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# Early Anthropogenic Soil Formation at Tofts Ness, Sanday, Orkney

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A buried, dark coloured loam soil horizon embedded between calcareous wind blown sand deposits is identified in three areas of the Tofts Ness landscape. The close association with early settlement sites and enhanced total phosophate levels suggests that this soil horizon is anthropogenic in orgin. Radiocarbon dating and stratigraphic relationships with settlement sites indicate that the horizon is associated with Bronze Age cultural landscape activity and may have commenced formation during the Late Neolithic period. Horizon formation is interpreted through a synthesis of thin section micromorphology, stable carbon isotope analysis and analysis of free soil lipids. These analytical methods indicate that formation was through the application of grassy turf material together with domestic waste midden, while cultivation was moderately intense as evidenced by the movement of fine material through the horizon. The closest parallels to these soil horizons are the cultural plaggen soils of continental north west Europe, with the Tofts Ness soils amongst the earliest known of these soil types. Application of this manuring technique at Tofts Ness allowed arable activity in what was a highly marginal farming environment; emerging evidence from other parts of the Northern Isles of Scotland suggests that these manuring strategies were commonly used in early arable systems.

*Keywords:* ANTHROPOGENIC SOILS, NEOLITHIC/BRONZE AGE LAND MANAGEMENT, NORTH ATLANTIC CULTURAL LANDSCAPES, SOIL MICROMORPHOLOGY, FREE SOIL LIPIDS, BIOMARKERS.

## Introduction

The low-lying Tofts Ness peninsula (HY 754 472) is located at the north-eastern end of Sanday, Orkney, bound by the inland North Loch to the south (Figure 1). Extensive deposits of shelly wind blown sands have, at various times, buried the early Tofts Ness landscape and this process has contributed to the area having one of the richest concentrations of archaeological sites in the Northern Isles of Scotland (Lamb, 1980). Good site survival and the fossilization of associated landscapes under the sand means that the area gives outstanding opportunities to examine sequences of early society-environment relationships within a landscape context as far back as the Neolithic. A preliminary chronological framework, together with evidence for a range of land management activities associated with different phases of early occupation has already been established for Tofts Ness (Dockrill & Simpson, 1994; Dockrill *et al.* 1994). Activities evident in the Neolithic/Early Bronze Age landscape include vegetation clearance, tillage and the application of manures and ash to soils. Much of this activity took place against an environmental backdrop of increasing soil wetness and substantial movement of wind blown calcareous sands. These sands formed the basis of a Late Bronze Age/Early Iron Age landscape, utilized for highly marginal agricultural activity but which was in turn buried by wind blown sand deposits.

This paper focuses on fossil (Bronger & Catt, 1993), dark coloured loam soil horizons of between 35 and 75 cm in thickness identified at three locations on the Tofts Ness peninsula. These horizons are embedded between wind blown sand deposits and are associated

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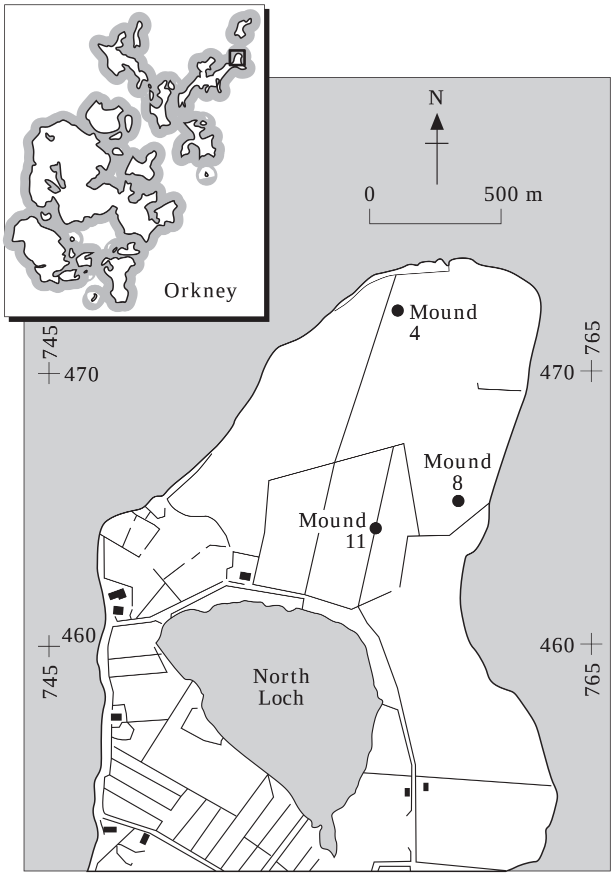

Figure 1. Tofts Ness, Orkney, showing early settlement locations.

with early settlement sites (Figures 2(a) and (b)). In view of the stratigraphic context of these horizons and their field properties, the hypothesis advanced and tested in this paper is that these horizons represent early anthropogenic soils that arose as a result of deliberate application of turf and manure to allow cultivation in a landscape marginal for arable agriculture. Questions addressed here include establishing the anthropogenic origins of these horizons, the age of the horizons, the nature of formation materials and the intensity of cultivation. Answers to these questions emerge through synthesizing a number of approaches. Radiocarbon measurement together with the part excavation of one settlement site (Mound 11) provides a stratigraphic and chronological link between the soil horizons, archaeological structures and associated midden deposits. Laboratory derived soil properties including total phosphate, stable carbon isotopic composition, micromorphological features observed in thin section and organic geochemical analysis of free soil lipids allows insight into the formation processes associated with these soils. Interpretation of horizon formation processes made on the basis of the observed properties can then be placed in a wider chronological and cultural landscape context.

## Methods

### *Field survey and sampling*

Soils around three settlement sites, Mound 11 (M11), Mound 4 (M4) and Mound 8 (M8) in the Tofts Ness peninsula (RCAHMS notations; Figure 1) were surveyed to identify the extent and thickness of the horizons forming the focus of the investigation. At M11 and M4 survey was by hand auger where Munsell colours of 10YR 3/2 or 10YR 3/3 and hand textures of sandy loam and sandy silt loam distinguished the horizons. At M8 (known as Shelly Knowe), where the horizons of interest are generally buried deeper and thicknesses could not be fully ascertained by conventional hand auger, a fluxgate gradiometer survey was used to determine the spatial extent of this buried soil (Dockrill & Simpson, 1994). The geophysical data from the fluxgate gradiometer survey of the area surrounding M8 were processed by J. A. Gater and were displayed as a grey scale. Soil profiles were exposed in each of the identified areas (Figures 2(a) and (b)), where representative bulk samples were collected for radiocarbon determination and chemical analysis; undisturbed samples were collected in 10 × 5 cm Kubiena tins for micromorphological analysis. Examination of the stratigraphic relationship between the fossil soil horizons and the settlement site at M11 was made possible through detailed archaeological excavation targeted to examine the edge of the settlement mound (Figure 3). Contemporary materials, of the type that may have been used, were collected to assist in the interpretation of the fossil soil properties. These materials included old turf roof material, seaweed, straw/manure byre waste and turf/manure byre waste. These materials came from West Mainland Orkney, except for the turf/manure material which came from North Ronaldsay, Orkney.

### *Laboratory analysis*

Bulk soil samples from the fossil soil horizons were air dried and passed through a 2 mm sieve. Subsamples were then analysed for total phosphate, stable carbon isotopic composition and free soil lipids. Total phosphate analysis took place at the Soil Chemistry Laboratory, University of Stirling. The <180 μm fraction was fused with sodium hydroxide in a nickel crucible, followed by 2 hours digestion (Smith & Bain, 1982). Colorometric determination was by the ammonium molybdate/stannous chloride procedure (Murphy & Riley, 1962). Results are reported in mg/100 g $P_2O_5$ of the calcium carbonate free fraction with an analytical error of ± 20 mg/100 g based on replicate samples.

Both $\delta^{13}C$ and % organic carbon determinations were made at the NERC Radiocarbon Laboratory, East Kilbride, on the acid (0·5M HCl) insoluble detritus of the air dried, <2 mm fraction. Analysis of

