottling	0	0	0	0	0	0	0	-
	Organic Matter Status	0	0	0	0	0	0	0	-
	Stoniness:								
	Size	2	0	0	0	0	0	0	-
	Abundance	1	0	0	0	0	0	0	-
	Shape	30	0	0	0	0	0	0	-
	Inclusions:								
	Type	0	0	1	1	1	1	1	-
	Abundance	0	0	1	1	1	1	1	-
	Size	0	0	1	1	1	1	½	-
HORIZON ORGANISATION PROPERTIES	Mean Horizon Thickness (cm)	18	14	7	4	13	6	16	2
	Mean Horizon Orientation	3	1	0	0	0	0	0	0
	Horizon Continuity	5	5	5	5	5	1	5	2
	PED shape	0	5	4	0	4	5	5	-
	PED size	0	2	2	0	2	2	2	-
	PED grade	1	3	6	1	3	3	3	-
	Horizon Boundary and Form	5	5	5	5	5	9	5	-
	Root Size	0	0	0	0	0	0	0	-
	Root Nature	0	0	0	0	0	0	0	-
	Root Abundance	0	0	0	0	0	0	0	-
	Phosphate Spot Test Value	3	3	3	3	3	3	3	-

FIELD OBSERVATIONS, WESTBROUGH DATA SET Cont'd 5.

PROFILE & HORIZON NO	WB3/16	WB3/17	WB3/18	WB3/19	WB3/20	WB4/1	WB4/2	WB4/3
NUMBER FOR CLUSTER ANALYSIS	64	65	66	67	68	69	70	71
HORIZON DISCRIMINATION PROPERTIES								
Hue	7.5	7.5	7.5	7.5	10	10	10	10
Value	3	4	5	5	3	4	3	3
Chroma	2	4	4	4	1	3	3	3
Texture	19	19	-	19	17	19	-	17
Mottling	0	0	-	0	1	0	-	0
Organic Matter Status	0	0	-	0	2	2	-	1
Stoniness:								
Size	2	0	-	0	2+1	2	3	0
Abundance	1	0	-	0	1	1	4	0
Shape	30	0	-	0	20+12	30	30	0
Inclusions:								
Type	1	1	-	1+3	5	0	-	0
Abundance	1	1	-	1+1	1	0	-	0
Size	1	1	-	1+1	1	0	-	0
HORIZON ORGANISATION PROPERTIES								
Mean Horizon Thickness (cm)	3	6	2	18	-	88	68	9
Mean Horizon Orientation	1	0	1	0	-	3	0	0
Horizon Continuity	5	1	1	5	5	5	5	5
PED shape	4	5	-	5	4	4	-	4
PED size	2	2	-	2	2	2	-	2
PED grade	3	3	-	3	6	6	-	6
Horizon Boundary and Form	5	5	-	5	-	5	-	5
Root Size	0	0	-	0	0	0	-	0
Root Nature	0	0	-	0	0	0	-	0
Root Abundance	0	0	-	0	0	0	-	0
Phosphate Spot Test Value	3	3	-	3	3	3	-	3

PROFILE & HORIZON NO		WB4/4	WB4/5	WB4/6	WB5/1	WB5/2	WB5/3	WB5/4	WB5/5	WB5/6
NUMBER FOR CLUSTER ANALYSIS		72	73	74	75	76	77	78	79	80
HORIZON DISCRIMINATION PROPERTIES	Hue	5	10	10	10	5	5	7.5	5	5
	Value	4	3	4	3	7	5	2.5	5	5
	Chroma	3	3	2	3	6	2	1	2	1
	Texture	18	22	22	24	18	5	17	19	-
	Mottling	0	0	0	0	0	0	0	0	0
	Organic Matter Status	0	1	1	2	0	0	3	1	-
	Stoniness:									
	Size	0	2/3	0	2	0	0	2	3	-
	Abundance	0	1	0	1	0	0	1	1	-
	Shape	0	30	0	12	0	0	30	12	-
	Inclusions:									
	Type	0	1+2	1+3	2	1	1	5	1+2	-
	Abundance	0	1+1	1+1	1	1	1	1	1+1	-
	Size	0	1+1	1+1	1	2	1	1	1+1	-
HORIZON ORGANISATION PROPERTIES	Mean Horizon Thickness (cm)	8	8	-	16	7	3	3	3	2
	Mean Horizon Orientation	0	0	-	3	4	2	0	0	0
	Horizon Continuity	5	5	5	5	5	2	3	5	1
	PED shape	0	4	4	4	0	0	4	-	-
	PED size	0	2	2	2	0	0	3	-	-
	PED grade	1	6	6	6	1	1	6	-	-
	Horizon Boundary and Form	5	9	5	5	5	5	5	-	-
	Root Size	0	0	0	2	0	0	0	-	-
	Root Nature	0	0	0	2	0	0	0	-	-
	Root Abundance	0	0	0	1	0	0	0	-	-
	Phosphate Spot Test Value	3	3	3	3	3	3	3	-	-

	PROFILE & HORIZON NO	WB5/7	WB5/8	WB5/9	WB5/10	WB5/11	WB5/12	WB5/13	WB5/14
	NUMBER FOR CLUSTER ANALYSIS	81	82	83	84	85	86	87	88
HORIZON DISCRIMINATION PROPERTIES	Hue	5	7.5	5	10	5	5	10	5
	Value	7	2.5	5	3	6	5	3	5
	Chroma	6	1	1	2	6	2	1	8
	Texture	-	-	-	19	18	-	22	19
	Mottling	-	-	-	0	0	-	0	0
	Organic Matter Status	-	-	-	1	0	-	2	0
	Stoniness:								
	Size	-	-	-	4	0	-	2	0
	Abundance	-	-	-	4	0	-	1	0
	Shape	-	-	-	30	0	-	30	0
	Inclusions:								
	Type	-	-	-	0	1	-	0	0
	Abundance	-	-	-	0	2	-	0	0
	Size	-	-	-	0	2	-	0	0
HORIZON ORGANISATION PROPERTIES	Mean Horizon Thickness (cm)	1	2	12	14	14	3	7	20
	Mean Horizon Orientation	0	0	3	1	1	5	0	0
	Horizon Continuity	1	1	5	5	5	1	5	5
	PED shape	-	-	0	0	0	-	0	0
	PED size	-	-	0	0	0	-	0	0
	PED grade	-	-	1	1	1	-	1	1
	Horizon Boundary and Form	-	-	5	5	5	-	5	5
	Root Size	-	-	0	0	0	-	0	0
	Root Nature	-	-	0	0	0	-	0	0
	Root Abundance	-	-	0	0	0	-	0	0
	Phosphate Spot Test Value	-	-	3	3	3	-	3	3

	PROFILE & HORIZON NO	WB5/15	WB5/16	WB5/17	WB5/18	WB5/19	WB5/20	WB5/21	WB5/22	WB5/23
	NUMBER FOR CLUSTER ANALYSIS	89	90	91	92	93	94	95	96	97
HORIZON DISCRIMINATION PROPERTIES	Hue	10	10	10	10	5	10	7.5	7.5	10
	Value	3	4	4	3	5	3	4	3	3
	Chroma	3	2	3	3	4	1	4	2	1
	Texture	24	19	19	-	18	19	24	19	20
	Mottling	0	0	0	-	0	0	0	0	0
	Organic Matter Status	1	0	1	-	0	1	0	0	0
	Stoniness:									
	Size	2	0	2	-	0	2	0	2	2
	Abundance	1	0	1	-	0	1	0	1	1
	Shape	30	0	30	-	0	30	0	20	30
	Inclusions:									
	Type	1+2+3	0	2	1+2	0	1	0	0	1
	Abundance	1+1+1	0	1	2+4	0	1	0	0	1
	Size	1+1+1	0	1	3+4	0	1	0	0	1
HORIZON ORGANISATION PROPERTIES	Mean Horizon Thickness (cm)	7	3	24	6	8	3	4	5	-
	Mean Horizon Orientation	0	0	0	2	2	2	0	0	-
	Horizon Continuity	5	5	5	5	5	5	1	2	5
	PED shape	4	0	0	-	0	4	4	4	4
	PED size	2	0	0	-	0	2	2	2	2
	PED grade	6	1	1	-	1	6	6	6	6
	Horizon Boundary and Form	5	5	5	-	5	5	5	5	5
	Root Size	0	0	0	0	0	0	0	0	0
	Root Nature	0	0	0	0	0	0	0	0	0
	Root Abundance	0	0	0	0	0	0	0	0	0
	Phosphate Spot Test Value	3	3	3	3	3	3	3	3	3

