Journal of Archaeological Science (1997) **24,** 365–380

Relict Properties of Anthropogenic Deep Top Soils as Indicators of Infield Management in Marwick, West Mainland, Orkney

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(*Received 12 December 1995, revised manuscript accepted 31 March 1996*)

Relict properties of anthropogenic deep top soils formed between the late 1200s and late 1800s are used to identify infield management practices in the coastal area of Marwick, West Mainland, Orkney. Properties examined include particle size distribution, total phosphate, $\delta^{13}C$ values, and micromorphological features. Interpretation of infield management practices from these properties is based upon their known characteristics, through comparisons with known materials and by comparisons with other areas of the Marwick landscape. The observed properties suggest that manuring practice involved the application of grassy turf material that came exclusively from the hill land, together with composted animal manure and a minor seaweed component. Materials from other possible sources were not utilized and differences in relict soil properties within and between the deep top soils in Marwick suggest that varying proportions of turf and manure were applied across the area of land that developed as deep top soil. Cultivation practices associated with the deep top soils were sufficiently intense to contribute to the downslope and down profile movement of fine material. The implications of the interpretations are discussed in relation to the wider organization of the cultural landscape in Orkney. More general conclusions are drawn on the implications for soils-based studies of infield systems.

Keywords: ORKNEY, ANTHROPOGENIC SOILS, INFIELD MANAGEMENT, CULTURAL LANDSCAPES.

Introduction

The Bilbster soil series in Orkney, Scotland, is a freely or imperfectly drained cultivated podsol developed on drift derived from the Stromness and Rousay Flags of the Middle Old Red Sandstone. Within this series is a deep top phase defined by the Soil Survey for Scotland (1981) as having a mineral top soil with a thickness generally in excess of 75 cm. The mapped extent of this phase is approximately 7 km^2, and apart from two small areas on the island of Stronsay is confined to the West Mainland of Orkney (Soil Survey for Scotland, 1981; Figure 1). Earlier research on these loamy deep top soils has demonstrated that top soil thickness increases with proximity to early farmsteadings and that total phosphate values are between two and three times background levels found in top soils of the parent Bilbster soil series (Davidson & Simpson, 1984; Table 1). Both characteristics are indicative of anthropogenic plaggen soils, commonly found on the Pleistocene sands of Belgium, Germany and the Netherlands. These soils 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 of wasteland areas and used as animal bedding in the byre; the composted turf and animal manure material was then applied to the arable land where the mineral component attached to the turf gradually contributed to the creation of an artificial, thick, top soil horizon (Pape, 1970; Conry, 1974; de Bakker, 1980; van de Westeringh, 1988; Mucher, Slotboom & Ten Veen, 1990; Spek, 1992). Deep top soil formation in Orkney can be interpreted as resulting from a similar process.

Further studies have established the chronological and spatial constraints on deep top soil formation. By examining the association of these soils with settlement features of known cultural age across Orkney and by radiocarbon dating deep top soils from Marwick, Simpson (1993) concluded that formation commenced during the mid- to late Norse period (12th to early 13th centuries AD). These soils are considerably later in origin than the intensively manured, but less thick and less extensive fossil Bronze Age and early Iron Age anthropogenic soils found beneath calcareous sands and peat deposits in other areas of the Northern Isles (Dockrill & Simpson, 1994; Simpson, 1995). Reasons advanced for the initiation of deep top soil formation include the introduction of the plaggen manuring technique by monastic settlement and the need to sustain increasing population levels during a climatic optimum. Formation of these soils is demonstrated to have continued through the mediaeval period until the late

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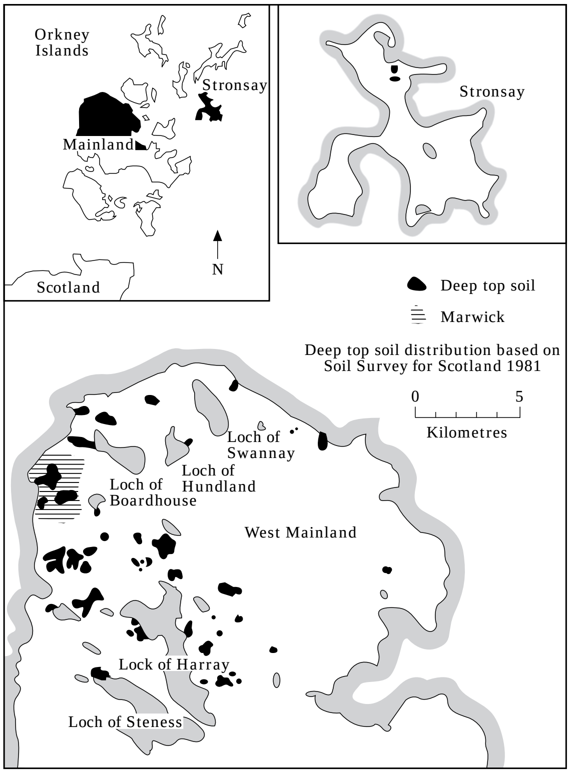

Figure 1. Deep top soil distribution in Orkney.