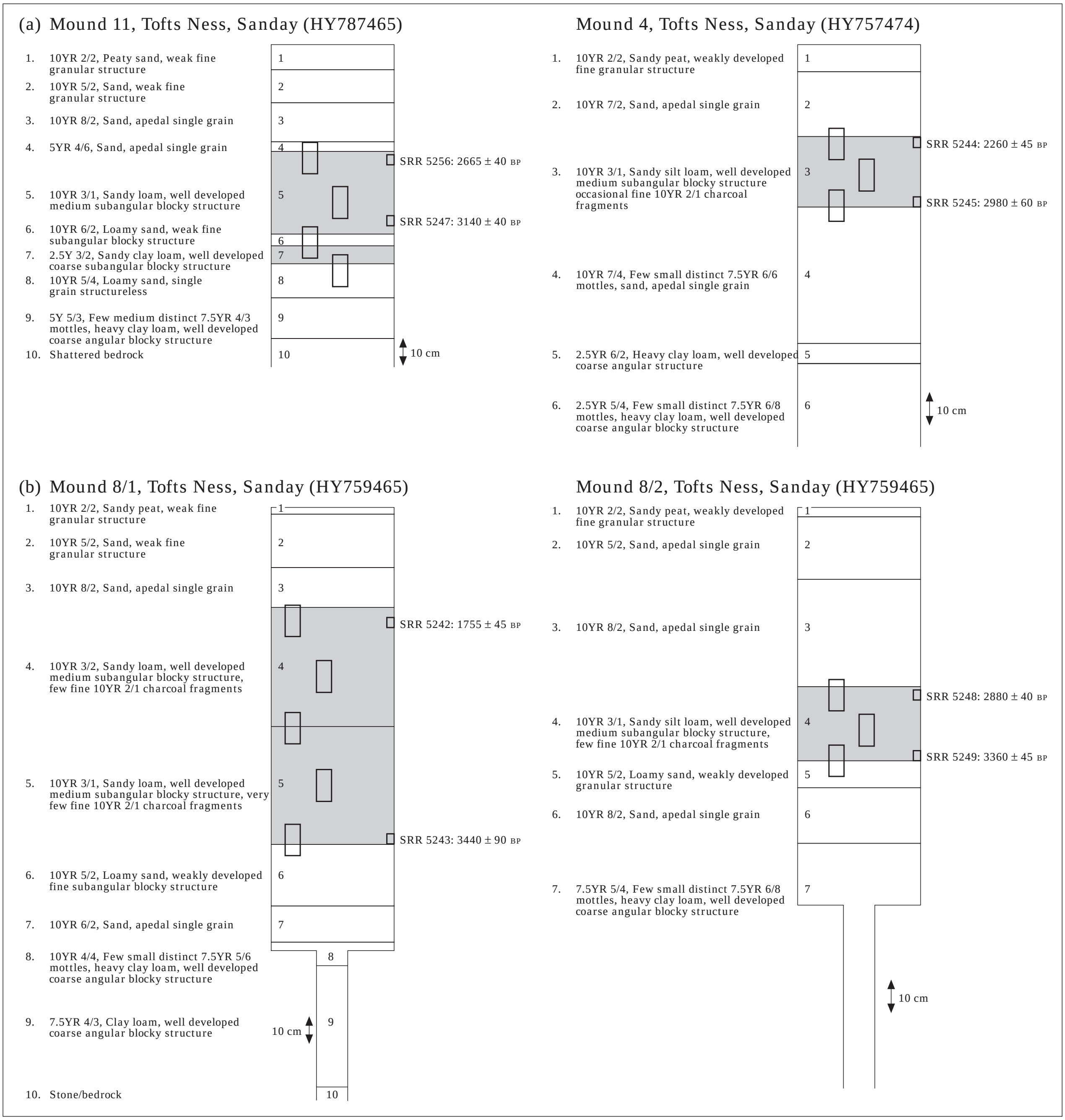

Figure 2. Soil stratigraphies beyond (a) Mounds 11 and 4, and (b) Mound 8. ▯, thin section samples; ☐, radiocarbon samples; ▨, anthropogenic soil.

subsamples was 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. Determination of $\delta^{13}C$ values was by isotope ratio mass spectrometry, measured against a bulk $CO_2$ working standard and calculated relative to the PDB limestone standard. Measurements of graphite standards were made at five sample intervals throughout sample analysis permitting an estimated analytical precision of ±0·2‰.

Subsamples of the <2 mm fraction were soxhlet extracted for 24 h using DCM/acetone (9:1 v/v) at the School of Chemistry, University of Bristol. Solutions of total lipid extracts (TLEs) were collected and evaporated under reduced pressure. TLEs were initially separated into two fractions using an amino propyl bond elute cartridge. The first fraction comprised neutral lipids and the second contained predominantly fatty acids. The former fraction was separated into five subfractions (‘hydrocarbon’, ‘aromatic’, ‘ketone/wax ester’,

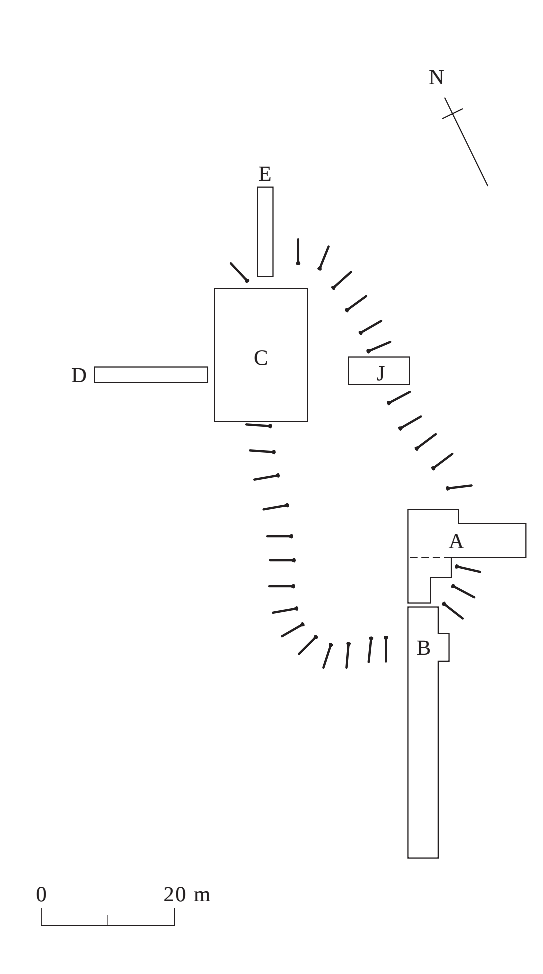

Figure 3. Excavated area at Mound 11, Tofts Ness.

'alcohol' and 'polar') via gradient elution on a silica flash column. Urea adduction of the ''alcohol'' fraction enabled it to be separated further into one fraction dominated by *n*-alkanols and another containing sterols. Compounds were derivatized by heating sample aliquots with *N*,*O*-bis(trimethylsilyl)trifluoroacetamide (BSTFA, 30 µl), containing 1% trimethylchlorosilane (TMCS), at 70°C for 1 h.

Gas chromatographic (GC) analyses were performed using a Hewlett-Packard 5890 series II gas chromatograph fitted with a fused silica capillary column (50 m × 0·32 mm) coated with a 100% polymethyl siloxane stationary phase (CPSil-5CB, film thickness 0·12 µm); wax ester analyses were made using a column capable of operation at elevated temperature (DB1, 15 m × 0·32 mm × 0·1 µm). Derivatized samples were injected (1·0 µl) via an on-column injector as solutions in hexane. The temperature was programmed from 40°C (1 min) to 200°C at a rate of 10°C $\text{min}^{-1}$, then to 300°C at a rate of 3°C $\text{min}^{-1}$, with a final time of 20 min; for wax ester analyses a temperature programme of 50°C (2 min) to 350°C at a rate of 10°C $\text{min}^{-1}$, with a final time of 10 min at 350°C, was used. Hydrogen was used as the carrier gas for all analyses except the ''hydrocarbon'' fraction when helium was employed as the carrier in order to facilitate resolution of the internal standard.

Gas chromatographic-mass spectrometric (GC/MS) analyses were performed using a Varian 3400 gas chromatograph fitted with a septum equipped temperature programmable injector (SPI) coupled via a heated transfer line, to a Finnigan MAT TSQ700 triple quadrupole mass spectrometer. The mass spectrometer was operated in single quadrupole mode, scanning the third quadrupole in the range of 50 to 650 *m/z* with a cycle time of 1 s. Electron ionization was performed with an electron energy of 400 µA and the ion source was maintained at a temperature of 170°C. GC/MS analyses of fractions containing wax ester components were made using a Carlo Erba 5160 GC equipped with on-column injection coupled, via a heated transfer line, to a Finnigan MAT 4500 quadrupole mass spectrometer scanning in the range of 50 to 850 *m/z* with a cycle time of 1 s. Electron energy was maintained at 300 µA with an ion source temperature of 170°C. Both mass spectrometers were operated with an electron voltage of 70 eV.

Gas chromatographic combustion isotope ratio mass spectrometric (GCC/IRMS) analyses were made on 1 µl sample aliquots using a Varian 3400 gas chromatograph fitted with a septum equipped temperature programmable injector (SPI) coupled to a Finnigan MAT Delta S stable isotope mass spectrometer (electron ionization, 100 eV electron voltage, 1 mA electron energy, 3 Faraday cup collectors at *m/z* 44, 45 and 46, CuO/Pt combustion reactor set to a temperature of 850°C).

In the absence of finds of substantial charcoal or bone in the fossil soil horizons, radiocarbon determinations were made on the bulk, acid insoluble organic detritus of the anthropogenic soils at the NERC Radiocarbon Laboratory, East Kilbride (SRR). Bulk raw samples were wet sieved through a 2 mm mesh to discard rootlets, shell fragments and stones. The fine soil was allowed to stand in 0·5M HCl until all component carbonate had reacted. The acid-treated residue was washed with cold distilled water, recovered by filtration and dried to constant weight prior to radiocarbon measurement. Radiocarbon measurements of animal bone and peat obtained from the Mound 11 settlement site stratigraphy were made at the Scottish Universities Research and Reactor Centre (GU).