FIELD OBSERVATIONS, SKELBRAE DATA SET

PROFILE & HORIZON NO	SK1/1	SK1/2	SK1/3	SK1/4	SK2/1	SK2/2	SK2/3	SK2/4	SK2/5
NUMBER FOR CLUSTER ANALYSIS	1	2	3	4	5	6	7	8	9
HORIZON DISCRIMINATION PROPERTIES									
Hue	10	10	7.5	5	10	10	10	10	10
Value	4	4	3	3	3	3	3	3	4
Chroma	2	3	2	2	3	3	3	2	2
Texture	20	18/19	19	18	22	-	22	19	19
Mottling	0	0	1	1	0	-	0	0	0
Organic Matter Status	-	-	-	-	1	-	1	1	1
Stoniness:									
Size	-	-	-	-	2	-	2	2	2
Abundance	-	-	-	-	1	-	1	1	1
Shape	-	-	-	-	40	-	40	40	30
Inclusions:									
Type	2	0	1	1	1+3	2	2	4	1
Abundance	-	0	1	1	1+1	4	1	1	1
Size	-	0	-	-	2+2	4	1	1	1
HORIZON ORGANISATION PROPERTIES									
Mean Horizon Thickness (cm)	12	37.5	75	-	18	4	12	6	7
Mean Horizon Orientation	0	3	0	-	0	0	0	1	2
Horizon Continuity	5	5	5	5	5	5	5	5	5
PED shape	-	-	-	-	4	4	4	4	4
PED size	-	-	-	-	2	2	2	2	2
PED grade	-	-	-	-	6	6	6	6	6
Horizon Boundary and Form	-	-	-	-	5	13	5	9	5
Root Size	-	-	-	-	2	2	2	2	0
Root Nature	-	-	-	-	2	2	2	2	0
Root Abundance	-	-	-	-	2	2	2	1	0
Phosphate Spot Test Value	3	3	3	3	3	3	3	3	3

	PROFILE & HORIZON NO	SK2/6	SK2/7	SK2/8	SK2/9	SK2/10	SK2/11	SK2/12	SK2/13
	NUMBER FOR CLUSTER ANALYSIS	10	11	12	13	14	15	16	17
HORIZON DISCRIMINATION PROPERTIES	Hue	7.5	10	10	7.5	5	7.5	10	10
	Value	4	4	3	4	3	3	5	5
	Chroma	2	2	3	2	2	2	1	1
	Texture	19	19	18	22	18	22	-	-
	Mottling	0	0	0	0	0	0	-	-
	Organic Matter Status	1	1	1	1	1	1	-	-
	Stoniness:								
	Size	0	0	0	1	2	2	-	-
	Abundance	0	0	0	1	1	1	-	-
	Shape	0	0	0	40	30	30	-	-
	Inclusions:								
	Type	1+4	1+5	0	0	0	0	-	-
	Abundance	1+2	1+2	0	0	0	0	-	-
	Size	3+2	3+2	0	0	0	0	-	-
HORIZON ORGANISATION PROPERTIES	Mean Horizon Thickness (cm)	32	19	4	14	5	19	2	1
	Mean Horizon Orientation	0	0	0	0	0	0	0	0
	Horizon Continuity	5	5	5	5	5	5	2	1
	PED shape	4	4	5	4	5	4	-	-
	PED size	1	1	2	2	2	2	-	-
	PED grade	6	6	7	6	7	6	-	-
	Horizon Boundary and Form	5	5	5	5	5	5	-	-
	Root Size	0	0	0	0	2	2	-	-
	Root Nature	0	0	0	0	2	2	-	-
	Root Abundance	0	0	0	0	1	1	-	-
	Phosphate Spot Test Value	3	3	3	3	3	3	-	-

PROFILE & HORIZON NO		SK2/14	SK3/1	SK3/2	SK3/3	SK3/4	SK3/5	SK3/6	SK4/1	SK4/2
NUMBER FOR CLUSTER ANALYSIS		18	19	20	21	22	23	24	25	26
HORIZON DISCRIMINATION PROPERTIES	Hue	10	10	10	7.5	7.5	7.5	7.5	10	7.5
	Value	3	3	4	4	3	3	3	3	3
	Chroma	2	2	2	2	2	2	2	2	2
	Texture	17	18	22	21	22	-	22	18	18
	Mottling	0	0	0	0	0	-	0	0	0
	Organic Matter Status	1	1	0	0	1	-	1	1	1
	Stoniness:									
	Size	2	0	0	0	0	3	0	2	2
	Abundance	1	0	0	0	0	5	0	1	1
	Shape	30	0	0	0	0	30	0	30	30
	Inclusions:									
	Type	1+2	2	0	2	0	-	0	2	0
	Abundance	1+1	1	0	1	0	-	0	1	0
	Size	1+1	1	0	1	0	-	0	1	0
HORIZON ORGANISATION PROPERTIES	Mean Horizon Thickness (cm)	-	70	11	13	19	6	-	20	25
	Mean Horizon Orientation	0	0	0	0	0	0	0	0	0
	Horizon Continuity	5	5	5	5	5	5	5	5	5
	PED shape	4	4	5	5	4	-	4	4	4
	PED size	2	2	1	1	2	-	2	2	2
	PED grade	6	6	3	3	6	-	6	6	6
	Horizon Boundary and Form	-	5	5	5	5	-	5	5	5
	Root Size	0	2	0	0	0	-	0	2	0
	Root Nature	0	2	0	0	0	-	0	2	0
	Root Abundance	0	1	0	0	0	-	0	1	0
	Phosphate Spot Test Value	3	3	3	3	3	-	3	3	3

	PROFILE & HORIZON NO	SK4/3	SK4/4	SK4/5
	NUMBER FOR CLUSTER ANALYSIS	27	28	29
HORIZON DISCRIMINATION PROPERTIES	Hue	10	10	10
	Value	3	4	4
	Chroma	2	2	4
	Texture	18	18	22
	Mottling	0	0	0
	Organic Matter Status	1	0	0
	Stoniness:			
	Size	2	3	3
	Abundance	1	2	2
	Shape	30	30	30
	Inclusions:			
	Type	3	0	0
	Abundance	1	0	0
	Size	1	0	0
HORIZON ORGANISATION PROPERTIES	Mean Horizon Thickness (cm)	56	8	-
	Mean Horizon Orientation	0	0	0
	Horizon Continuity	5	5	5
	PED shape	4	4	0
	PED size	2	2	0
	PED grade	6	6	2
	Horizon Boundary and Form	5	5	-
	Root Size	0	0	0
	Root Nature	0	0	0
	Root Abundance	0	0	0
	Phosphate Spot Test Value	3	3	2

PROFILE DESCRIPTIONS FROM SOILS ADJACENT TO THE WESTBROUGH AND SKELBRAE FARM MOUNDS

SITE INFORMATION

Soil Type:
Bilbster Series

Location:
Westbrough (early arable land)

Grid Ref:
HY 662 424

Observer:
Ian A Simpson

Date:
9/7/83

Rock Outcrops:

Relief:

Local:	Flat
Micro:	Flat
Slope$^{(o)}$:	0
Aspect:	--
Slope Form:	--
Altitude:	5m

Land Use & Vegetation:
Permanent/long term grassland

Soil Surface:
Flat

FIELD DESCRIPTIONS

Horizon	Depth (cm)	
S_1	0-35	10YR 4/3, no mottles, moderate organic matter intimate, clay loam, moderately well developed medium subangular blocky peds, few small subangular stones, frequent fine fibrous roots, few small charcoal flecks, smooth clear change to
B_2/C	35-55+	10YR 5/5, no mottles, no organic matter, sandy clay loam, moderately well developed medium subangular blocky peds, frequent small to medium subangular stones, no roots.

SITE INFORMATION

Soil Type: Bilbster Series

Location: Westbrough (Early grazing land)

Grid Ref: HY 661 424

Observer: Ian A Simpson

Date: 10/7/83

Rock Outcrops: ---

Relief:

Local:	Flat
Micro:	Flat
Slope$^{(o)}$:	0
Aspect:	-
Slope Form:	-
Altitude:	3m

Land Use & Vegetation: Permanent long term grassland

FIELD DESCRIPTION

Horizon	Depth (cm)	
S_1/A_1	0-49	10YR 4/3, no mottles, moderate organic matter intimate, sandy clay loam (contains calcareous wind blown sand components), moderately well developed medium subangular blocky peds, few small subangular stones, frequent fine fibrous roots, smooth clear change to
B_2/C(?)	49+	10YR 5/5, no mottles, no organic matter, sandy clay loam, moderately well developed medium subangular blocky peds, frequent small to medium subangular stones, no roots.

SITE INFORMATION

Soil Type:
Saltings

Location:
Westbrough

Grid Ref:
HY 665 425

Observer:
Ian A Simpson

Date:
9/7/83

Rock Outcrops:

Relief:

Local:	Flat
Micro:	Flat
Slope$^{(o)}$:	0
Aspect:	--
Slope Form:	--
Altitude:	2m

Land Use & Vegetation:
Bog

Soil Surface:
Flat

FIELD DESCRIPTION

Horizon	Depth (cm)	
A_2	0-50	10YR 4/4, no mottles, high organic matter content intimate, silty clay loam, well developed massive structure, no stones, frequent fine fibrous roots, smooth clear change to
A_3	50-60	10YR 3/2, no mottles, high organic matter content intimate, silty clay loam, well developed massive structure, no stones, frequent fine fibrous roots, smooth clear change to
B_{2g}	60-70	2.5Y 6/1, no mottles, no organic matter, silty clay, well developed massive structure, moderately stoney, small to medium subangular stones, no roots, smooth clear change to
Cg	70-85+ (water enters at 85)	10YR 5/2, no mottles, no organic matter, silty clay, well developed massive structure, moderately stoney, small subangular stones, no roots.