19th to early 20th centuries AD, when new methods of maintaining soil fertility were introduced and division of the common lands took place (Thomson, 1981; Simpson, 1993).

The spatial concentration of deep top soils in West Mainland can be explained by the lack of abundance of seaweed, the preferred arable land fertilizer in early Orkney (Fenton, 1978). The alternative of plaggen manuring was therefore adopted in West Mainland as a means of maintaining arable land fertility (Simpson, 1994). At a local scale, there is good association between the deep top soils and the assessed arable land known as *tunmal* (Old Norse). This land was held permanently by the adjacent farmstead and, unlike other areas of arable land, was not subject to periodic redistribution (Clouston, 1922; Thomson, 1987; Simpson, 1994). The deep top soils are therefore the result of a particular form of infield management.

While the general processes of anthropogenic soil formation and infield management practices are well established, the precise nature, source and depositional pattern of materials used in the formation of such soils remains to be resolved. The impact of cultivation practices on anthropogenic soil properties is also poorly understood. This paper addresses these issues through the identification and interpretation of relict anthropogenic properties in deep top soils from Marwick, West Mainland Orkney (Figure 1). Relict

Table 1. Field and laboratory data of a Bilbster Series deep top phase soil; Profile H13, Marwick

(a) *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 (10YR2·5/1) 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.

(b) Laboratory data

Horizon	Depth (m)	Loss on ignition	% Sand	% Silt	% Clay	Ca (exchangeable me per 100 g)	Mg (exchangeable me per 100 g)	Na (exchangeable me per 100 g)	K (exchangeable me per 100 g)	pH (H_2O)	Phosphorus (total mg P_2O_5 per 100 g)
S1	0·1	6·7	43·1	37·2	19·7	5·48	3·45	0·72	0·32	5·6	768
S2	0·2	4·9	34·5	41·4	24·1	5·49	2·88	0·67	0·36	5·8	430
S2	0·3	3·9	38·25	38·1	23·65	6·31	2·80	0·72	0·29	6·0	558
S2	0·4	3·5	34·6	40·4	25·0	6·11	2·79	0·78	0·22	6·1	522
S2	0·5	3·3	41·6	40·9	17·5	5·43	3·09	0·71	0·19	6·1	441
S2	0·6	3·0	37·2	42·7	20·1	4·80	3·40	0·73	0·17	6·2	429
S2	0·7	2·3	32·0	43·9	24·1	3·36	3·75	0·71	0·17	6·2	394
B3	0·8	2·2	37·3	34·0	28·7	3·76	4·65	0·78	0·12	6·2	197

soil properties (Bronger & Catt, 1993) examined include particle size distribution, total phosphate levels, $\delta^{13}C$ values and micromorphological features observed in thin sections. Within the context of change arising from post-depositional pedogenic processes, these soil properties permit elucidation of inorganic and organic materials of formation, the intensity and pattern of organic material deposition and an indication of the intensity of tillage. Interpretations can then be placed in a wider cultural landscape context providing fresh insights into the organization and function of the cultural landscape in Orkney.

Methods

Study area

The Marwick drainage basin is located in the parish of Birsay, West Mainland Orkney (HY 235 241) and covers an area of approximately 6·5 km^2 (Figure 2). Altitude ranges from 127 m to sea level, with the land sloping gently towards a small stream draining into Mar Wick, the bay that gives the area its name. Apart from the bay, which provides access to the open sea, sea cliffs up to 80 m in height form the western edge. Stromness Flags of the Middle Old Red Sandstone underlie the area and are covered by a uniform sandstone derived glacial drift. Soils mapped at 1:50,000 scale (Soil Survey for Scotland, 1981) indicate podsolic soils occupying mid-slope and upper south facing slope positions, within which are three discrete areas of anthropogenic deep top soils covering an area of approximately 150 ha (Figure 2). Peat-alluvium deposits and poorly drained gleys occupy bottom slope positions and hollows in the landscape; peaty podsols and peaty gleys are found on upper, north facing slopes; saline gleys fringe the sea cliffs. The principal land use is permanent grassland, with occasional barley and oats, for livestock production. At West Howe, where most of the sampling was carried out, much of the deep top soil area is not used intensively and is currently semi-improved pasture used for rearing horses.

The close spatial association of deep top soils with Norse farm name elements in Marwick, and the lack of association with earlier cultural elements of the landscape, suggest that formation was ongoing during the Norse and mediaeval period (Simpson, 1993). Deep top soils are found associated with both the early skatted (assessed) physiographic and *Skali* Norse farm name elements, as well as the unskatted *Kvi* farm names which represent later extensions of the Norse township (Marwick, 1952). This chronological interpretation is further supported by radiocarbon dates from Netherskaill, Marwick (Table 2) which, when appropriate corrections are made for rejuvenation effects and the age of material when deposited, indicate a late Norse period of origin (Simpson, 1993). Historical evidence for the application of turf, manures