A total of 15 undisturbed samples from the freshly exposed soil profile faces were collected in Kubiena tins. Thin sections were prepared at the Micromorphology Laboratory, University of Stirling following the procedures of Murphy (1986). Water was removed by acetone exchange and confirmed by specific gravity measurement. The samples were impregnated using polyester crystic resin ''type 17449'' and the catalyst ''Q17447'' (methyl ethyl ketone peroxide, 50% solution in pthalate). The mixture was thinned with acetone and a standard composition of 180 ml resin, 1·8 ml catalyst and 25 ml acetone used for each Kubiena tin. No acceleration was used but the sample was impregnated under vacuum to ensure out-gassing of the soil. The blocks were then cured for 3–4 weeks culminating with 4 days in a 40°C oven. Cured blocks were bonded to glass, precision lapped to 30 µm and coverslipped. Sections were described using an Olympus BH-2 petrological microscope and by following the terminology of Bullock *et al.* (1985). This allows systematic description of soil microstructure, basic mineral components, basic organic components, groundmass and pedofeatures. A range of magnification ( × 10– × 400) and light sources (plane polarized, cross polarized and oblique incident) were used to obtain detailed descriptions and semi-quantitative estimates of features that were recorded in standard summary tables. Interpretation of the features observed in thin section was assisted by Courty, Goldberg & Macphail (1989) and Fitzpatrick (1993).

## Results and Discussion

### *Anthropogenic soil characteristics*

The field survey evidence suggests a small scale occurrence of fossil soil horizons partially surrounding M11, M4 and M8, with extents of slightly less than 1 ha (Figures 4 and 5). Such extents are consistent with an intensive style of cultivation akin to a garden plot. Horizon thicknesses at M11 and M4 demonstrate a progressive decline with distance from the associated settlement site, indicating small scale spatial variability in the formation of the horizon. The geophysical survey from around M8 identifies the edge of the magnetically enhanced buried soil, with a lesser degree of enhancement evident on the northern edge corresponding to greater overburden of wind blown sand (Figure 5). This magnetically enhanced soil surrounds a positive horseshoe-shaped magnetic anomaly representing a burnt mound and a figure of eight anomaly representing a structural complex south of the burnt mound. These two distinct features represent the earthwork complex identified as M8. A series of parallel striations within the south east magnetically enhanced area appear to be magnetic anomalies associated with later disturbance cutting into the magnetic soil where it is closest to the surface. This disturbance in a soil containing a high magnetic susceptibility produces a contrast in the data forming the series of parallel edges.

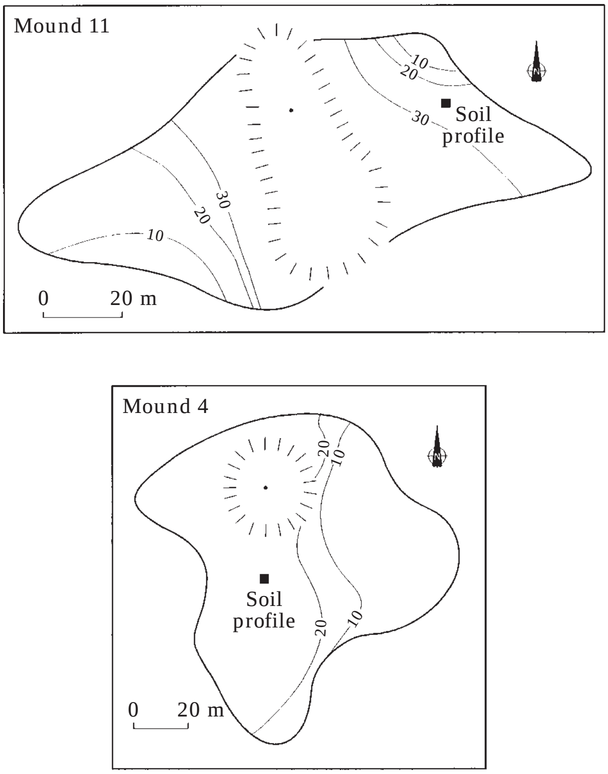

Figure 4. Buried anthropogenic soil thickness' around Mound 11 and Mound 4. –10–, Anthropogenic horizon thickness (cm); —, anthropogenic horizon extent.

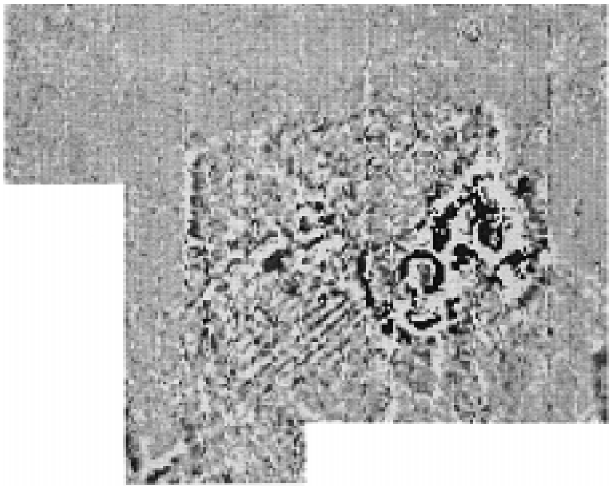

Figure 5. Gradiometer data from around Mound 8 (Shelly Knowe). Min − 1 (white) to max 4 nT (black). Survey area 200 m × 160 m. North at top of page.

Total phosphate analysis of the fossil soil horizons reveals levels ranging from 138–501 mg/100 g $P_2O_5$ with a mean of 304 mg/100g ($N = 18$; Table 1). The highest phosphate levels are evident around M8 and M11 and are least in soils around M4. No consistent trend with depth in the fossil soil horizon is observed. The levels of total $P_2O_5$ in these soil horizons can be regarded as enhanced; total $P_2O_5$ levels of the calcareous sands and the silty clay horizons within the stratigraphies examined, including present day surface soils, are considerably less than the fossil horizon under consideration (Table 1). Such levels of enhancement are consistent with the application of organic materials, even though they are less than those levels found in the relict mediaeval and early modern anthropogenic plaggen soils of West Mainland Orkney where

*Table 1. Total $P_2O_5$ and $\delta^{13}C$ values from soil stratigraphies at Tofts Ness*

| Sample | Total $P_2O_5$ mg/100g | $\delta^{13}C$ (‰) | %C |
|---|---|---|---|
| **Mound 11** | | | |
| 0–5 | 85 | — | — |
| 39–42 | 224 | − 26·1 | 3·43 |
| 45–48 | 287 | − 26·0 | 2·92 |
| 51–54 | 501 | − 26·1 | 2·65 |
| 62–65 | 211 | — | 1·15 |
| **Mound 4** | | | |
| 0–5 | 54 | — | — |
| 30–35 | 197 | − 26·4 | 1·47 |
| 39–44 | 311 | − 26·0 | 2·88 |
| 49–54 | 180 | − 25·9 | 1·30 |
| **Mound 8/1** | | | |
| 0–5 | 83 | — | — |
| 35–40 | 278 | − 25·9 | 2·02 |
| 45–50 | 139 | − 25·9 | 1·90 |
| 55–60 | 155 | − 25·9 | 2·14 |
| 65–70 | 184 | − 26·0 | 2·37 |
| 75–80 | 193 | − 26·1 | 1·98 |
| 85–90 | 194 | − 26·0 | 2·34 |
| 95–100 | 175 | − 26·0 | 1·59 |
| 105–110 | 465 | − 25·4 | 1·48 |
| **Mound 8/2** | | | |
| 0–5 | 106 | — | — |
| 60–65 | 347 | − 25·8 | 2·82 |
| 70–75 | 351 | − 25·9 | 2·63 |
| 78–83 | 319 | − 25·8 | 2·01 |

a range of 249–1166 and a mean of 537 mg/100 g have been identified (Simpson, 1997).

### *Chronology*

Radiocarbon measurement (Table 2; Figure 2) of anthropogenic soil material from the four examined profiles indicates age ranges in close proximity to one another. Lower anthropogenic horizon radiocarbon measurements range from SRR 5249: 3360 ± 45 BP to SRR 5245: 2980 ± 60 BP; upper anthropogenic horizon ages' range more widely, from SRR 5248: 2880 ± 40 BP to SRR 5242: 1755 ± 45 BP. The dates suggest a Bronze Age origin for these fossil soil horizons, with formation continuing into the Iron Age. These dates do however need to be interpreted with some caution. Dating anthropogenic soils through radiocarbon measurement is difficult due to the radiocarbon age of the applied material, rejuvenation effects associated with cultivation and the pedogenic movement of carbon through the profile (Scharpenseel & Becker-Heidmann, 1992; Simpson, 1993; Wang & Amundson, 1996). However, thin section micromorphology from the examined stratigraphies at Tofts Ness indicates an absence of organic coatings on the overlying sands suggesting that there has been no post-burial introduction of carbon to the fossil soil horizons (Tables 3–6). There has however been movement of organic material within the fossil soil horizons which will have served to blur the true ages of the horizon. Nevertheless, given their stratigraphical position and fossilized nature, these radiocarbon dates can be interpreted as providing a reasonable estimate of the commencement and cessation of horizon formation and suggest a Bronze Age context. A still earlier, undated, fossil soil context can however be seen as horizon 7 in the M11 profile (Figure 2).