SITE INFORMATION

Soil Type:
Bilbster Series

Location:
Skelbrae 5

Grid Ref:
HY 675 437

Observer:
Ian A Simpson

Date:
7/7/83

Rock Outcrops:
--

Relief:

Local:	Bottom slope
Micro:	Flat
Slope$^{(o)}$:	1^{o}
Aspect:	240^{o}
Slope Form:	-
Altitude:	4m

Land Use & Vegetation:
Permanent grass land

Soil Surface:
Flat

FIELD DESCRIPTION

Horizon	Depth (cm)	
S	0-32	10YR 3/3, no mottles, moderate organic matter status intimate, silty clay loam, moderately well developed medium subangular blocky peds, frequent small subangular stones, frequent fine fibrous roots, clear smooth change to
B_2	32-47	10YR 5/4, no mottles, no organic matter, loam, moderately well developed blocky peds, frequent medium subangular stones, no roots.
C/D	47 +	

SITE INFORMATION

Soil Type:	Location:	Grid Ref:
Bilbster Series	Skelbrae(6)	HY 675 436
Observer:	**Date:**	**Rock Outcrops:**
Ian A Simpson	7/7/83	---

Relief:

Local:	Bottom slope
Micro:	Flat
Slope(o):	1^o
Aspect:	240
Slope Form:	-
Altitude:	3m

Land Use & Vegetation:

Permanent grassland

Soil Surface:

Flat

FIELD DESCRIPTION

Horizon	Depth (cm)	
S	0-18	10YR 5/6, no mottles, moderate organic matter status intimate, silty clay loam, moderately well developed medium subangular blocky peds, frequent small subangular stones, frequent fine fibrous roots, clear smooth change to
B_2	18-36	10YR 5/4, no mottles, no organic matter, loam, moderately well developed blocky peds, frequent medium subangular stones, profile lies directly on rock.
C/D	at 36+	

METHODS OF ANALYSIS FOR CHAPTER 7

This Appendix describes the methods of analysis used to identify the land use and land use intensity of the deep top soils and farm mounds. Five subsections are contained within this Appendix, each representing the different methodologies used.

1. Field Description and Analysis

Field description of the profiles was achieved using the Soil Survey Field Handbook (Soil Survey, 1976). Features additional to this system were inclusions (charcoal and shell), estimated horizon orientation, horizon continuity and phosphate spot test value. The table overleaf lists the properties of the profiles assessed in the field. A brief description of the site and soil/sediment surface was made before describing the profile itself. Profile properties of the deep top soils were described in full, profile properties of the farm mounds were recorded in the numeric form of the Soil Survey Field Handbook.

Properties identified in the field were considered to represent two classes. One class includes field colour, mottling, organic matter status, particle size, inclusions and stoniness properties. These permitted identific tion of discrete horizons. The second class included structure, organisms, phosphate spot test value, mean horizon thickness, mean horizon orientation and horizon continuity. These properties indicate the organisation within and between horizons and potential causes of that organisation. On the basis of horizon organisation it maybe possible to make comment on the function of deep top soils and farm mounds.

Examination of "organisational" field properties is taken a stage further with the farm mounds by subjecting this data to cluster analysis. A coefficient of similarity was calculated for the 97 discreet horizons recognised in the Westbrough and Skelbrae farm mounds. Gowers Coefficient of Similarity (Gower, 1972) was used because it allowed for dichotomous, qualitative and

FIELD PROPERTIES OF SOILS AND SEDIMENTS IDENTIFIED

Field Colour

Hue
Value
Chroma

Mottling

Abundance
Size
Contrast
Boundary Sharpness
Colour

Organic Matter Status

Particle Size Class

Stoniness

Size
Abundance
Shape

Structure

Ped shape
Ped size
Ped grade

Organisms

Root size
Root nature
Root abundance

Phosphate Spot Test Value

(After Hammond, 1983)

High
Medium
Low

Inclusions

Type
Abundance
Size
Colour

Mean Horizon Thickness

Mean Horizon Orientation (estimated)

$<1^{\circ}$
$1-5^{\circ}$
$5-10^{\circ}$
$10-15^{\circ}$
$15-20^{\circ}$

Horizon Continuity (% of profile breadth)

1-20
21-40
41-60
61-80
81-100

quantatative data in the calculation of similarity. A computer programme written by Don Evans of Strathclyde University Computer Advisory Centre calculated Gowers Coefficient of Similarity for the 97 horizons on a Commodore Pet microcomputer. This matrix was then edited and transferred to the EMAS 2988 mainframe computer in Edinburgh and fed directly into the HIERARCHY procedure of the Clustan package (Wishart, 1978). In an attempt to achieve the best grouping three methods were used, single linkage, furtherest neighbour linkage and average linkage. Each grouping method was used with both a minimum of two and a maximum of eight and a minimum of two and a maximum of twenty clusters. This gave six dendrograms from which to identify groupings of horizon types in the farm mounds.

2. Micromorphology

Thirteen thin sections were prepared by Dr E A FitzPatrick, Department of Soil Science, Aberdeen University. Six came from farm mounds, six from the West Howe deep top soil unit and one Control from undisturbed hill land. Full details of thin section preparation are given in FitzPatrick (1980) and are not repeated here. An important procedure used was the acetone replacement of water in the specimen prior to impregnation with resin. This meant that there was little or no shrinkage and cracking of the specimen due to drying.

Viewing of the thin sections was carried out under plane, polarized, reflected and circular polarized light at magnifications ranging from x 10 to x 100. Description of the 10 x 3.5cm thin sections was carried out according to the terminology of FitzPatrick (1980) to which reference should be made. This system proved easier to use than that of Brewer (1964).

3. Total Phosphate Analysis

Extraction of total phosphate from the soil sample was achieved by fusion with Na_2CO_3 (Jackson, 1958). A sub sample of the soil was ground to 180um. 4g of Na_2CO_3 was weighed and c 1g of this placed in a platinum crucible. 0.5g of $<$180um soil was placed in the crucible and mixed with a further c 2g Na CO_3. The remaining 1g of Na_2CO_3 covered the mixture. The crucible was heated over a bunsen burner (propane gas) to drive off excess moisture, the lid placed on the crucible, the mass gently fused and then heated at full blast for ten minutes. After this period the crucible was removed from the heat and rotated using platinum tipped tongs so that the melt was deposited in a thin layer on the side of the crucible. This was then left to cool. Once cool the crucible was placed in a 400ml beaker (rendered phosphate free by soaking in concentrated H_2SO_4) with c 125ml deionised water and digested on a hot plate for two hours. The melt was then removed from the crucible using a rubber tipped glass rod and deionised water. Crucible and lid were then placed in boiling 6N HCl to clean them while the sample digested for a further thirty minutes whereafter it was cooled and washed into a 250ml volumetric flask and made up to the mark. The suspension was then filtered through No 41 ashless filter paper (Whatmans) into a clean polythene bottle. Colorometric determination was carried out against a blank determination using a WPA S107 spectrophotometer at 640nm by the Ammonium molybdate/ Stannous chloride procedure. The amount of phosphate in solution was calculated from a calibrated curve and expressed in terms of mgP_2O_5/100g. Analytical error was estimated at $\pm$ 15mg/100g for deep top soil material and $\pm$ 19mg/100g for farm mound material. This error was estimated from five replicate samples in each type of material.

Statistical analysis of the results from the deep top soils was by trend surface analysis (Unwin, 1975) using a University of Liverpool, Department of Geography microcomputer package on a Commodore Pet computer. Up to five orders were calculated, tested for significance and plotted together with the residual values. The total phosphate values for the farm mounds were analysed as a function of depth using linear regression, polynomial regression (up to four orders) and curvilinear regression using Biostatistics Package III on an Apple 11e microcomputer.

4. Phosphate Fractionation Analysis

This was carried out following the procedures of Eidt (Eidt and Woods, 1974; Eidt, 1977; 1984). Fractionation of samples was carried out four at a time. All glassware and centrifuge tubes were rendered phosphate free by soaking overnight with concentrated H_2SO_4 or, latterly, with Decon-90 detergent.