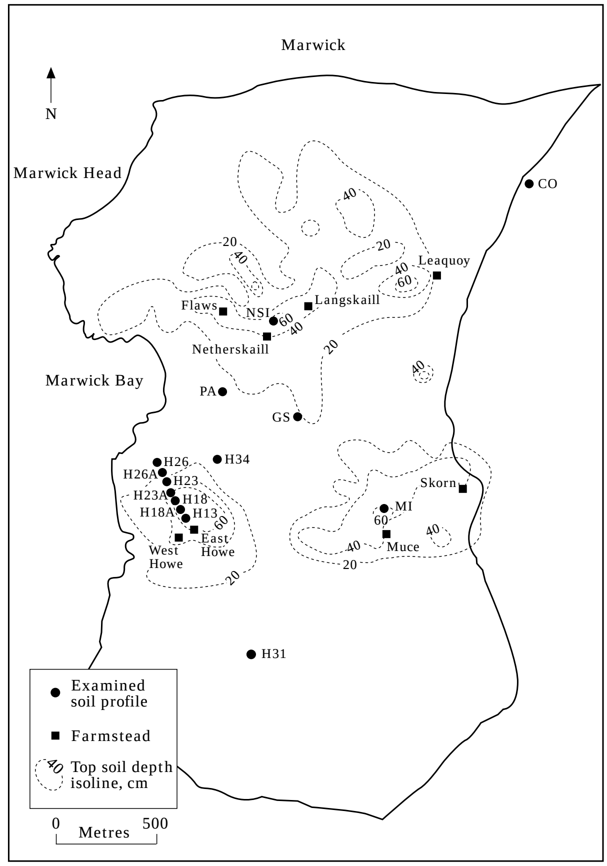

Figure 2. Deep top soil depth distribution and sample profile location in Marwick.

and seaweed to arable land in Orkney is recorded up to the late 1800s (Pococke, 1747–1760; Fenton, 1978).

The earliest map of Marwick is from 1769 and demonstrates a broad division in the cultural landscape between the hill land and the agricultural land enclosed by a turf based hill dyke (MacKenzie, 1750; Figure 3). Different functional areas are evident within the enclosed land, with substantial patches of arable land in a grassland matrix. Areas of meadow land are also evident, although superimposition of these early functional areas onto the soils map suggests that meadow land is associated with peat-alluvium and gley soils, that arable land and grassland is associated with the better drained podsolic soils and that the deep top soils form only a part of the arable area. The township hill dyke closely follows the boundary of the podsolic and peaty podsols and peats to the south and east; there is no obvious relationship between the hill dyke and soil type to the north.

Skat (land tax) values in the 1595 rental for farms spatially associated with the deep top soils in Marwick vary. Howe is assessed as six pennylands, while Netherskaill/Langskaill, Muce and Skorn are assessed as three pennylands each. Leaquoy does not have a skat value and would have been settled once the early tax system had been established, probably in the

Table 2. Measured ^{14}C age values and corresponding calibrated calendar ranges for deep top soils at Netherskaill, Marwick

Location	Composition	Depth in profile (cm)	Laboratory code no.	Conventional ^{14}C age (years BP $\pm$ 1 σ)	Dendro timespan (years AD)
Netherskaill (NS1)	Soil	25–30	SRR 4114	440 ± 55	1425–1475
Netherskaill (NS1)	Soil	65–70	SRR 4115	930 ± 55	1022–1187

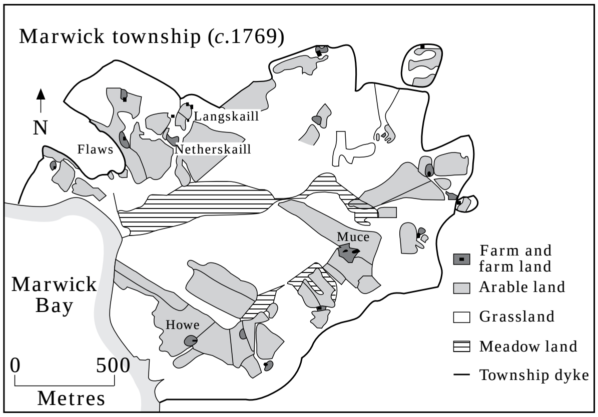

Figure 3. Marwick Township *c.* 1769.

13th century AD (Figure 2; Peterkin, 1820; Marwick, 1952; 1970).

Field survey and sampling

Top soil thickness of the three deep top soils was mapped by hand auger on a 50 m sample grid, providing a framework for soil profile sampling (Figure 2). A total of 14 soil profiles was examined and described using the notation of the Soil Survey for Scotland. Within the deep top soil areas, a surveyed transect consisting of four profiles at 25 m intervals was examined at West Howe (H13, H18a, H18, H23a), one profile from Netherskaill (NS1) and one profile from Muce (M1). To assist with the interpretation of soil properties within the deep top soils, a further eight soil profiles were examined from other areas of the Marwick landscape. Five soil profiles were from the podsolic Bilbster soil series (CO, H34, H26, H26a, H23), four of which were located on the West Howe transect, and one soil profile was examined from each of the peat-alluvium deposits (PA), the gley soils (GS) and the area mapped as peaty podsol (H31). Profiles CO and H31 were located in the mediaeval hill land area, beyond the hill dyke; all other profiles came from within the early enclosed land.