In an effort to provide a more secure chronological framework for the fossil soil horizons, their positions were examined in relation to the dated stratigraphical sequences at M11. This established that fossil soils are sealed under a Neolithic structure and associated midden deposits (Areas A and B; Figures 3 and 6). Radiocarbon measurements (Table 2) for animal bone from the midden deposits are GU 2209: 4430 ± 70 BP and GU 2210: 4480 ± 70 BP, confirming the early date

*Table 2. Radiocarbon measurement from fossil soil horizons and materials from Mound 11*

| Location | Composition | Depth in profile (cm) | Lab code No. | Conventional $^{14}C$ age (years BP ± 1 $\sigma$) | Dendro timespan* (years BC) |
|---|---|---|---|---|---|
| M11 | Soil | 36–41 | SRR 5256 | 2665 ± 40 | 829–802 |
| M11 | Soil | 55–60 | SRR 5247 | 3140 ± 40 | 1429–1328 |
| M4 | Soil | 30–33 | SRR 5244 | 2260 ± 45 | 387–206 |
| M4 | Soil | 50–53 | SRR 5245 | 2980 ± 60 | 1296–1115 |
| M8/1 | Soil | 36–41 | SRR 5242 | 1755 ± 45 | 375–238 |
| M8/1 | Soil | 108–113 | SRR 5243 | 3440 ± 90 | 1878–1625 |
| M8/2 | Soil | 59–64 | SRR 5248 | 2880 ± 40 | 1116–993 |
| M8/2 | Soil | 78–83 | SRR 5249 | 3360 ± 45 | 1685–1530 |
| Mound 11 | Animal bone | | GU 2209 | 4430 ± 70 | 3308–2926 |
| Mound 11 | Animal bone | | GU 2210 | 4480 ± 70 | 3342–3036 |
| Mound 11 | Peat | | GU 2544 | 2470 ± 50 | 770–422 |
| Mound 11 | Animal bone | | GU 2183 | 2990 ± 100 | 1600–1400 |
| Mound 11 | Animal bone | | GU 2208 | 2470 ± 50 | 770–422 |
| Mound 11 | Animal bone | | GU 2207 | 2510 ± 140 | 810–400 |

*Calibration according to Pearson *et al.*, 1986 and Pearson & Stuiver, 1986.

*Table 3. Thin section descriptions: M 11, Tofts Ness (HY 787465)*

| | | Coarse mineral material (>10 μm) | | | | | | | | | | | | Fine mineral material (<10 μm) | Coarse organic material (>5 cells) | | | Fine organic material (<5 cells) | | | | Pedofeatures | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Section | | Quartz | Feldspar | Biotite | Garnet | Calcium carbonate | Compound quartz grains | Sandstones | Siltstones | Diatoms | Phytoliths | Heated stone | Bone | | Fungal spores | Lignified tissue | Parenchymatic tissue | Amorphous (black) | Amorphous (yellow/orange) | Amorphous (reddish brown) | Cell residue | Charcoals | Textural (silty clay) | Textural (clay coatings) | Organic coatings | Amorphous & crypto crystalline nodule | Amorphous & crypto crystalline infills+ coatings | Excremental (mamillate) | Excremental (spheroidal) | Depletion | Microstructure | Coarse material arrangement | Groundmass b Fabric | Related distribution |
| 32–42 | Upper | • | | | | •••• | • | | | | | | | Brown; dotted limpidity | | | | | | | | | | | | | | | | | Bridged | Random | Stipple speckled | Chitonic |
| | Lower | •• | • | | | •• | • | • | • | | | • | | Brown and Grey, dotted limpidity | | | | *t* | | •• | | *t* | | | | • | • | • | | • | Intergrain microaggregate | Random | Stipple speckled | Porphyric |
| 47–57 | | •• | • | | | •• | • | • | • | | | • | • | Grey and brown, dotted limpidity | • | | | • | | •• | | • | • | | | • | | • | | • | Intergrain microaggregate | Random | Stipple speckled | Porphyric |
| 60–70 | Upper | •• | • | | • | •• | • | • | • | • | • | • | | Grey and brown, dotted limpidity | • | | | • | | • | | •• | | | | | | • | | • | Intergrain microaggregate | Random | Stipple speckled | Porphyric |
| | Mid | • | | | | •••• | | | | | | | | — | | | | • | | | | | | | | | | | | | Single grain | Random | Stipple speckled | Chitonic |
| | Lower | ••• | • | | • | • | | | | | • | • | • | Brown, dotted limpidity | | | | • | | • | | • | • | | | • | • | • | | • | Intergrain microaggregate to channel and chamber | Random | Stipple speckled | Porphyric |
| 69–79 | Upper | •• | • | • | • | • | • | • | • | | • | | • | Grey; dotted limpidity | • | | | • | • | • | | | • | | • | • | | | • | • | Intergrain microaggregate to channel and chamber | Random | Stipple speckled | Porphyric |
| | Lower | ••• | • | • | • | | • | • | • | | | | | Grey; dotted limpidity | | | | • | • | | | | •• | • | • | • | | • | | • | Intergrain microaggregate to channel and chamber | Random | Stipple speckled | Porphyric |

Frequency class refers to the appropriate area of section (Bullock *et al.* 1985). *t*, trace; •, very few; ••, few; •••, frequent/common; ••••, dominant/very dominant.
Frequency class for textural pedofeatures (Bullock *et al.* 1985). •, Rare; ••, occasional; •••, many.

*Table 4. Thin section descriptions: M 4, Tofts Ness (HY 757474)*

|  |  | Coarse mineral material (>10 µm) |  |  |  |  |  |  |  |  |  |  |  | Fine mineral material (<10 µm) | Coarse organic material (>5 cells) |  |  | Fine organic material (<5 cells) |  |  |  | Pedofeatures |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Section |  | Quartz | Feldspar | Biotite | Garnet | Calcium carbonate | Compound quartz grains | Sandstones | Siltstones | Diatoms | Phytoliths | Heated stone | Bone |  | Fungal spores | Lignified tissue | Parenchymatic tissue | Amorphous (black) | Amorphous (yellow/orange) | Amorphous (reddish brown) | Cell residue | Charcoals | Textural (silty clay) | Textural (clay coatings) | Organic coatings | Amorphous & crypto crystalline nodule | Amorphous & crypto crystalline infills+ coatings | Excremental (mamillate) | Excremental (spheroidal) | Depletion | Microstructure | Coarse material arrangement | Groundmass b Fabric | Related distribution |
| 28–38 | Upper | • |  |  |  | ••• | • |  |  |  |  |  |  | Brown; dotted limpidity |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | Single grain and bridged | Random | Stipple speckled | Chitonic |
|  | Lower | •• | • | • | • | •• | • | • | • | • | • | • | • | Brown; dotted limpidity |  |  |  | • | • | • | • | •• | • |  | • |  | • | • |  | • | Channel and chamber | Random | Stipple speckled | Porphyric |
| 38–48 |  | •• | • | • | • | •• | • | • | • | • | • | • | • | Brown; dotted limpidity |  |  |  | • |  | • | • | •• | • |  | • |  | • | • |  | • | Channel and chamber | Random | Stipple speckled | Porphyric |
| 48–58 | Upper | •• | • | • | • | •• | • | • | • | • | • | • | • | Brown; dotted limpidity | • |  |  | • | • |  | • | •• | • |  | • |  | • | • |  | • | Channel and chamber | Random | Stipple speckled | Porphyric |
|  | Lower | • |  |  |  | •••• | • |  |  |  |  |  |  | Brown; dotted limpidity |  |  |  | • |  |  |  |  |  |  |  |  |  |  |  |  | Single grain and bridged | Random | Stipple speckled | Porphyric |

Frequency class refers to the appropriate area of section (Bullock *et al.* 1985). *t*, trace; •, very few; ••, few; •••, frequent/common; ••••, dominant/very dominant.
Frequency class for textural pedofeatures (Bullock *et al.* 1985). •, Rare; ••, occasional; •••, many.

*Table 5. Thin section descriptions: M 8, Profile 1, Tofts Ness (HY 759465)*

| Section | | Coarse mineral material (>10 µm) | | | | | | | | | | | | Fine mineral material (<10 µm) | Coarse organic material (>5 cells) | | | Fine organic material (<5 cells) | | | | Pedofeatures | | | | | | | | | Microstructure | Coarse material arrangement | Groundmass b Fabric | Related distribution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Quartz | Feldspar | Biotite | Garnet | Calcium carbonate | Compound quartz grains | Sandstones | Siltstones | Diatoms | Phytoliths | Heated stone | Bone | | Fungal spores | Lignified tissue | Parenchymatic tissue | Amorphous (black) | Amorphous (yellow/orange) | Amorphous (reddish brown) | Cell residue | Charcoals | Textural (silty clay) | Textural (clay coatings) | Organic coatings | Amorphous & crypto crystalline nodule | Amorphous & crypto crystalline infills+ coatings | Excremental (mamillate) | Excremental (spheroidal) | Depletion | | | | |
| 32–42 | Upper | • | | | | •••• | • | | | | | | | | | | | | | | | | | | | | | | | | Single grain | Random | Stipple speckled | Chitonic |
| | Lower | •• | • | • | • | •• | • | • | • | • | • | • | • | Brown; dotted limpidity | • | | | • | • | • | • | •• | • | | | • | | • | | • | Channel and chamber | Random | Stipple speckled | Porphyric |
| 50–60 | | •• | • | • | • | •• | • | • | • | • | • | • | • | Brown; dotted limpidity | • | | | • | • | • | • | •• | • | | | • | | • | | • | Channel and chamber | Random | Stipple speckled | Porphyric |
| 66–76 | | •• | • | • | • | •• | • | • | • | • | • | • | • | Brown and pale grey; dotted limpidity | • | | | • | • | • | • | •• | • | | | • | | • | | • | Channel and chamber | Random | Stipple speckled | Porphyric |
| 86–96 | | •• | • | • | • | •• | • | • | • | • | • | • | • | Brown; dotted limpidity | • | | | • | • | • | • | •• | • | | • | • | | • | | • | Channel and chamber | Random | Stipple speckled and crystallitic | Porphyric |
| 104–114 | Upper | •• | • | • | • | •• | • | • | • | • | • | • | • | Brown; dotted limpidity | • | | | • | • | • | • | •• | • | | • | • | | • | | • | Channel and chamber | Random | Stipple speckled and crystallitic | Porphyric |
| | Lower | • | | | | •••• | • | | | | | | | Brown; dotted limpidity | | | | | | | | | | | | | | | | | Single grain to bridged | Random | Stipple speckled and crystallitic | Chitonic |

Frequency class refers to the appropriate area of section (Bullock *et al.* 1985). *t*, trace; •, very few; ••, few; •••, frequent/common; ••••, dominant/very dominant.
Frequency class for textural pedofeatures (Bullock *et al.* 1985). •, Rare; ••, occasional; •••, many.