Extraction of Phosphate Fractions 1g air dried, lightly ground, seived 500um soil was shaken with 20ml 0.1N NaOH and 20ml NaCl for 12 hours on an end-over-end shaker in a 50ml polypropylene centrifuge tube. The sample was then centrifuged for 30 minutes at 2500rpm and the supernatent decanted to a 50ml volumetric flask. This supernatent is Fraction 1a. The soil remaining in the centrifuge tube was washed by adding 25ml 1N Na Cl, shaken on the shaking machine for 3 minutes and centrifuged for 30 minutes at 2500rpm, discarding the supernatent and repeating the process. The sample was then transferred to a 250ml polypropylene centrifuge tube with 50ml 0.22M Na-citrate/0.11M Na-bicarbonate solution and placed in an 82^{o}C waterbath for 15 minutes. Approximately 30 minutes was needed to bring the sample to 82^{o}C. Stirring of the sample was done every 3 minutes. After the waterbath treatment the sample was allowed to cool to room temperature and then centrifuged for 15 minutes at 2500rpm. The supernatent was transferred to a 100ml volumetric flask and one drop 0.9M Fe Cl_3 in 0.04N HCl added. This represented Fraction 1b. The sample was then washed and centrifuged as in the procedure above and 50ml 0.22N Na-citrate/ 0.11N Na-bicarbonate added to the sample in the centrifuge tube. The waterbath treatment was repeated except that after the sample temperature had reached 82^{o}C 1g Na-dithionite was added. After cooling to room temperature and centrifuging for 15 minutes at 2500 rpm the supernatent was transferred to a 100ml volumetric flask. 25ml of 1.0N Na Cl was added to the remaining soil sample, shaken for 3 minutes, and centrifuged for 10 minutes at 2500 rpm. The supernatent was then added to the volumetric flask containing the Na-citrate/Na-bicarbonate/Na-dithionate extractant. One drop of 0.9M Fe Cl_3 in 0.04N HCl was then added. This extractant was allowed to stand at least eight days to allow oxidation of the dithionite. This is Fraction 2. Oxidation was recognised by a change in the colour of the extractant from clear to straw coloured. The sample remaining was again washed by the above procedures. After washing, 40ml 1N HCl was added to the sample in the centrifuge tube and shaken for four hours on the end-over-end shaker. After centrifuging for 15 minutes at 2500rpm the supernatent was decanted to a 50ml volumetric flask. This is Fraction 3.

Clearing Organic Carbon from Fractions 1a and 1b Before colorimetry could be carried out on these fractions it was necessary to clear the organic carbon in solution. Three reagents were tried in an effort to clear the carbon, activated charcoal in 2.7N H_2SO_4 (Eidt, 1974), 0.05% aqueous polyacrylamide (Banderis et al 1975) and 2.5M H_2SO_4 (Banderis et al 1975; Chang and Jackson, 1957). In practice it proved impossible to render the activated charcoal phosphate free despite considerable concentrated HCl treatment. Addition of aqueous polyacrylamide to the extractant prior to shaking did serve to clear the solution but not sufficient to allow colorimetry. The addition of 2ml 2.5M H_2SO_4 to 10ml of the Fraction 1a and 1b supernatent followed by centrifuging for 10 minutes at 1500rpm was sufficient to clear the solution prior to colorimetry. This dilution needs to be taken into account when calculating the amount of phosphate in a solution.

Colorimetry Colorimetry of Fractions 1a and 4 was carried out by Murphy-Riley solution (Murphy and Riley, 1962) on a WPA S107 spectrophotometer set at 882.5nm. The machine was calibrated using extrantants spiked with known quantities of phosphorous. Colorimetry of Fractions 1b and 2 was carried out by pippetting a 2ml aliquot of the extract into a 25ml volumetric flask. 4ml of dionised water was then added followed by 2ml amnonium molybdate (Watanabe-Olsen) reagent and 6ml of stannous chloride dilute solution. Colorimetric determination was made on a WPA S107 spectrophotometer at 725nm. Standards and blanks were prepared in the normal way using extract and spiking with known amounts of phosphorous. An alternative color-metric procedure to that above is the isobutyl alcohol method (Eidt and Woods, 1974; Watanabe and Olsen, 1962) but this is more time-consuming and more difficult compared to that outlined above.

The amounts of phosphate in the extract solution was interpolated from calibration curves. Analytical error from five replicate samples is $\pm$ 1.6% for Fraction 1, 1.9% for Fraction 2 and 0.9% for Fraction 3. The error is therefore low.

Reagents

0.1N Na OH	Stock solution
1.0N Na Cl	58.44g Na Cl/litre H_2O
H_2O	Deionised
0.22M Na-citrate/ 0.11M Na-bicarbonate solution	64.70g Na-H-citrate and 9.24g NaH CO_3 in 1 litre H_2O
Na-dithionite	Stock material
0.9M Fe Cl_3 in 0.04N HCl	136.06g Fe $Cl_3.H_2O$ dissolved in 475ml H_2O. 1.7ml concentrated HCl is added and the solution brought to 500ml volume with H_2O
1.0M HCl	83ml concentrated HCl/litre H_2O.
Ammonium Molybdate reagent (for Watanabe-Olsen colorimetry)	Dissolve 50g Ammonium Molybdate in a 1000ml volumetric flask with 500ml deionised water. Add 400ml 10N H_2SO_4 and bring to volume with H_2O.
10N H_2SO_4	278ml concent.H_2SO_4 made up to 1 litre with H_2O
2.5M (5N) H_2SO_4	139ml concent.H_2SO_4 made up to 1 litre with H_2O
0.25% p-nitrophenol indicator	
Stannous Chloride stock solution	Weigh 10g $SnCl.2H_2O$ and dissolve crystals in a 50ml beaker containing 25ml concentrated HCl. Store under refrigeration in a glass bottle. Keeps for only twelve days.
Stannous Chloride dilute solution	Dilute 1ml of Stannous Chloride stock solution,which has been allowed to come to room temperature,to 200ml with 1.0N H_2SO_4. Prepare daily.
Ammonium Molybdate reagent (for Murphy-Riley colorimetry)	20g of Ammonium Molybdate dissolved in 500ml H_2O.
0.1M Ascorbic Acid	Dissolve 1.32g of Ascorbic Acid in 75ml H_2O. Prepare daily.
Potassium Antimonyl Tartrate	Dissolve 0.2743g of Potassium Antimonyl Tartrate in H_2O and dilute to 100ml.

5. Accessory Techniques; Bulk, Density and pH

Bulk Density Bulk Density was determined in the laboratory to allow the results of total phosphate analysis to be presented in mg/cm-3. Expressed in this way, the total phosphate results take into account any variation there may be in the density of samples taken for analysis. It allows for the fact that although the same weight of material may have been used for analysis of different samples, the amount of material used varies.

The procedure adopted to determine bulk density was that of the West of Scotland College of Agriculture (unpublished manuscript). Approximately 25g of seived 2mm air dried soil was accurately weighed and carefully transferred to a dry 100ml plastic measuring cylindar with the aid of a brush. The cylinder was gently tapped as the soil was added. The volume of soil was recorded and bulk density was calculated by the equation

$$g/cm^{-3} = \frac{Wt}{Vt}$$

Where Wt = weight of air dried soil(g)
and Vt = volume of air dried soil(cm^{-3})

Results were then expressed on an oven dry basis.

pH Determination of soil pH was carried out on those samples used for phosphate fractionation as pH values assist the interpretation of phosphate fractionation values. The method used is that of the Macaulay Institute for Soil Research (unpublished manuscript). 15g of $<$ 2mm air dried soil was mixed with 45ml deionised water in a clean glass bottle. The bottle was thoroughly shaken and allowed to stand for four hours after which the pH of the suspension was measured using a glass electrode andcalibrated Kent pH meter.

THIN SECTION DESCRIPTIONS

CONTROL PROFILE : 8-18CM

Brief Description

Examination of the thin section for areas of relative uniformity by holding it up to a light source identified three areas of comparative uniformity based on structure and stone distribution.

The section is from an A horizon and the current land use is rough grazing.

Zone 1

Structure : Subangular blocky, strongly accordant, incomplete 9mm x 5mm peds, dominant, smooth to bulbious surface characteristics, random distribution pattern, intimate relationship between features, random orientation.

Pores (i) Continuous Pores : Incomplete, frequent 2 x 12mm, tuberose, rounded tabular, dendritic with some crescentic, unrelated, almost vertical, moderately orientated, parallel to aggregates, loosely infilled with faecal material.

Pores (ii) Discrete Pores : Occasional, very small, crescentic to granular, subrounded ovoid, smooth, rounded, intra-related, random orientation.

Passages : Very frequent, distinct contrast, many filled with faecal material, circular to ovoid, 1 x 0.25mm, smooth, random, unrelated, random orientation, because some passages are filled with faecal material as described below they appear well integrated with the general soil matrix.

Faecal Material(i) Arthropod : 7.5YR 5/6 (slightly lighter than general matrix) 7.5YR 3/2 (slightly darker than general matrix), abundant, faint contrast, very small, ovoid, rounded smooth, abrupt to diffuse, clustered, intra-related with pores or decomposing plant material, random orientation, frequently incorporates the intra-related material, highly integrated, passage filling is dominant, high degree of assimilation.

Faecal Material (ii) Enchytrid Worm : 7.5YR 5/6, occasional, faint contrast, medium, vermicular, rounded, smooth, clear, uneven, intra-related, passage filling is very abundant, highly integrated, assimilated into matrix.