Bulk samples were taken from the profiles at 10 cm intervals on the West Howe transect and at 20 cm intervals elsewhere. A total of 11 undisturbed soil samples was collected in 10 × 5 × 5 cm Kubiena tins for micromorphological analysis. Eight of these samples came from the West Howe deep top soil transect, and three from top soils of the Bilbster series.

Contemporary materials of the type that may have been used to create the anthropogenic soils (Fenton, 1978) were also collected to assist in the interpretation of deep top soil properties. These materials included beach sand, old turf roof material, peat ash, podsolic soil surface litter, seaweed, straw/manure byre wastes and turf/manure byre wastes. These materials came from Marwick, with the exception of the peat ash which came from Birsay, immediately to the north of Marwick, and the turf/manure material which came from North Ronaldsay, the northernmost island of Orkney.

Laboratory analysis and statistical treatments

Bulk soil samples were air dried and passed through a 2 mm sieve. Subsamples were then analysed for particle size distribution, total phosphate and $\delta^{13}C$. Particle size distribution of subsamples was by sieving and sedimentation using an Andreason pipette after the subsample had been pretreated with H_2O_2 to remove organic carbon and dispersed with 8 h shaking in calgon solution. Combined sieving and sedimentation partitioned the subsample into 1 φ intervals from which cumulative particle size percentages were calculated. These values were plotted on probability paper and mean, sorting and skewness calculated according to the equations of McCammon (1962); analytical errors based on replicate samples are ± 0·025, 0·025 and 0·008 respectively.

Total phosphate analysis of the <180 μm fraction was by fusion with Na_2CO_3 in a platinum crucible followed by 2 h digestion (Jackson, 1958). Colorimetric determination was by the ammonium molybdate/stannous chloride procedure (Murphy & Riley, 1962). Results are reported in mg per 100 g P_2O_5 and analytical error is ± 15 mg per 100 g based on replicate samples.

Analysis of subsamples for organic carbon and $\delta^{13}C$ was by quantitative oxidation to CO_2 in a quartz semi-micro combustion rig, after separate subsamples had been tested for calcium carbonate by acid washing. 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 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 five sample intervals throughout sample analysis permitting an estimated analytical precision of ± 0·2‰.

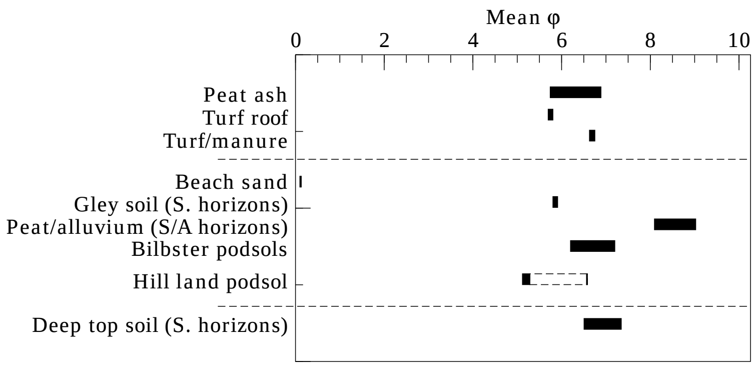

Figure 4. Mean particle size values; West Howe deep top soil, Marwick, and control data.

Soil thin sections were prepared following the procedures of FitzPatrick (1984). Water was removed by acetone exchange and the samples impregnated using polyester crystic resin. 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). 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 which were recorded in standard summary tables.

Comparative statistics were calculated using the MINITAB package. Trend surface analyses of data from the West Howe transect data were undertaken using program 573 of the Department of Geography, University of Liverpool. Up to five orders were calculated and tested for significance using F ratios.

Results and discussion

Inorganic formation materials

Identification and sourcing of the inorganic materials brought into the infield area and contributing to the formation of the deep top soil is based on particle size distribution data supported by the mineral component observed in soil thin sections. Deep top soil horizons in Marwick have a mean particle size range of between 6·50 φ and 7·38 φ; for West Howe the mean range is from 6·50 φ to 7·16 φ. Patterns of particle size distribution are evident within the West Howe deep top soil, but are interpreted as resulting primarily from post depositional fine material movement rather than variation in deposition, and are discussed below.

Comparison of the mean particle size distribution values from the deep top soil with the potential input materials indicates that the deep top soils are within the range for the upper horizons of podsolic soils (Figure 4). A more minor peat ash component may also be present, but sorting and skewness values are substantially different from those found within the deep top soils (Tables 3 & 4) and no burnt stone material is evident in thin sections. Although the mineral component observed in thin section is virtually uniform, suggesting a common source for all inorganic materials, the occurrence of iron depleted stone rims supports the podsolic origin of much of the material forming the deep top soil (Table 5). These features are indicative of podsol soil environments and their thickness (up to 800 µm) and uniformity with depth suggests that the podsolization process giving rise to them did not take place within the deep top soil, but rather occurred in the upper horizons of well-developed podsols (Romans & Robertson, 1975).