*Table 6. Thin section descriptions: M 8, Profile 2, Tofts Ness (HY 759465)*

| Section | | Coarse mineral material (>10 µm) | | | | | | | | | | | | Fine mineral material (<10 µm) | Coarse organic material (>5 cells) | | | Fine organic material (<5 cells) | | | | Pedofeatures | | | | | | | | | Microstructure | Coarse material arrangement | Groundmass b Fabric | Related distribution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Quartz | Feldspar | Biotite | Garnet | Calcium carbonate | Compound quartz grains | Sandstones | Siltstones | Diatoms | Phytoliths | Heated stone | Bone | | Fungal spores | Lignified tissue | Parenchymatic tissue | Amorphous (black) | Amorphous (yellow/orange) | Amorphous (reddish brown) | Cell residue | Charcoals | Textural (silty clay) | Textural (clay coatings) | Organic coatings | Amorphous & crypto crystalline nodule | Amorphous & crypto crystalline infills+ coatings | Excremental (mamillate) | Excremental (spheroidal) | Depletion | | | | |
| 58–68 | Upper | • | | | | ••• | • | | | | | | | Brown; dotted limpidity | | | | | | | | | | | | | | | | | Single grain and bridged | Random | Stipple speckled | Chitonic |
| | Lower | •• | • | • | • | •• | • | • | • | • | • | • | • | Brown; dotted limpidity | | | | • | • | • | • | • | •• | | | • | | • | | • | Channel and chamber | Random | Stipple speckled | Porphyric |
| 69–79 | | •• | • | • | • | •• | • | • | • | • | • | • | • | Brown; dotted limpidity | • | | | • | • | • | • | • | •• | | | • | | • | | • | Channel and chamber | Random | Stipple speckled | Porphyric |
| 79–89 | Upper | •• | • | • | • | •• | • | • | • | • | • | • | • | Brown; dotted limpidity | | | | • | • | • | • | • | •• | | • | • | | • | | • | Channel and chamber | Random | Stipple speckled | Porphyric |
| | Lower | • | | | | •••• | • | | | | | | | Brown; dotted limpidity | | | | | | | | | | | • | | | | | | Single grain and bridged | Random | Stipple speckled and crystallitic | Chitonic |

Frequency class refers to the appropriate area of section (Bullock *et al.* 1985). *t*, trace; •, very few; ••, few; •••, frequent/common; ••••, dominant/very dominant.
Frequency class for textural pedofeatures (Bullock *et al.* 1985). •, Rare; ••, occasional; •••, many.

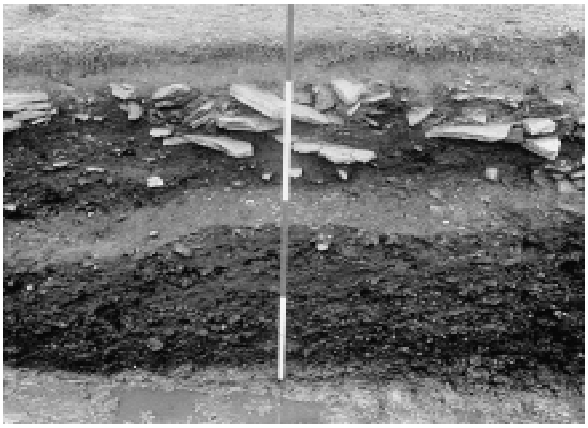

Figure 6. Mound 11, Area B: Neolithic anthropogenic soil sealed by a stratigraphical sequence containing later Neolithic midden and an Early Bronze Age structure, which are in turn sealed by later sandier soils (Crown Copyright, reproduced by permission of Historic Scotland).

Figure 7. Mound 11, Area J: Bronze Age anthropogenic soil sealed by a ‘‘sand based’’ anthropogenic soil which in turn is sealed by Early Iron Age midden deposits and wind blown sand (Crown Copyright, reproduced by permission of Historic Scotland).

of origin for the fossil soils associated with Mound 11. They are however earlier than that indicated by the soil sample dates (Table 2) and it is likely that the fossil soil beneath the settlement is the same stratigraphical unit as horizon 7 identified above (Figure 2).

The archaeological evidence from stratigraphical sequences from excavation Areas C and J (Figures 3 and 7) suggests that the development of the fossil soil horizons continued throughout the Bronze Age. This supports the interpretation that the continued development of fossil soil horizons was over the considerable time period identified in horizon 5 of the Mound 11 profile. In the Late Bronze Age/Early Iron Age the fossil soil horizons are sealed by wind blown sands within Areas C and J. Cultivation of these sands is evidenced by ard marks cutting the earlier buried soil and the application of midden materials corresponding to the continued use of an Atlantic Roundhouse structure within Area C (Dockrill & Simpson, 1994). This second sand-based anthropogenic soil is sealed by Early Iron Age midden derived from the latest phase of the Roundhouse. Radiocarbon dates for this late phase of the site indicate a first millennium BC date (GU 2544: 2470 ± 50 BP, peat; GU 2183: 2990 ± 100 BP, bone; GU 2208: 2470 ± 50 BP, bone; GU 2207: 2510 ± 140 BP, bone; Table 2).

### *Formation materials and cultivation*

Features observed in thin section provide a first estimate of the nature of materials forming the fossil soil horizons and for the intensity of cultivation, with each of the examined anthropogenic horizons exhibiting a remarkable degree of similarity in their micromorphological characteristics (Tables 3–6). The evidence from the thin sections would suggest that the principal material forming the anthropogenic soil horizon was a grassy turf with an attached mineral component from soils that were starting to exhibit characteristics of podsolization. Key features that support this interpretation are the predominance of very few slightly weathered quartz grains and the occurrence of iron depleted sandstone and siltstones with stone rims. Iron depletion must have taken place before deposition as the acidification process required to form them would not have occurred in the calcareous depositional environment. Phytoliths are clearly evident, suggesting a grass based organic input, while the minor occurrence of diatoms is indicative of turf material associated with wetter surface conditions. The turf material could potentially have come from a wide variety of landscape positions but given that wind blown sands already covered much of the Tofts Ness peninsula, the most likely locations are the better drained soils to the north and east of North Loch (Figure 1) where wind blown sand deposition was limited (Soil Survey for Scotland, 1981). This means that turves may have been transported over distances of up to 1·5 km.

That at least some of the turf material applied to the arable area, that forms the anthropogenic horizon, was burnt is evident from the occurrence of small oxidized stones and fine charcoals. These are not however major features within the thin sections and give the impression that burning was light, possibly associated with vegetation clearance some time prior to turf stripping. Small quantities of ash material, formed in settlement hearths as a result of burning turf and manure, were deposited with the turf material, with fine pale grey material evident in all the thin sections, together with very few linear patterns of oxidized stone. The ubiquitous occurrence of small bone fragments (some burnt) in the fossil soil horizons further testifies to the application of domestic waste material.

While enhanced levels of total phosphate (Table 1) indicate that there has been a significant organic contribution to the formation of these soil horizons, these materials are now entirely decomposed and cannot be observed in this section. Nevertheless, observations in thin section include a range of yellow/orange and reddish brown fine organic materials, suggesting that a variety of organic materials were applied. Enhanced levels of biological activity, evidenced through the frequency of excremental pedofeatures and the occurrence of channel and chamber structures in thin section, indicates that the application of organic materials may have been substantial. Despite the application of organic material, which would have contributed to the maintenance of soil structure, there has been structural breakdown within the fossil horizons as evidenced by the movement of fine material through the fossil horizons. Movement of silts, which infill pore spaces and fine organic material, that coat quartz and calcium carbonate grains, is evident. Such features are widely associated with moderately intensive cultivation practice disturbing the soil (Jongerius, 1970; Macphail, Romans & Robertson, 1987).

Micro-morphological features observed in the fossil soil horizons are in sharp contrast to the overlying single grain and bridged microstructures. The sharpness of the boundary, seen in thin section, between the fossil soil horizon and the overlying sands indicates that burial was rapid, contributing to good preservation. Similarly, the sharp boundary between the fossil soil horizons and underlying horizons suggests that considerable volumes of material were initially deposited at the commencement of fossil horizon formation.

Because organic materials of formation are well decomposed and could not be directly observed in thin section, stable carbon isotope ratios were used in an attempt to indicate the origin of the principal organic materials used in the formation of the fossil horizons. Interpretation of $\delta^{13}$C values rests upon the kinetic isotope effects which give rise to intermolecular and intramolecular discrimination between the lighter $^{12}$C and heavier $^{13}$C in biogeochemical processes (Craig, 1953; Simpson, 1985) and these fractionation effects permit a broad division between material from marine and terrestrial sources (Simpson, 1997). The $\delta^{13}$C values from the Tofts Ness fossil horizons range from −25·4 to 26·4‰ thus exhibiting a remarkable isotopic homogeneity (Table 1). Mean $\delta^{13}$C values from seaweed, turf and turf/straw/manure control materials are −17·9, −28·5 and −31·2‰ respectively. These observations imply that organic material composition was broadly similar in each of the fossil soil horizons examined and was predominantly terrestrial in origin with a small amount of marine derived material.