Organic Materials : All stages of decomposition are observed but the three stages below are dominant -
(i) Slightly Decomposed 7.5YR 3/2, occasional,

marked contrast, medium, circular, random distribution, unrelated to similar features.

(ii) Strongly Decomposed 7.5YR 4/2, occasional, distinct contrast, small, ovoid, rounded, random distribution pattern, unrelated to similar features, dominantly decomposing plant material.

(iii) Charcoal Opaque, 7.5YR 2.5/0, rare, medium, marked contrast, tabular, angular, random, unrelated.

Rock Fragments : None

Detrital Grains : Occasional quartz/feldspar

Average Particle Size Distribution : 2-20um (estimated)

Fine Material/Matrix : 7.5YR 5/4, brown, complete matrix surrounding pores, no colour pattern. Very rare aniso ropic areas, yellow domains, very short, very narrow, random distribution and orientation.

Other Characteristics : Fungal hyphae evident.

Zone 2

Structure : Crumb, weak degree of accordance, small peds, dominant, irregular, subrounded, subspherical, slightly rough, random, unrelated, random orientation.

Pores (i) Continuous Pores : Incomplete, abundant, 3 x 1.25mm, medium, irregular, rough, random, inter-related, random orientation.

Pores (ii) Discrete Pores : Occasional, very small, crescentic to granular, subrounded, ovoid, smooth, random, intra-related, random orientation.

Passages : Very frequent, distinct, medium, circular, smooth, predominantly random with some grouped, random orientation, filled with faecal material of virtually the same colour as general matrix.

Faecal Material (i) Arthropod : 7.5YR 5/6, occasional, faint contrast, very small, ovoid, rounded, smooth, diffuse, clustered, intra-related with pores, random orientation, incorporates the intra-related material, highly integrated, passage filling is dominant, high degree of assimilation.

Faecal Material (ii) Enchytrid Worm : 7.5YR 5/6, abundant, very faint contrast, medium vermicular as a whole unit (individual units are contained within the whole unit), smooth, clear uneven, intra-related, very abundant passage filling, highly integrated, assimilated into matrix.

Organic Materials (i) Completely and Very Strongly Decomposed : 5YR 4/6 and 7.5YR 6/8, occasional, distinct contrast, small to medium fragments, circular to linear in shape, random, intra-related with general matrix.

Organic Materials (ii) Charcoal : Opaque, 7.5YR 2.5/0, occasional, small, marked contrast, tabular, angular, random, unrelated.

Rock Fragments : Rare, some evidence of bleached rims (see Zone 3 below).

Detrital Grains : Frequent quartz/ feldspar.

Average Particle Size Distribution : 2-20um (estimated).

Fine Material/Matrix : 7.5YR 5/4, brown, complete matrix, surrounding pores, no colour pattern. Very rare aniotropic areas, yellow domains, very short, very narrow, random distribution pattern, random orientation.

Zone 3

Structure : Fine subangular blocky, strongly accordant, dominant, large, blocky, subangular, subspherical, wavy to smooth boundary, random, inter-related with pore space.

Pores (i) Continuous Pores : Abundant, large sinuous, angular inter-related, tabular, smooth to wavy, random, random orientation.

Pores (ii) Discrete : (Probably passages for roots - evidence of root remains). Occasional, medium, circular rounded, ovoid, smooth, random.

Passages : (Sometimes difficult to distinguish what are passages and what are pores).

Faecal Material : Earthworm faecal material only. Otherwise as for Zone 2 above.

Organic Materials (i) Strongly Decomposed : 5YR 5/6, rare, small to medium fragments, circular to linear in shape, random, intra-related to general matrix.

Organic Materials (ii) Charcoal : Opaque 7.5YR 2.5/0, occasional, small, marked contrast, tabular, angular, random, unrelated.

Rock Fragments : Frequent, marked contrast, large, irregular, subangular, ovoid, weakly manilated, random, intra-relational within general matrix, random orientation, rock structure well preserved. Surface residues of rock fragment characteristics: colour of rock = 7.5YR 3/3, colour of surface residue = 10YR 6/1, thickness = up to ¼mm, occasional, random distribution pattern.

All other characteristics as for Zone 2 above.

WEST HOWE PROFILE 13, 20-30CM

Brief Description

The thin section is uniform in terms of structure and texture. Two tones of matrix colour can however be observed by visual inspection. Passages are an important component part of this thin section.

Structure and Pores : Alveolar structure, probably welded. Pores are all discrete, occasional, ovoid to planar shape, rounded, slightly rough surface characteristics, random unrelated distribution pattern, random orientation. Pores are frequently lined with silt and occasionally with clay.

Passages : Frequent, marked contrast when not filled, very faint contrast when filled with matrix material, circular and sinuous shapes observed, slightly rough surface characteristics, random unrelated distribution pattern, random orientation. Filling where present is the same as the matrix.

Faecal Material : Some passage filling may be earthworm casts. Rare arthopod pellets, 10YR2.5/1, ovoid, distinct contrast, well rounded, smooth surface characteristics, random distribution pattern, random orientation.

Organic Materials : Rare, strongly decomposed to very strongly decomposed, 10YR3/1 to 10YR2.5/1, marked contrast, irregular shape, no interference colours, random unrelated distribution pattern, random orientation.

Rock Fragments : Occasional, distinct to marked contrast, ovoid to tabular, subrounded, no surface residues, random unrelated distribution pattern, random orientation.

Detrital Grains : Frequent quartz/feldspar.

Average Particle Size Distribution : 20-50um (estimated)

Fine Material/Matrix : Composite colours, dominantly 10YR4/3 with darker zones of 10YR3/2. Darker zones are irregular in shape and size and have random orientation and random distribution pattern. Occasional domains observed.

Additional Observations : A few fungal hyphae observed.

WEST HOWE PROFILE 13, 40-50CM

Brief Description

Two discrete areas can be seen in this thin section based on colour differences. A lighter coloured matrix occupies the left central part of the thin section.

Zone 1 (The darker coloured matrix)

Structure and Pores : Alveolar structure. Pores are all discrete, ovoid to planar shape, occasional, rounded, slightly rough surface characteristics, random unrelated distribution pattern, random orientation. Pores are frequently lined with silt and occasionally with clay.

Passages : Rare, marked contrast when not filled (other passages maybe filled with matrix material and therefore cannot now be seen), circular, ovoid and sinuous shapes observed, slightly rough surface characteristics, random unrelated distribution, random orientation.

Faecal Material : Rare arthopod pellets, 10YR2.5/1, ovoid, smooth to slightly rough surface characteristics, distinct contrast, well rounded, random distribution, random orientation.

Organic Materials : Occasional, strongly decomposed to very strongly decomposed and charcoal, 10YR3/1 to 10YR2.5/1 and 7.5YR3/1, marked contrast, irregular shape, no interference colours, random unrelated distribution pattern, random orientation.

Rock Fragments : Rare, distinct contrast, ovoid, subrounded, no surface residues, random unrelated distribution pattern, random orientation.

Detrital Grains : Frequent quartz/feldspar.

Average Particle Size Distribution : 20-50um (estimated).

Fine Material/Matrix : Composite, dominantly 10YR4/4 with small zones of 10YR3/3, occasional domains.

Zone 2

As for Zone 1 except -

Matrix : 10YR5/4.

WEST HOWE PROFILE 18, 20-30CM

Brief Description

This section contains a complex matrix colour pattern. Six distinct zones can be identified by colour differences. Apart from these colour differences there is a variation in passage occurrence. Passages are more prevalent in the top right area of the thin section. An infilled passage dominates the centre right.

Only colour and occurrence of passages vary within this thin section. Descriptions below apply to each of the discrete areas.

Structure and Pores : Alveolar structure. Pores are all discrete, ovoid to planar shape, frequent, rounded, slightly rough surface characteristics, random unrelated distribution pattern, random orientation. Pores are frequently lined with silt and occasionally with clay.

Faecal Material : Rare arthopod pellets, 10YR2.5/1, ovoid, smooth to slightly rough surface characteristics, distinct contrast, well rounded, random distribution, random orientation.

Organic Materials : Occasional, strongly decomposed to very strongly decomposed and charcoal, 10YR3/1 to 10YR2.5/1, marked contrast, irregular shape, no interference colours, random unrelated distribution pattern, random orientation.

Rock Fragments : Occasional, distinct contrast, tabular to subspherical, subrounded. Rare surface weathering, colour of rock, 7YR3/3, colour of residue 10YR6/1 ½mmthick, random unrelated distribution pattern, random orientation.

Detrital Grains : Frequent quartz/feldspar.

Average Particle Size Distribution : 20-50um (estimated).

Passages and Matrix Characteristics of the Six Zones:

Zone 1

Passages : Rare, marked contrast when not filled, irregular to planer shape, well rounded, smooth to slightly rough surface characteristics, random unrelated distribution, random orientation.