Sourcing the inorganic materials of deep top soil formation can be refined by examining the field properties of profile H31, the podsolic soil located on what was the hill land beyond the turf dyke enclosing the mediaeval township. Field observation of soil horizons in profile H31 demonstrates a grassy turf layer buried at 20 cm depth (Table 6), while the particle size distribution data (Table 4) are also consistent with a truncated soil profile that has subsequently been reclaimed. Field and particle size distribution evidence of truncation is not found in profiles of the Bilbster series from within the mediaeval hill dyke and so the inference is that turf with mineral material attached has been stripped from podsolic soils of the hill land, beyond the township boundary, to supply materials for the infield area. Furthermore, the consistent 10YR 3/2 and 10YR 3/3 field Munsell colour of the deep top soils suggests that the turf was predominantly grass based and may have been preferred to heath based turfs (Pape, 1970). On the basis of anthropogenic soil thicknesses (Figure 2) it is estimated that 199,000 m^3 has been removed from the surrounding hill land and deposited as deep top soil in Marwick, emphasizing the importance of the hill land for the maintenance of arable agricultural activity in medieval West Mainland Orkney.

Organic formation materials

Total phosphate and $\delta^{13}C$ values can be used in conjunction to identify the intensity of organic material

Table 3. Analytical data of Bilbster series deep top phase soils: Marwick

Profile	Horizon	Sample depth (cm)	Particle size distribution φ Mean	Sorting	Skewness	$\delta^{13}C$‰	Total P_2O_5 mg per 100 g
H13	S1	10	6·74	2·55	0·23	− 28·3	768
	S2	20	7·02	2·80	0·11	− 28·2	430
	S2	30	6·96	2·53	0·24	− 27·4	558
	S2	40	7·16	2·42	0·14	− 27·8	552
	S2	50	6·78	2·28	0·10	− 27·5	441
	S2	60	7·04	2·41	0·03	− 27·3	429
	S2	70	7·02	2·61	0·16	− 27·6	394
	B2	80	7·06	2·80	0·24	− 27·0	197
H18A	S1	10	6·74	2·82	0·26	− 28·1	637
	S2	20	6·72	2·70	0·29	− 27·9	430
	S2	30	6·60	2·65	0·30	− 27·5	479
	S2	40	6·66	3·99	0·05	− 26·7	520
	S2	50	7·00	2·67	0·16	− 27·5	363
	S2	60	6·76	3·43	0·06	− 27·5	326
	S2	70	6·96	2·69	0·14	− 27·7	326
	S2/B2	80	6·88	2·79	0·13	− 28·7	249
	B2	90	6·12	3·35	− 0·08	− 28·2	196
H18	S1	10	6·64	2·71	0·15	− 27·9	626
	S1	20	6·50	2·65	0·19	− 27·8	423
	S2	30	6·92	2·65	0·23	− 27·3	474
	S2	40	7·12	2·70	0·08	− 27·0	401
	S2	50	6·80	2·83	− 0·11	− 26·8	393
	$B2_x$	60	4·02	3·28	− 0·55	− 26·8	195
	$B2_x$	70	5·36	3·17	0·06	− 26·8	132
H23A	S1	10	6·66	2·65	0·15	− 28·2	470
	S2	20	6·82	2·64	0·12	− 27·5	354
	S2	30	7·04	2·74	0·15	− 27·3	324
	A1	40	6·62	3·14	− 0·03	− 27·3	92
	B2	50	6·98	2·60	0·04	− 27·2	80
NS1	S1	20	7·38	3·23	0·28	− 28·6	1166
	S2	40	6·88	2·38	0·21	− 28·6	747
	S2	60	7·00	2·76	0·15	− 28·7	841
	B2	80	6·14	3·25	− 0·08	− 27·6	359
MU1	S1	15	6·68	2·63	0·22	− 28·7	750
	S2	30	6·64	2·79	0·31	− 28·6	796
	S2	50	6·72	2·96	0·06	− 28·3	1148
	$B2_g$	70	4·32	3·46	0·02	− 29·8	451

application to the deep top soil area and the origin of that material. Comparison of mean and range total phosphate values from the deep top soil S horizons (mean, 537 mg per 100 g; range, 249–1166 mg per 100 g) and from topsoils of the surrounding landscape (mean, 374 mg per 100 g; range, 111–529 mg per 100 g; Mann–Whitney U test significant at 0·01) demonstrates the enhanced levels of total phosphate found in the deep top soils. This level of enhancement can be attributed to the substantial use of organic materials in the formation of the deep top soil and the long term retention of phosphorus in the soil system (Pape, 1970; Proudfoot, 1976; Hamond, 1983; Eidt, 1977, 1984). However, examination of total phosphate levels in the B horizons of deep top soils demonstrates that there has been some downward movement of phosphate (Tables 3 & 4). In Marwick the mean increase is from 97 mg per 100 g to 228 mg per 100 g, an increase of a factor of 2·36, and means that phosphate distribution patterns have to some extent been blurred by post-depositional movement.