Further information on the nature of organic input material was obtained by GC and GC/MS analyses of five lipid classes (*n*-alkanes, wax esters, *n*-alkanols, *n*-alkanoic acids and sterols) obtained from the separated TLEs as described above. Additionally, the *n*-alkane soil components were subjected to GCC/IRMS analysis, providing compound specific stable carbon isotopic data.

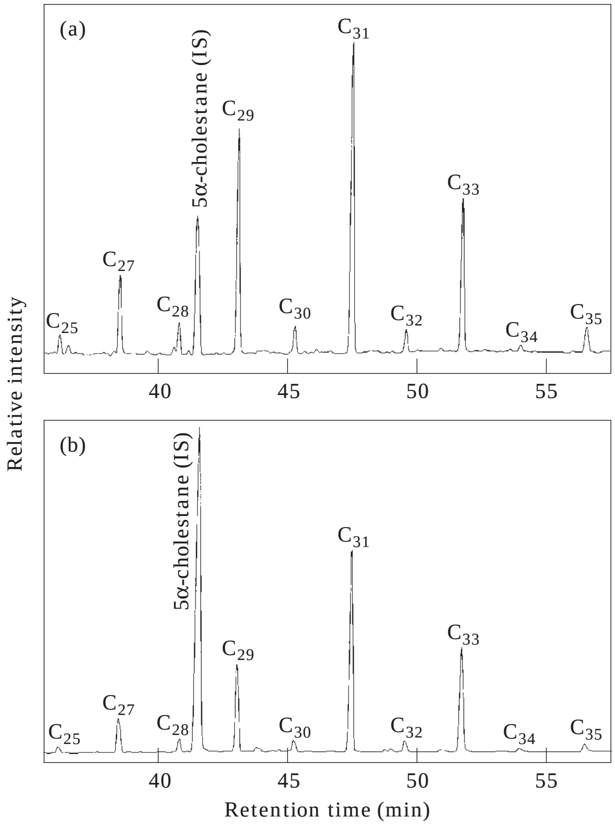

Figure 8. Partial GC traces depicting (a) a typical soil *n*-alkane distribution, and (b) the *n*-alkane distribution derived from the soil of a roofing turf.

*n-Alkanes.* Each sample contains a practically identical series of *n*-alkanes, characterized by a monomodal distribution centred about $C_{31}$, with the $C_{27}$, $C_{29}$ and $C_{33}$ homologues also dominant (Figure 8). The $\delta^{13}$C values obtained for the three dominant *n*-alkanes are very similar for the majority of samples studied with values generally within the range of −32 to −35‰ (Figure 9). The narrow range of values obtained for the three soils infers a close similarity in stable carbon isotopic composition of the major component of formation for each deposit. The sample taken at 0–5 cm depth from the M4 soil exhibits *n*-alkane $\delta^{13}$C values which, for the $C_{29}$, $C_{31}$ and $C_{33}$ components, are isotopically lighter by about 1·5‰ than the corresponding component present in samples taken at greater depth.

The large odd over even predominance of the observed homologous series is indicative of a substantial input from terrestrial vegetation (Peters & Moldowan, 1993). The $C_{31}$ dominated distribution supports the notion that grasses may have been the predominant organic input since this *n*-alkane profile is common in temperate grasses (Maffei, 1996). The similar distributions suggest a constant primary input of this type for all of the soils studied. Inspection of an *n*-alkane profile derived from the grassy turf roof material (Figure 8(b))

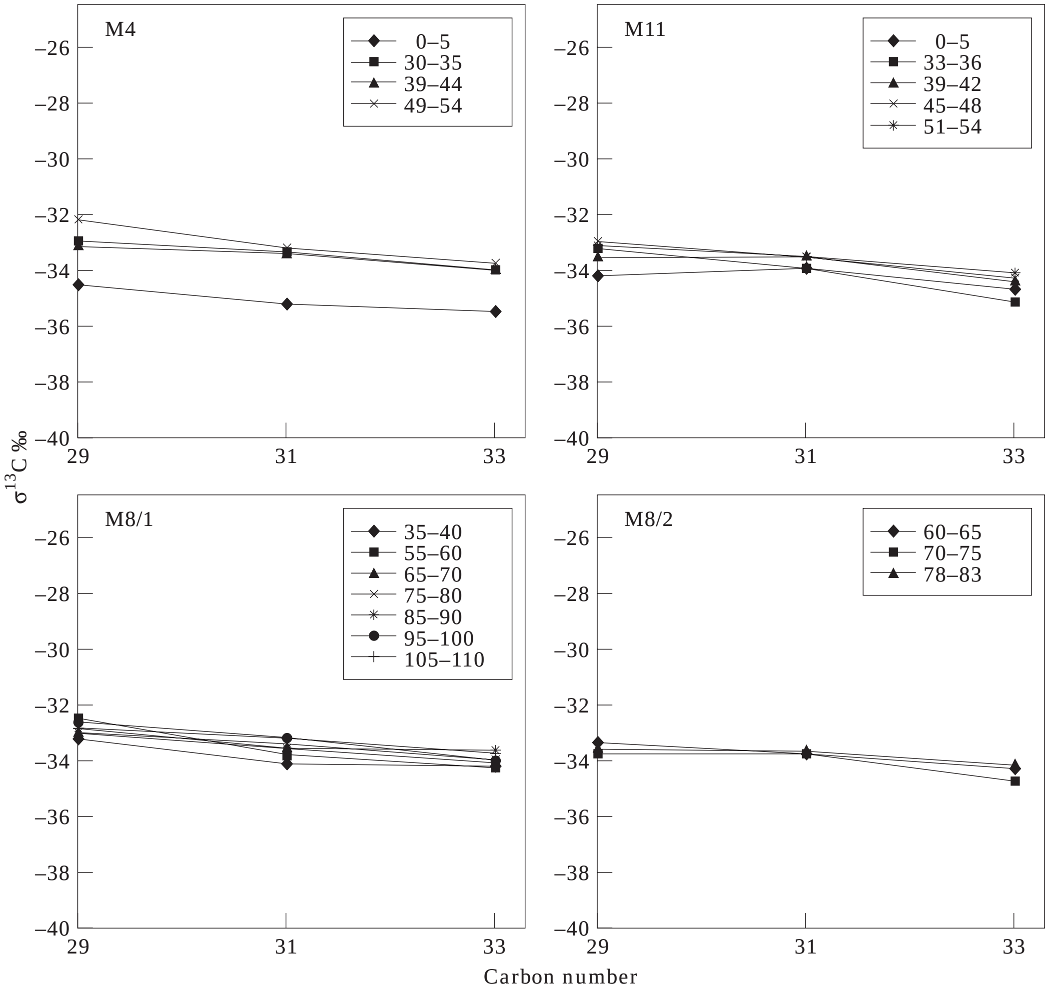

Figure 9. Plots of the results from GCC/IRMS analysis of the major *n*-alkanes in the four soil profiles.

reveals a distribution that is very similar to that observed in the soil samples. The results of GCC/IRMS analysis are also consistent with a large input of terrestrial vegetation, possessing a $C_3$ metabolism for $CO_2$ fixation, to fossil soil formation. These values agree favourably with the results obtained from thin section micromorphology and bulk $\delta^{13}C$ analysis. The isotopically lighter series of components observed at 0–5 cm depth (the present day land surface) from M4 infers an input from a modern-day source of vegetation since the *c.* 1·5‰ difference observed agrees with observations previously made on the isotopic shift caused by the uptake of isotopically lighter $CO_2$, produced by combustion of fossil fuels, into the biosphere (Coleman & Fry, 1991).

*Wax esters.* The majority of samples from the M8/1, M8/2 and M11 soil profiles contain wax esters ranging from $C_{36}$ to $C_{60}$ whilst components derived from M4 exhibit the narrower range of $C_{42}$ to $C_{58}$. Distributions for M8/1, M8/2 and M4 generally contain components of similar abundance although homologues in the $C_{44}$ to $C_{52}$ range are persistently more abundant. Closer inspection of this narrower range of more dominant homologues reveals the $C_{50}$ wax ester, in each case, as the characteristically most minor component barring a few notable exceptions (M8/2 78–83 cm, M11 0–5 cm and M4 30–35 cm). Soils obtained from the M11 profile exhibit $C_{52}$ components which are significantly more abundant than peripheral homologues, especially in the 0–5 cm soil samples. Interestingly, the uppermost (0–5 cm) sample obtained from the profile of M4 also exhibits an unusually dominant $C_{52}$ homologue. Further inspection of mass spectrometric data reveals the majority of wax ester acid fragment ions to correspond with a loss of a dominant $C_{26}$ *n*-alkanol moiety.

The homologous series of wax esters observed for the M4, M8/1 and M8/2 soil profiles are similar in composition to that of the wax esters derived from the roofing turf vegetation which also exhibits a broad carbon number distribution ($C_{36}$ to $C_{60}$) with an unpronounced $C_{52}$ component. Considering the age, and the former environmentally exposed position of the roof turf, one would expect this sample to have suffered severe degradation especially for those components of particularly high abundance. Hence, the pronounced $C_{52}$ homologue in distributions from M4 0–5 cm and all samples from the profile of M11 are possibly the consequence of enhanced preservation compared with soils from other profiles. The preferential occurrence of the $C_{26}$ *n*-alkanol moiety correlates with the dominant free *n*-alkanol component observed to occur in *n*-alkanol distributions derived from the turf soil and its associated vegetation (see below).