Fine Material/Matrix : Composite, dominantly 10YR5/3 with small areas of 10YR3/3, occasional domains.

Zone 2

Passages : Frequent, marked contrast when not filled, sinuous to irregular shape, well rounded, smooth to slightly rough surface characteristics, random unrelated distribution, random orientation.

Fine Material/Matrix : Composite, dominantly 10YR3/3 with areas of 10YR5/3, occasional domains.

Zone 3 (Large infilled passage)

Passages : Rare micro-passages, marked contrast, smooth to slightly smooth surface characteristics, ovoid to irregular shape, random unrelated distribution pattern, random orientation.

Fine Material/Matrix : 10YR4/4, occasional domains.

Zone 4

Passages : None

Fine Material/Matrix : 10YR3/3, occasional domains.

Zone 5

Passages : None

Fine Material/Matrix : 10YR4/3, occasional domains.

Zone 6

Passages : Rare, marked contrast when not filled, smooth to slightly smooth surface characteristics, ovoid to planer shape, well rounded, random unrelated distribution pattern, random orientation.

Fine Material/Matrix : 10YR3/3, isotropic.

WEST HOWE PROFILE 18, 40-50CM

Brief Description

A triangular shaped lighter coloured zone dominates the centre left portion of the thin section. A darker matrix is found over the remaining portion of this section.

Zone 1

Structure and Pores : Alveolar structure. Pores are all discrete, ovoid to planar to irregular shape, frequent, rounded, slightly rough surface characteristics, random unrelated distribution pattern, random orientation. Pores are frequently lined with silt and occasionally with clay.

Passages : Rare, marked contrast when not filled, ovoid to sinuous shape, well rounded, smooth to slightly rough surface characteristics, random unrelated distribution pattern, random orientation. One large empty passage dominates the bottom right of the section.

Faecal Material: : Rare arthropod pellets, 10YR2.5/1, ovoid, smooth to slightly rough surface characteristics, distinct contrast, well rounded, random distribution pattern, random orientation.

Organic Materials : Occasional, very strongly decomposed and charcoal, 10YR3/1 to 10YR2.5/1, marked contrast, irregular shape, no interference colours, random unrelated distribution pattern, random orientation.

Rock Fragments : Occasional, distinct contrast, tabular to subspherical, subrounded, no surface weathering, random unrelated distribution pattern, random orientation.

Detrital Grains : Frequent quartz/feldspar.

Average Particle Size Distribution : 20-50um (estimated).

Fine Material/Matrix : 10YR3/2, occasional domains.

Zone 2

As for Zone 1 except -

Matrix : 10YR5/2

WEST HOWE PROFILE 23A, 20-30cm

Brief Description

Two discrete areas can be seen in this section based on colour differences. A darker coloured matrix dominates the upper portion of the thin section and a lighter coloured matrix the bottom portion. The interface of the two zones is diagonal. Small areas of darker coloured material occur.

Zone 1 (The darker coloured matrix)

Structure and Pores : Alveolar structure. Pores are all discrete, ovoid to planar shape, frequent, rounded, slightly rough surface characteristics, random unrelated distribution pattern, random orientation. Pores are frequently lined with silt and occasionally with clay.

Passages : Rare, marked contrast when not filled (other passages may be filled with matrix material and therefore cannot now be seen), laminar to prolate shape, tabular, well rounded, slightly rough surface characteristics, random unrelated distribution pattern, vertical orientation.

Faecal Material : Rare arthopod pellets, 10YR2.5/1, ovoid, smooth to slightly rough surface characteristics, distinct contrast, well rounded, random distribution pattern, random orientation.

Organic Materials : All organic materials appear to have been incorporated into the general matrix.

Rock Fragments : Occasional, distinct contrast, ovoid to tabular, subrounded. Rare surface weathering, colour of rock, 7.5YR3/3, colour of residue 10YR6/1 ½mm thick, random unrelated distribution pattern, random orientation.

Detrital Grains : Frequent quartz/feldspar

Average Particle Size Distribution : 20-50um (estimated)

Fine Material/Matrix : Composite, 10YR3/, 10YR3/2, occasional domains.

Zone 2

As for Zone 1 above except -

Passages : Occaxional, marked contrast when not filled, circular, ovoid and sinuous shapes observed, slightly rough surface characteristics, random unrelated distribution pattern, random orientation.

Organic Materials : Rare, strongly to very strongly decomposed, 10YR3/1, distinct contrast, irregular shape, no interference colours, random unrelated distribution pattern, random orientation.

Fine Material/Matrix : Composite, dominantly 10YR5/3 with patches of 5YR6/6 and 10YR4/3.

WEST HOWE PROFILE 23A, 30-40CM

Brief Description

This thin section can be considered as a whole. The major distinguishing feature of this section is the abundance of rock fragments in the lower half.

Structure and Pores : Alveolar structure. Pores are all discrete, ovoid to planar shape, frequent, rounded, slightly rough surface characteristics, random unrelated distribution pattern, random orientation. Pores are frequently flined with silt and occasionally with clay.

Passages : Rare, marked contrast when not filled, ovoid to sinuous to irregular shape, well rounded, tabular, smooth to slightly rough surface characteristics, random unrelated distribution pattern, random orientation.

Faecal Material : Rare arthopod pellets, 10YR2.5/1, ovoid, smooth to slightly rough surface characteristics, distinct contrast, well rounded, random distribution pattern, random orientation.

Organic Materials : Occasional, very strongly decomposed and charcoal, 10YR3/1 to 10YR2.5/1, marked contrast, irregular shape, no interference colours, random unrelated distribution pattern, random orientation.

Rock Fragments : Occasional becoming very abundant in the lower half of the section, distinct contrast, tabular to subspherical, subrounded, rare surface weathering(?), random unrelated distribution pattern, random orientation.

Detrital Grains : Frequent quartz/feldspar.

Average Particle Size Distribution : 20-50um (estimated)

Fine Material/Matrix : 10YR4/4, occasional domains.

WESTBROUGH PROFILE 2, 96-106CM

Brief Description

Eight discrete areas of different colour and texture can be identified. These eight areas are organised in a laminar fashion. A large circular channel dominates the centre of the thin section.

Zone 1

Structure and Pores : Alveolar, welded structure. Pores are all discrete, occasional, ovoid to planar in shape, subrounded, slightly rough characteristics (at x 50 magnification), random unrelated distribution pattern, random orientation.

Passages : Occasional marked contrast, circular shape, slightly rough surface characteristics, random unrelated distribution pattern. Filling = 10YR 2.5/1, strongly decomposed organic material with no interference colours, contains occasional mineral grains dominantly quartz.

Faecal Material : Passage filling is considered to be earthworm casts, otherwise no faecal material.

Organic Materials : Strongly decomposed to very strongly decomposed, 10YR 3/1, rare, marked contrast, irregular shape, no interference colours, random unrelated distribution pattern, random orientation.

Rock Fragments : None.

Detrital Grains : Frequent quartz/feldspar.

Average Particle Size Distribution : 20-50um (estimated)

Fine Material/Matrix : 10YR 4/2 with small 10YR 5/3 zones, dominant, isotropic.

Zone 2

Structure and Pores : Alveolar, welded structure. Pores are discrete, occasional, ovoid to planar in shape, ovoid to tabular sphericity, subrounded, slightly rough surface characteristics, random unrelated distribution pattern, random orientation.

Passages : Rare, marked contrast, moderately rough, random unrelated distribution pattern, random orientation. Filling as in Zone 1.

Organic Materials : Occasional, remaining characteristics as for Zone 1. Several phytoliths evident, frequently fragmented, only one type, comb-like surface characteristics. Some evidence of badly decomposed pollen.

Rock Fragments : None.

Detrital Grains : Frequent quartz/feldspar.

Average Particle Size Distribution : 20-50um (estimated)

Fine Material/Matrix : Composite, colours are 10YR 3/2, 10YR 5/3, 10YR 4/2, 10YR 6/3. Isotropic.

Zone 3

As for Zone 1 except Matrix colour is 10YR 3/3.

Zone 4

As for Zone 1 except -

Pores	Frequent
Passages	No filling, some lined with darker 10YR 3/2 and 10YR 2.5/1 amorphous organic material, rough, broken (ie does not surround whole of passage).
Matrix	10YR 6/2 colour.

Zone 5

As for Zone 2.

Zone 6

This Zone represents a thin discontinuous band lying on the surface of a dark organic horizon, Zone 7.

Structure and Pores : Massive structure, no pores.

Passages : None.

Faecal Material : None.

Organic Material : Rare, 10YR 2.5/1, marked contrast, irregular shape, no interference patterns, random distribution pattern, random orientation, strongly decomposed.

Rock Fragments : None.

Detrital Grains : Frequent quartz/feldspar.

Average Particle Size Distribution : 20-50um (estimated).

Fine Material/Matrix : 10YR 6/4, isotropic.