Nevertheless, marked spatial distinctions in total phosphate pattern are evident within the West Howe deep top soil and can be interpreted as reflecting differences in the depositional pattern of organic material (Figure 5). There is a general trend of declining total phosphate values with distance from the farmstead and with depth in the profile, suggesting that intensity of organic material application increased as the deep top soil developed. It is also evident that application intensity has been consistently greater closer to the farmstead and this view is reinforced by examination of the raw data which shows a clear distinction between the two fields of which the deep top soil area is now comprised.

The field closest to the farmstead has total soil phosphate values in the upper horizons of greater than 750 mg per 100 g; values for the upper horizons of the

Table 4. Analytical data of non-anthropogenic soils from Marwick and from potential input materials

(a)

Profile	Horizon	Sample depth (cm)	Particle size distribution φ			$\delta^{13}C$‰	Total P_2O_5 mg per 100 g
			Mean	Sorting	Skewness		
H26	S1	10	6·82	2·85	0·12	ND	525
	S1	20	6·76	2·96	0·06	ND	439
	B2	30	ND	ND	ND	ND	191
H26A	S1	10	ND	ND	ND	ND	529
	S1	20	ND	ND	ND	ND	441
	$B2_x$	30	ND	ND	ND	ND	135
H23	S1	10	6·92	2·74	0·13	− 28·1	583
	S1	20	6·66	2·54	0·13	− 27·8	651
	$B2_x$	30	6·54	2·79	0·03	− 26·8	310
	$B2_x$	40	6·40	2·41	0·09	− 27·0	338
H34	S1	10	6·32	2·56	0·38	ND	255
	S1	20	6·50	2·91	0·07	ND	218
	B2	30	5·68	3·09	0·26	ND	52
	B2	40	5·80	3·56	− 0·09	ND	63
Co	A1	10	7·22	2·70	0·15	− 27·7	197
	A2	20	6·81	2·91	0·09	− 27·6	176
	A2	30	6·22	3·05	− 0·06	− 27·5	111
	B2	40	5·76	2·53	− 0·23	− 27·1	93
	B2	50	5·38	3·22	− 0·21	− 27·1	95
	B2/C	60	5·82	3·09	− 0·25	− 27·1	80
PA	S1	20	8·98	1·89	0·26	ND	165
	A2	40	8·10	2·10	0·10	ND	126
	$B2_g$	60	7·62	2·15	0·10	ND	131
	C_g	80	5·70	1·99	0·35	ND	152
G2	S1	20	5·82	2·64	0·24	ND	165
	$B2_g$	40	6·02	2·52	0·24	ND	126
H31	S1	10	6·58	2·78	0·31	ND	141
	B2	20	5·28	2·79	− 0·05	ND	231
	B2	30	5·19	2·95	− 0·04	ND	90
	B_x	40	5·12	3·12	− 0·03	ND	83

(b)

Material	Source	Particle size distribution φ			$\delta^{13}C$‰
		Mean	Sorting	Skewness	
Beach sand	Marwick	0·12	0·17	1·00	ND
		0·12	0·17	0·99	ND
		0·13	0·17	0·23	ND
Turf roof	Muce, Marwick	5·78	2·83	− 0·09	ND
		5·71	2·85	0·08	ND
		5·73	2·81	0·08	ND
Peat ash	Birsay	5·76	2·09	− 0·41	− 25·7
		6·86	2·01	− 0·46	− 23·2
Byre turf/manure	Cruesbreck N. Ronaldsay	6·74	3·12	0·05	− 32·1
		6·62	3·09	0·04	− 29·4
Straw/manure	Marwick	ND	ND	ND	− 32·0
		ND	ND	ND	− 31·3
Seaweed	Marwick	ND	ND	ND	− 18·2
		ND	ND	ND	− 17·7
Podsol surface litter	Marwick	ND	ND	ND	− 28·5
		ND	ND	ND	− 28·6

ND = not determined.

Table 5. Summary of features observed in thin section; West Howe deep top soil and Bilbster series controls