*n-Alkanols*. *n*-Alkanol distributions exhibit a greater overall abundance than those of wax ester components. A bimodal distribution ranging from $C_{20}$ to $C_{34}$ with a maxima at $C_{22}$ and $C_{26}$ is observed for the majority of samples. For some soils this bimodality is particularly pronounced although no obvious correlation with depth may be made. A number of samples from Mound 4 (39–44 cm) and Mound 11 (33–36, 39–42 and 51–54 cm) deviate from the general trend and exhibit monomodal distributions with a maximum at $C_{26}$. However, even in such cases the differences, when compared with bimodal distributions, are minimal.

*n*-Alkanols ($C_{22}$–$C_{34}$) are well documented components of terrestrial higher plants, including grasses, commonly occurring as integral components of epicuticular leaf waxes (Walton, 1990). The similarities observed between the distributions in the mound profiles are interesting, inferring similar inputs of higher plant vegetation. Inspection of *n*-alkanol distributions derived from the roof turf soil and the associated vegetation reveals two distributions; the former bimodal with maxima at $C_{22}$ and $C_{26}$ and the latter monomodal with a maximum at $C_{26}$. Hence, the various monomodal/bimodal distributions observed in the mound soils most likely result from differing quantities of turf soil and associated vegetation being applied to the mounds during periods of anthropogenic activity. The, seemingly random, fluctuations in total concentration of *n*-alkanols between samples are almost certainly the result of anthropogenic, and not natural, processes such as variable levels of turf input and/or increased post-depositional exposure, the latter resulting in enhanced degradation.

*n-Alkanoic acids*. Every fraction analysed exhibits a bimodal distribution, generally ranging from $C_{12}$ to $C_{34}$ although the M8/2 70–75 cm and M4 30–35 cm soils both exhibit higher homologues ($C_{36}$ and $C_{38}$) albeit at low abundance. The lower molecular weight components of each distribution are centred about the $C_{16}$ homologue whilst the carbon number maximum of the higher homologues is variable. The second homologue maximum for the 0–5 cm sample from the M11 profile occurs at $C_{24}$ whilst samples at greater depth show an increased abundance of higher homologues exhibiting a maximum at $C_{26}$. This trend to a higher molecular weight with depth is also paralleled by the M4 profile which changes from a $C_{24}$ to $C_{28}$ maximum in lower levels of the profile. In the majority of samples the long-chain *n*-alkanoic acids describe similar distributions, all possessing a strong even over odd predominance, indicative of a higher terrestrial plant input to the soils. The distributional shifts observed in the M4 and M11 samples indicate a more recent input of terrestrial origin to the uppermost soil samples from each profile.

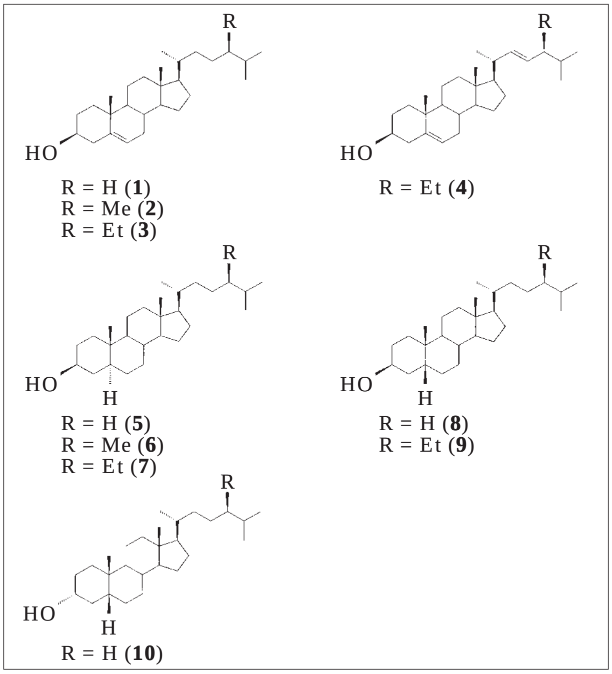

Figure 10. Sterol structures.

*Sterols*. (Figure 10). No identifiable sterols are present in any of the M4 soil samples analysed except in the 0–5 cm soil. However, samples from M8 and M11 are all dominated by the phytosterols 24-methylcholest-5-en-3β-ol (2), 24-ethylcholest-5,22-dien-3β-ol (4), 24-ethylcholest-5-en-3β-ol (3) and the $C_{27}$ homologue cholest-5-en-3β-ol (1). 24-ethyl-5α-cholestan-3β-ol (7) is also highly abundant and, in the M8/2 60–65 cm and 70–75 cm samples, is the dominant sterol; present at a higher concentration than the usually dominant 24-ethylcholest-5-en-3β-ol (3). 5α-cholestan-3β-ol (5) and 24-methyl-5α-cholestan-3β-ol (6) are both present albeit at lower concentration as is 5β-cholestan-3β-ol (8) and 24-ethyl-5β-cholestan-3β-ol (9). The former 5β-stanol is the more abundant compound and, in the M8/1 and 8/2 soil samples, is accompanied by the presence of its 3α-epimer, 5β-cholestan-3α-ol (10).

The ‘‘sterol’’ fractions for each of the M4 soil samples contain a number of unidentified compounds. However, the absence of the common phytosterols indicates either a large difference in the components used to construct the soil or the result of severe diagenetic alteration. The predominance of 24-

methylcholest-5-en-3β-ol (2), 24-ethylcholest-5,22-dien-3β-ol (4), 24-ethylcholest-5-en-3β-ol (3) and their corresponding 5α-stanols 24-methyl-5α-cholestan-3β-ol (6) and 24-ethyl-5α-cholestan-3β-ol (7), in M8 and M11, is consistent with an input of material derived from terrestrial higher plant vegetation (Killops & Killops, 1993). The presence of the 5β-stanols 5β-cholestan-3β-ol (8), 24-ethyl-cholestan-3β-ol (9) and, in a number of cases, 5β-cholestan-3α-ol (10) is of particular interest. 5β-stanols have previously been used as indicators of faecal deposition in a number of studies (Knights *et al.*, 1983; Evershed & Bethel, 1996; Evershed *et al.*, 1997). The survival of 5β-stanols, derived from manure deposition, in agricultural soils subjected to near constant crop cultivation for over 120 years has also been established (Bull *et al.*, 1998). Obviously this was in a biologically active soil with inherently high levels of degradative processes occurring; the fact that a manuring signature still survives supports the use of this technique in archaeological applications concerned with sealed fossil soils.

Whilst high concentrations of 5β-stanols, relative to other sterol components, have been used to indicate a faecal input to sediments (Laureillard & Saliot, 1993) this is not reliable enough for use in chemical studies of archaeological soils since there is a natural background of 5β-stanols in the soil environment (Bethel *et al.*, 1994). Grimalt *et al.* (1990) have proposed the 5β-stanol/(5α-stanol+5β-stanol) ratio as a more reliable parameter for the investigation of suspected faecal deposition. This parameter is independent of 5β-stanol concentration and its increased reliability for the detection of faeces has made it useful in detecting the existence of an ancient Minoan manuring regime (Bull *et al.*, in press). For the soil samples, from M8/1 and M11, an increase in this ratio with depth is observed in each case (Figure 11) perhaps reflecting the mobility of the fine organic fraction observed in thin section (Tables 3 and 5). However, the increase in the ratio is not due to concentration effects, inherent in possible migration to greater depths, since the corresponding 5α-epimer, 5α-cholestan-3β-ol (5), would possess identical properties of physical migration. Whilst the highest observed ratios do not encroach on the 0·7 limit (the highest being 0·55, 8/1 105–110 cm), proposed by Grimalt *et al.* (1990) as a lower limit for definite faecal deposition, it must be remembered that this application of the technique is on soils of archaeological date and not modern-day material. Given the possibility of partial degradation of soil components over time it is not unreasonable to expect a decrease in the lower limit proposed for this ratio. We would interpret these results to indicate faecal material was probably used as a minor component in the construction of soils around M8 and M11, but not, however, around M4. This is supported by the high phosphate levels measured in M8 and M11 compared with the lower concentration observed in soils around M4. Furthermore the distribution of 5β-stanols is indicative of human or porcine derived faecal material (Bethel *et al.*, 1994). This can be observed in Figure 12 which clearly shows the presence of 5β-cholestan-3β-ol (8); 24-ethyl-5β-cholestan-3β-ol (9) co-elutes with the more dominant 24-methyl-cholest-5-en-3β-ol (2) and is only a minor component.