Zone 7

Structure and Pores : Spongy, but with slightly welded appearance. Continuous pores; frequent, bladed, tabular or spherical, angular to subangular roundness, slightly rough anastomosing distribution pattern, random orientation. Discrete pores; abundant, ovoid, subrounded, slightly rough, random distribution pattern, random orientation.

Passages : (Distinct from pores because of larger size). Rare, marked contrast, ovoid, slightly rough, random distribution pattern, random orientation, normally no filling but in some passages occasional filling of Zone 3 material.

Faecal Material : Difficult to recognise in this matrix but some ovoid arthropod pellets observed.

Organic Materials : This zone is dominantly organic material, amorphous and strongly decomposed.

Rock Fragments : Rare, marked contrast, laminar, tabular, angular, random distribution pattern, random orientation, slightly rough surface characteristics, no surface residues, embedded in general matrix.

Detrital Grains : Frequent quartz/feldspar.

Average Particle Size Distribution : 20-50um (estimated).

Fine Material/Matrix : 10YR 2.5/1, isotropic.

Zone 8

As for Zone 2.

WESTBROUGH PROFILE 2, 174-184CM

Brief Description

Four discrete areas of different colour/texture within the generally peaty matrix could be identified by visual inspection. The boundaries of these areas are diffuse except the midden-like material in the top left corner. An infilled channel dominates the left of the thin section. The general matrix exhibits a whorled pattern.

Zone 1 ("Midden" Material)

Structure and Pores : Alveolar structure. Pores are all discrete, occasional, ovoid, subrounded, slightly rough surface characteristics, random distribution pattern.

Passages : None.

Faecal Material : None.

Organic Materials : Moderately to strongly decomposed, 10YR2.5/1, occasional, marked contrast, ovoid, subangular, moderately rough, no interference colours.

Rock Fragments : None.

Detrital Grains : Frequent quartz/feldspar, marked contrast.

Average Particle Size Distribution : Not applicable.

Fine Material/Matrix : 5YR 4/3, isotropic.

Zone 2 (Peaty Material)

Structure and Pores : Alveolar. Pores are all discrete, occasional, ovoid, subrounded, slightly rough, random unrelated distribution pattern, random orientation.

Passages : None.

Faecal Material : Occasional black (10YR2.5/1) arthropod pellets.

Organic Materials : Moderately to strongly decomposed, no interference colours, entire zone is an organic fabric.

Rock Fragments : None.

Detrital Grains : Frequent quartz/feldspar.

Average Particle Size Distribution : Not applicable.

Fine Material/Matrix : 5YR 4/3, isotropic.

Zone 3 (Peaty Material)

Structure and Pores : Massive structure, pores rare.

Passages : None.

Faecal Material : None.

Organic Materials : Moderately to strongly decomposed, no interference colours, entire zone is an organic fabric.

Rock Fragments : Rare, marked contrast, ovoid, subangular, no surface characteristics, random unrelated distribution pattern, random orientation.

Detrital Grains : Occasional quartz/feldspar.

Average Particle Size Distribution : Not applicable.

Fine Material/Matrix : Composite colours, 5YR4/3, 5YR 3/2, 5YR3/3, isotropic.

Zone 4 (Very badly decomposed organic horizon)

Structure and Pores : Massive, no pores.

Passages : None

Faecal Material : None

Organic Materials : Moderately to strongly decomposed, no interference colours, entire zone is an organic fabric.

Rock Fragments : Rare, marked contrast, ovoid, subangular, no surface residues, random unrelated distribution pattern, random orientation.

Detrital Grains : Occasional quartz/feldspar.

Average Particle Size Distribution : Not applicable.

Fine Material/Matrix : Composite colours, 10YR4/3, 10YR4/4, isotropic.

Root Channel Filling: 10YR4/3, granual material, dendritic distribution pattern.

WESTBROUGH PROFILE 2, 206-216CM

Brief Description

Four discrete areas of different densities and pore occurrence can be observed in this peaty matrixed thin section. Ignoring the differences in density it would be possible to treat the thin section as a whole.

Zone 1

Structure and Pores : Spongy to alveolar, a welded structure. Pores are all discrete, rare, dominantly laminar but some are ovoid, tabular, rounded, slightly rough characteristics, random distribution pattern, often associated with moderately decomposed organic material, laminar pores are horizontal and strongly orientated, ovoid pores have random orientation.

Passages : None.

Faecal Material : None

Organic Material : Entire thin section is dominantly organic, moderately to strongly decomposed, 5YR3/2.

Rock Fragments : Rare, marked prominence, ovoid, subangular, no surface residues, random unrelated distribution pattern, random orientation.

Detrital Grains : Occasional quartz/feldspar.

Average Particle Size Distribution : Not applicable.

Fine Material/Matrix : 5YR 3/2 organic material, isotropic.

Zone 2

As for Zone 1 except -

Structure and Pores : Pores are discrete, occasional, 50% lenticellular and 50% ovoid.

Fine Material/Matrix : composite, 5YR 4/3 is dominant colour, other colours are 5YR 5/3 and 5YR 3/2.

Zone 3

As for Zone 1 except -

Structure and Pores : Pores are smaller in size, 50% lenticellular and 50% ovoid.

Fine Material/Matrix : composite, dominant colour is 5YR 3/2, patches of 5YR 2.5/2.

Zone 4

As for Zone 1 except -

Structure and Pores : Pores are smaller in size, 50% lenticellular and 50% ovoid.

Fine Material/Matrix : Composite, dominant colour is 5YR 4/3, with patches of 10YR 4/3.

SKELBRAE PROFILE 1, 78-88CM

Brief Description

The thin section is uniform in terms of colour and texture. Components such as stones, charcoal flecks and pores are randomly distributed.

Structure and Pores : Alveolar structure. Pores are discrete, abundant, circular, ovoid and irregular, slightly rouugh characteristics, random distribution pattern, random orientation.

Passages : Occasional, marked contrast when observed, slightly rough characteristics, linear, random distribution pattern, random orientation pattern. Occasional filling with granual matrix material (other passages may now be completely infilled).

Faecal Material : None. (None evident but maybe now fully incorporated into the general matrix).

Organic Materials : Occasional, moderately to strongly decomposed. Charcoal, 10YR 2.5/1. Random orientation, random distribution pattern, ovoid to irregular.

Rock Fragments : Occasional, marked contrast, subangular, tabular to subsperical, slightly rough surface characteristics, random distribution pattern, random orientation. Red coloured rock fragments show evidence of surface weathering (¼mm thick). Lighter coloured rock fragments show no evidence of surface weathering.

Detrital Grains : Frequent quartz/feldspar.

Average Particle Size Distribution : 20-50um (estimated).

Fine Material/Matrix : Composite, dominantly 10YR3/3 with 10YR4/3, isotropic.

SKELBRAE PROFILE 1, 100-120 CM

Brief Description

The thin section is uniform in terms of colour and texture. Components such as stones, charcoal flecks and pores are randomly distributed.

Structure and Pores : Alveolar structure. Pores are discrete, abundant, circular, ovoid and irregular, slightly rough surface characteristics, random distribution pattern, random orientation.

Passages : Occasional, marked contrast when observed, slightly rough surface characteristics, linear, random distribution pattern, random orientation pattern, occasional filling with granular matrix material (other passages may now be completely infilled).

Faecal Material : None. (None evident, but maybe now fully incorporated into the general matrix).

Organic Materials : Occasional, moderately to strongly decomposed and charcoal, 10YR 2.5/1, random orientation, random distribution pattern, ovoid to irregular.

Rock Fragments : Occasional, marked contrast, subangular, tabular to subspherical, slightly rough surface characteristics, random distribution pattern, random orientation. Red coloured rock fragments show evidence of surface weathering (¼mm thick). Lighter coloured rock fragments show no evidence of surface weathering.

Detrital Grains : Frequent quartz/feldspar.

Average Particle Size Distribution : 20-50um (estimated)

Fine Material/Matrix : Composite, dominantly 10YR5/4 with darker zone of 10YR4/4 in centre of thin section, isotropic.

SKELBRAE PROFILE 2, 70-80CM

Brief Description

Eight discrete areas could be identified by visual inspection and these eight areas can be grouped as four types. Zones 1 and 8, Zones 2, 4 and 6, Zones 5 and 7 and Zone 3 represent these four types. The zones are organised in a laminar fashion. Dominating the left top corner is a large stone with a significant amount of surface residue.

Zones 1 & 8

Stucture and Pores : Alveolar, welded structure. Only discrete pores are present, occasional, ovoid to planar shape, ovoid to tabular sphericity, subrounded, slightly rough surface characteristics, random unrelated distribution pattern, random orientation.

Passages : Rare, marked contrast, moderately rough, random unrelated distribution pattern, random orientation. Filling is 10YR2.5/1, strongly decomposed organic material, no interference colours, contains occasional mineral grains dominantly quartz.

Faecal Material : None.

Organic Materials : Occasional, strongly decomposed to very strongly decomposed, 10YR3/1, marked contrast, irregular shape, no interference colours, random unrelated distribution pattern, random orientation.