		Coarse mineral material								Coarse organic material			Fine organic material				Pedofeatures												
Section	Depth (cm)	Quartz	Feldspar	Compound quartz grains	Sandstone rock fragments	Phytoliths	Bone	Ca Co_3	Fine mineral material	Fungal spores	Lignified tissue	Parenchymatic tissue	Amorphous (black)	Amorphous (yellow/orange)	Amorphous (reddish brown)	Cell residue	Textural (silty clay)	Textural (clay coatings)	Textural (limpid clay)	Amorphous & crypto crystalline nodule	Amorphous & crypto crystalline infills + coatings	Excremental (mamillate)	Excremental (spheroidal)	Depletion	Microstructure	Coarse material arrangement	Groundmass B fabric	Related distribution
H13	20–30	●●●	●	●	●	●	●		Brown to grey brown ppl; dotted limpidity	●			●●	●			●●			●		●		●	Channel and chamber	Random	Stipple	Porphyric
H13	40–50	●●●		●	●	●			Brown to grey brown ppl; dotted limpidity		●		●●			●	●●	●●		●		●●		●	Channel and chamber	Random	Stipple porostriated	Porphyric
H18A	20–30	●●●	●	●●	●	●	●		Brown to grey ppl; dotted and speckled limpidity	●			●●	●			●			●		●		●	Channel and chamber	Random	Stipple	Porphyric
H18A	40–50	●●●●	●	●	●	●	●	●	Brown to pale brown ppl; dotted limpidity	●			●●	●								●			Channel	Random	Stipple	Porphyric
H18	20–30	●●●	●	●	●	●	●		Brown to pale brown ppl; dotted and speckled limpidity	●●			●				●●●	●		●		●		●	Channel and chamber	Random	Stipple	Porphyric
H18	40–50	●●●	●	●	●	●	●	●	Brown to grey brown ppl; dotted limpidity	●			●●				●●	●●	●●	●		●		●	Channel and chamber	Random	Stipple	Porphyric
H23A	20–30	●●●	●	●	●	●	●		Brown ppl; dotted limpidity	●			●●	●			●●	●		●		●		●	Channel and chamber	Random	Stipple	Porphyric
H23A	30–40																											
Upper		●●●	●	●	●●				Brown to pale brown ppl; dotted and speckled limpidity	●			●●				●●					●		●	Channel and chamber	Random	Stipple mosaic porostriated	Porphyric
Lower		●●●	●	●	●●●				Brown and pale brown ppl; dotted and speckled limpidity	●							●●				●	●	●	●	Channel and chamber to subangular blocky	Random	Stipple mosaic porostriated	Porphyric
Co	8–18	●●●	●	●	●				Brown ppl; dotted and speckled limpidity	●●		●●	●		●●							●	●	●	Subangular blocky	Random	Stipple	Porphyric
H34	8–18	●●●	●	●	●				Brown ppl; dotted and speckled limpidity		●	●	●	●			●					●		●	Channel and chamber to subangular blocky	Random	Stipple	Porphyric
H34	22–30	●●●	●	●	●●				Brown to pale brown ppl; dotted and speckled limpidity				●									●		●	Channel and chamber to subangular blocky	Random	Stipple	Porphyric

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

Table 6. Field description of profile H31, Marwick

Horizon	Depth (cm)	Field description
S1	0–17	Dark yellowish brown (10YR 4/4), no mottling, silty clay loam, few very small angular tubular 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 (10YR 5/8), no mottling, silty clay loam, few very small angular stones, medium subangular blocky peds moderately well developed, common fine fibrous roots. Within this horizon is a broken line of grass based organic material at 20 cm with abundant roots and stems. Horizon has abrupt smooth boundary to:
BX	30–40	Yellowish brown (10YR 5/6) massive.
C	Bedrock at 40 cm	

deep top soil field furthest from the farmstead are between 600 and 650 mg per 100 g. There is also a distinct break in the total phosphorus distribution pattern on the downslope edge of the deep top soil area where values drop to between 500 and 600 mg per 100 g (Figure 5). Here too, though, it is evident that there has been significant application of organic material to this area, mapped as arable by the McKenzie map of 1769 (Figure 3). However the levels of application have been generally lower than those associated with the deep top soil and it is evident that turf has not been used as there has been no thickening of the top soil. These observations may reflect the process of tathing the outfield area through the occasional stocking of domestic animals.

The organic materials of formation are now entirely decomposed and cannot be observed directly in thin section (Table 5), although the occurrence of fungal spores suggests the application of animal manures (Table 5; Romans & Robertson, 1983). Stable carbon isotope ratios are therefore used to indicate the origin of the principal organic materials applied to the deep top soil area. 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). These fractionation effects are evident in the potential input material examined for $\delta^{13}C$ values and permit a broad division between material from marine and terrestrial sources (Figure 6). Isotopic fractionation effects within the terrestrial class of material are small but in general demonstrate a $\delta^{13}C$ differentiation greater than the 1·1‰ fractionation effect that may be attributed to the processes of decomposition and humification of surface soil litter seen in the A horizon of the control profile (Table 5; Figure 6).

$\delta^{13}C$ values from the deep top soils in Marwick range from −28·7‰ to −26·7‰, a wider range than that evident within the A horizon of the Bilbster series samples. Comparison of these $\delta^{13}C$ values against the control data indicates that the organic materials used in the formation of the deep top soils were predominantly terrestrial in origin and, allowing for pedogenic fractionation effects, that turf with varying proportions of manure was used (Figure 6). In some isolated locations within the West Howe deep top soil $\delta^{13}C$ values are less negative than would be expected from the application of terrestrial material alone (H18a, 40 cm; H18, 50 cm) and it is likely therefore that some seaweed has been applied in small quantities to these parts of the deep top soil area. An alternative explanation is that peat ash had been applied, but the very few fragments of substantially decomposed calcium carbonate observed in thin section from this area of the deep top soil, which could have been attached to seaweeds, support the former interpretation (Table 5). A more negative pattern of $\delta^{13}C$ values is evident at Muce and Netherskaill (Table 3) suggesting that a significantly greater amount of animal manure was applied to these two top soils compared with West Howe.