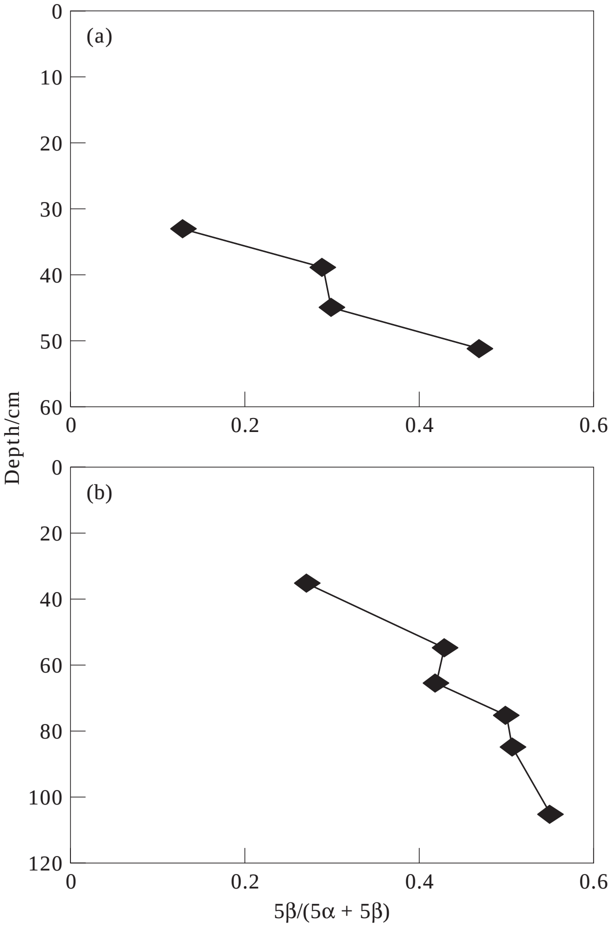

Figure 11. $C_{27}$ 5β-stanol/(5α-stanol+5β-stanol) ratio plots for the (a) M11 soils, and (b) M8/1 soils.

## Conclusions

The close association of the fossil soil horizons at Tofts Ness with early settlement sites and their enhanced total phosphate levels supports the hypothesis that these horizons are anthropogenic in origin and were subject to moderately intensive cultivation. Furthermore, the evidence so far available suggests that the small areas of anthropogenic soil horizons at Tofts Ness arose primarily through the application of podsolized, occasionally burnt, grassy turf material of different composition to present day turf cover. Application of faecal material derived from a human or porcine source also contributed to the formation of the soils around M8 and M11. As pig bone was only 1–2%

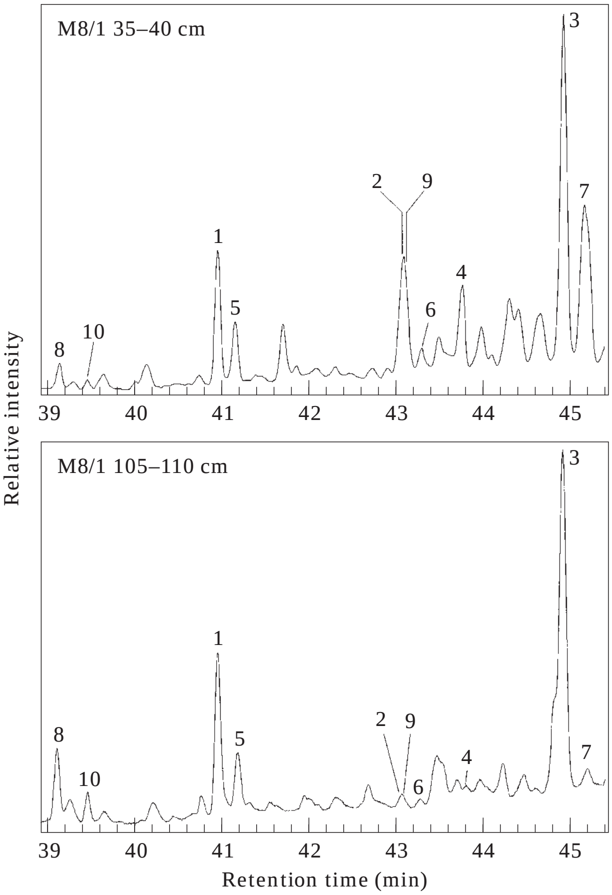

Figure 12. A partial GC trace comparing the sterol components from the M8/1 35–40 cm and M8/1 105–110 cm soil samples. Peak numbers refer to structures in Figure 10.

of all bone fragments found during excavation of M11 (J. M. Bond, pers. comm.), a human origin is the more likely. Ash material was applied and, in the absence of evidence for cattle or sheep manure being applied directly to the field, it is suggested that animal manures contributed as fuel source. Such observations emphasize the marginal nature of this area for arable cultivation and highlight the utilization of all available resources to enable continuity of settlement.

The formation of these fossil soils is similar to mediaeval and early modern plaggen soil formation evident across large extents of north-west Europe (Pape, 1970). Plaggen soils are found extensively on the Pleistocene sands of Belgium, Germany and the Netherlands, and have also been identified in the West Mainland of Orkney (Simpson, 1997). They arose within a mixed pastoral-arable economy as a result of efforts to maintain and enhance the fertility of arable soils. Heather or grass turves were stripped from podsolic soils and used as animal bedding; the composted turf and animal manure were then applied to the arable land where the mineral component attached to the turf gradually contributed to the creation of an artificial, thick, soil horizon. Characteristic properties of plaggen soil horizons include an increase in soil thickness with proximity to early farm steadings and enhanced levels of total phosphate (Pape, 1970; Conry, 1974; de Bakker, 1980; van de Westeringh, 1988; Mucher, Slotboom & ten Veen, 1990; Simpson, 1997).

The process of anthropogenic soil formation at Tofts Ness is not therefore unique, although the use of human manure in place of animal manure is distinctive, but in light of the continuing debate over the origins of plaggen soil formation, what is significant are the estimated ages of the Tofts Ness anthropogenic soil horizons. Plaggen soils from continental north-west Europe have been dated by radiocarbon as far back as 600 BC (reported by Pape, 1970), and have been reported in earlier Bronze Age site stratigraphies on the German North Sea island of Sylt (Kossack & Reichstein, 1987). Recent analyses through radiocarbon dating and pollen analysis have suggested that the expansion of plaggen soils took place between AD 750 and AD 1200 (Castle, Koster & Slotboom, 1989) and the review by Spek (1992) has brought the date of formation further forward indicating that the most plausible date of origin of the widespread use of plaggen manure is not earlier than the 13th century. In Scotland soils similar to the continental plaggen soils have been identified in a number of localities. In Aberdeenshire anthropogenic top toils of between 30 and 75 cm in thickness (Glentworth, 1944) have been correlated with concentrations of population recorded in the Poll tax returns of AD 1697 (Walton, 1950). Using this historical documentation, Walton argues that these soils arose in association with the long term improvement of the intensively cultivated infield land during and since the Middle Ages. Anthropogenic soils with surface horizons of 50 cm thickness and exceptionally high phosphate values have been identified in Iona (Barber, 1981). These soils are considered to have been raised between the 7th and 11th centuries AD, a major period of monastic activity. Plaggen soils in West Mainland Orkney have been dated to the late 12th/early 13th centuries AD on the basis of radiocarbon dating and association with settlements of known cultural age (Simpson, 1993). Current evidence suggests therefore that the Tofts Ness anthropogenic soil horizons are considerably earlier than most plaggen soils found elsewhere in Europe or in Scotland and are amongst the earliest of their type.

Reasons for these land management practices are not difficult to find. The calcareous sands of the Bronze Age Tofts Ness landscape would have been unviable for any form of arable activity through a lack of available water in summer and a high risk of erosion when cultivated. Only intensive forms of manuring made this landscape viable for sustained arable production by alleviating these two limitations. This emphasises the importance placed on the arable sector to the overall economy, an importance highlighted by Dockrill (1993) who calculated that such areas growing barley could have provided as much as 65–70% of the population's energy requirements. A wider, social explanation for the origins of these soils may be that there was substantial land pressure on Sanday during the Late Bronze Age/Early Iron Age, forcing the maintenance of earlier secondary settlements despite increases in marginality of sites such as Tofts Ness M11. This continuity of land use and settlement is mirrored in the north-eastern part of the Tofts Ness peninsula by the funerary landscape which spans the Neolithic and Bronze Age (Lambe, 1980).

The hypotheses of continued anthropogenic plaggen-type soil development in the Neolithic and Bronze Age needs to be tested by making spatial and temporal links between amended palaeosols and associated settlements within other early cultural landscapes on Sanday and in the Northern Isles as a whole. Evidence from a deep soil profile from Spur Ness, a non machair site on the southern peninsula of Sanday, is of interest here. This deep soil profile survives adjacent to both a post medieval structure to the west and a prehistoric structure surviving as an earthwork with elements of faced walling to the east. This profile contains five visible horizons with the upper two related to agricultural practices associated with the later structure (SRR 5250: 285 ± 40 BP). Horizon 4 however represents a buried soil with strong evidence for amendments which mirror those discussed above with reference to Tofts Ness. Furthermore, radiocarbon dating of soil material from this horizon suggests a late Neolithic context for this horizon (SRR 5251: 4010 ± 45 BP); similar early fossil plaggen type soils have also been identified at Burn of Furse, Fair Isle (SRR 5257: 3560 ± 45 BP; SRR 5256: 2870 ± 45 BP) and South Nesting in Shetland (SRR 5255: 3620 ± 55 BP; SRR 5254: 1630 ± 45 BP; Simpson, 1995) and new excavation work at Scatness, Shetland, has shown that other sites survive with these relationships intact. Preliminary excavation in 1996 at Scatness identified an anthropogenic soil with evidence of ard cultivation separated from the settlement mound by a boundary wall. Evidence based on the ceramic assemblage suggests a possible Late Bronze Age context for this soil. The detailed investigation of this and other amended soils will form a key theme for the 1996 Scatness excavation programme. This will allow the investigation of not only temporal but also spatial change of these early anthropogenic soils which are emerging as a critical element in the early palaeo-economy of Orkney and Shetland.

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