Rock Fragments : Occasional, marked contrast (reddish stones) to faint contrast (lighter coloured stones), ovoid, sub-spherical, subrounded, slightly rough surface characteristics, random distribution pattern, random orientation. Large stone in top left corner demonstrates a badly weathered stone rim, otherwise there are no surface features on the rock fragments.

Detrital Grains : Frequent quartz/feldspar.

Average Particle Size Distribution : 20-50um (estimated).

Fine Material/Matrix : Composite, 10YR3/2, 10YR5/3, 10YR6/3, 10YR4/2, isotropic.

Zones 2, 4 & 6

Structure and Pores : Alveolar, welded structure. Pores are all discrete, occasional, ovoid to planar shape, subrounded, slightly rough surface characteristics, random unrelated distribution pattern, random orientation.

Passages : Occasional, marked contrast, circular shape, slightly rough surface characteristics, random unrelated distribution pattern. Filling is 10YR2.5/1, strongly decomposed organic material, no interference colours, contains occasional mineral grains dominantly quartz.

Faecal Material : Earthworm casts form passage filling.

Organic Materials : Rare, strongly decomposed to very strongly decomposed, 10YR3/1, marked contrast, irregular shape, no interference colours, random unrelated distribution pattern, random orientation.

Rock Fragments : None.

Detrital Grains : Frequent quartz/feldspar.

Average Particle Size Distribution : 20-50um (estimated)

Fine Material/Matrix : Composite, dominantly 10YR4/2, with small 10YR5/3 zones, isotropic.

Zone 3

Structure and Pores : Spongy but with slightly welded appearance. Continuous pores; frequent, bladed, tabular sphericity, angular to subangular roundness, slightly rough surface characteristics, anastomosing distribution pattern, random orientation. Discrete pores : abundant, ovoid, subrounded, slightly rough surface characteristics, random distribution pattern, random orientation.

Passages : (Distinct from pores because of larger size). Rare, marked contrast, ovoid, slightly rough surface characteristics, random distribution pattern, random orientation, no filling.

Faecal Material : Rare ovoid arthopod pellets.

Organic Materials : This zone is dominantly organic materials, amorphous (no interference colours) and strongly decomposed.

Rock Fragments : None.

Detrital Grains : Frequent quartz/feldspar.

Average Particle Size Distribution : 20-50um (estimated).

Fine Material/Matrix : 10YR2.5/1, istropic.

Zones 5 & 7

Structure and Pores : Alveolar, welded structure. Pores are all discrete, occasional, ovoid to planar shape, subrounded, slightly rough surface characteristics, random unrelated distribution pattern, random orientation.

Passages : Occasional, marked contrast, circular shape, slightly rough surface characteristics, random unrelated distribution pattern. Filling is 10YR2.5/1, strongly decomposed organic material with no interference colours, contains occasional mineral grains dominantly quartz.

Faecal Material : Passage filling is considered to be earthworm casts, otherwise no faecal material.

Organic Materials : Rare, strongly to very strongly decomposed, 10YR3/1, marked contrast, irregular shape, no interference colours, random unrelated distribution pattern, random orientation.

Rock Fragments : None

Detrital Grains : Frequent quartz/feldspar.

Average Particle Size Distribution : 20-50um (estimated)

Fine Material/Matrix : Composite, dominantly 10YR4/4 with occasional 10YR4/3 zones, isotropic.

APPENDIX X

ANALYTICAL METHODS FOR CHAPTER 8; PARTICLE SIZE ANALYSIS AND $\delta^{13}C$ ANALYSIS

1. Particle Size Analysis

Pre-treatment to remove the organic material and dispersal of the less than 2mm sample was as in Appendix I (1). The sample suspension was then quantitively transferred to a 500ml glass measuring cylinder and placed overnight in a waterbath at 24°C where it was kept for the duration of the sampling period. Shaking, sampling and calculation of subsample amounts of the suspension is as in Appendix I(1) except that samples were taken at appropriate times for 1ϕ intervals at 24°C (Brimblecombe, et al, 1980). Having sampled up to 10ϕ the remaining suspension was washed through a 4ϕ seive and the retained sand fraction dried overnight. After drying the sand material was seived through a nest of seives at 1ϕ intervals giving separation between 0ϕ and 4ϕ intervals. Seiving was accomplished by placing the seive nest on a seive shaker for five minutes. Combining the seiving and sedimentation in the measuring cylinder partitioned the soil/sediment sample into 1ϕ intervals between 0ϕ and 10ϕ.

Cumulative particle size percentages at 1ϕ intervals were calculated according to the procedures in McBride (1971). These values were plotted on probability paper and the line extended to 14ϕ according to Folk (1966). From this graph particle size distribution values for mean, sorting, skewness and kurtosis were calculated by the equations below:

$$\text{Mean} = \frac{(\phi 10 + \phi 30 + \phi 50 + \phi 70 + \phi 90)}{5}$$

(After McCammon, 1962)

$$\text{Sorting} = \frac{(\phi 70 + \phi 80 + \phi 90 + \phi 97 - \phi 3 - \phi 10 - \phi 20 - \phi 30)}{9.1}$$

(After McCammon, 1962)

$$\text{Skewness} = \frac{\phi 84 + \phi 16 - 2 \times \phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 95 + \phi 5 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

(After Folk and Ward, 1957)

$$\text{Kurtosis} = \frac{\phi 95 - \phi 5}{2.44\ (\phi 75 - \phi 25)}$$

(After Folk and Ward, 1957)

Estimated errors for the four particle size distribution characteristics determined are given in the table overleaf.

To aid the spatial interpretation of the mean, sorting and skewness values in the deep top soils, trend surface analysis was carried out as in Appendix VIII(3).

2. $\delta^{13}C$ Analysis

Less than 2mm samples of soil or sediment were used for this analysis. The presence of carbonate was tested visually by washing a part of the sample with 50% HCl. Samples containing carbonate had the carbonate converted to CO_2 by 100% phosphoric acid. The $\delta^{13}C$ value of this gas was then measured. The residual was washed and dried and subject to the standard treatment outlined below.

Aliquots of the less than 2mm fraction were accurately weighed and the total carbon in each sample was recovered by quantitative oxidation to CO_2 in a quartz semi-micro combustion rig. The gas was dried and collected in a series of cryogenic traps before its volume was determined. $\delta^{13}C$ values of mound samples were calculated by a VG Micromass 602B mass spectrometer. The calculation of values for the input materials and deep top soil samples, carried out at a later date was by a Finnigen Delta D mass spectrometer. $\delta^{13}C$ values were measured against a bulk CO_2 working standard and calculated relative to the PDB limestone standard. Measurements of graphite standards were made at 5 sample intervals throughout the sample analysis program, permitting an estimated analytical precision of $\pm$ 0.2‰ .

Separation of humin, humic acid and fulvic acid for $\delta^{13}C$ analysis was attempted by the following procedure. 25g of sub-sample less

PARTICLE SIZE DISTRIBUTIONS : ANALYTICAL ERROR

SAMPLE NO	SUB-SAMPLE NO	MEAN	SORTING	SKEWNESS	KURTOSIS
Howe 18A 50cm	1	7.06	2.57	0.17	0.78
	2	7.10	2.55	0.15	0.77
	3	7.12	2.57	0.16	0.73
	4	7.00	2.50	0.12	0.79
	5	7.00	2 67	0.16	0.87
Number of samples		5 0	5.0	5.0	5.0
Mean		7.056	2.572	0.152	0.788
Standard deviation		0.055	0.062	0.017	0.0512
Standard error		0.025	0.025	0.008	0.023

SAMPLE NO	SUB-SAMPLE NO	MEAN	SORTING	SKEWNESS	KURTOSIS
Westbrough Farm Mound Profile 2 Horizon 11	1	5.62	2.42	0.24	1.12
	2	5.86	2.60	0.17	1.10
	3	5.38	2.61	0.18	1.19
	4	5.66	2.46	0.35	1.09
	5	5.76	2.39	0.25	1.05
Number of samples		5.0	5.0	5.0	5.0
Mean		5.656	2.496	0.238	1.110
Standard deviation		0.180	0.103	0.064	0.051
Standard error		0.081	0.046	0.029	0.023

than 2mm soil material was placed in a beaker with 250ml 0.1M NaOH for 24 hours at room temperature. The sample was then filtered by suction through silicone filter paper. The residual left on the filter paper was the alkali insoluble humin material. The solution was then acidified to pH3 with concentrated H_2SO_4. Slight frothing occurred as the humic acids precipitated.and these were filtered from the solution by suction through silicone filter paper. The organic material remaining in the solution are the fulvic acids. Attempt was made to extract them by evaporating and washing out the sulphuric acid. In practice it proved difficult to remove all the sulphuric acid. This made it difficult to determine accurately $\delta^{13}C$ values for the fulvic acids because sulphur compounds in the solution broke down to the same mass values as carbon -12 and carbon -13. It would appear that dialysis is required to extract fulvic acids for the determination of their $\delta^{13}C$ values.

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