A statistically significant correlation exists between the total phosphate and $\delta^{13}C$ values of the deep top soils (r_s=0·901; N=28; significant to 0·01 level), with total phosphate levels increasing as $\delta^{13}C$ values become more negative. This relationship can be interpreted as animal manures making up an increasing proportion of the organic content relative to turf as application intensity became greater.

These results suggest a simple system of organic material application comprising largely of varying proportions of turf and animal manures; seaweed was applied only in limited amounts. A distinctive temporal pattern to deposition is evident with animal manures assuming greater importance as the deep top soil developed. This may have been the result of both an increase in livestock numbers and a greater degree of stock management to ensure the availability of animal manures for the infield arable land. The spatial pattern of deposition suggests that the application of manures was controlled with a progressive decline in application with distance from the farmstead.

Cultivation practice

One important characteristic of the deep top soil at West Howe is the occurrence of fine material

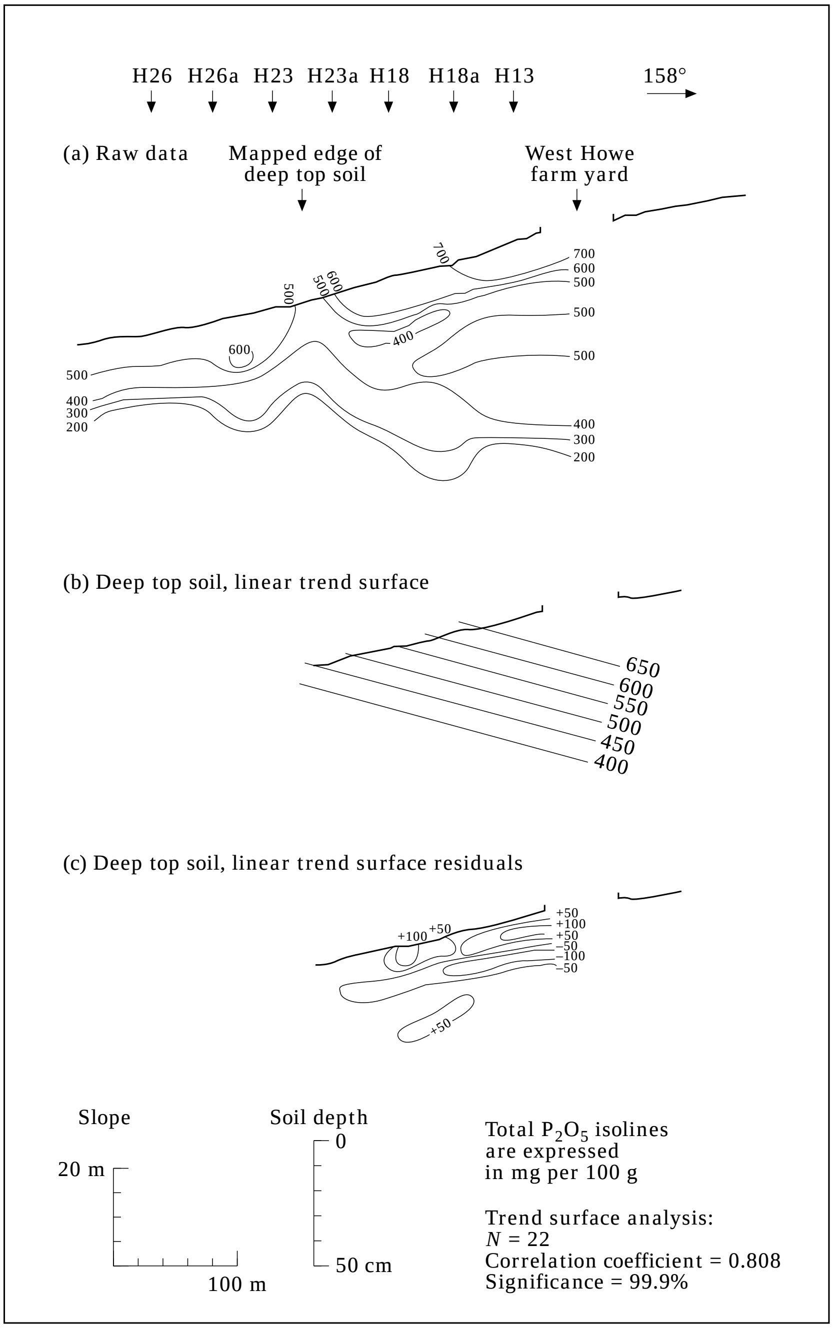

Figure 5. Total phosphate distribution pattern in the West Howe deep top soil, Marwick.

accumulation, evident in both the particle size distribution data and in thin section. Trend surface analysis reveals a quadratic trend for mean (Figure 7) and a linear trend for skewness (Figure 8) with both parameters significant at the 95% confidence level. The quadratic mean trend can be interpreted as reflecting both down profile and downslope movement of fine material, with the former more prevalent closer to the farmstead and the latter process more marked with greater distance from the farmstead. Skewness values support this interpretation but emphasize downslope movement of fine material profile. 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 first order linear trend surface pattern of particle size skewness must be interpreted as resulting from the movement of finer material predominantly downslope.

Further evidence of fine material movement in the deep top soil at West Howe are the silt and clay

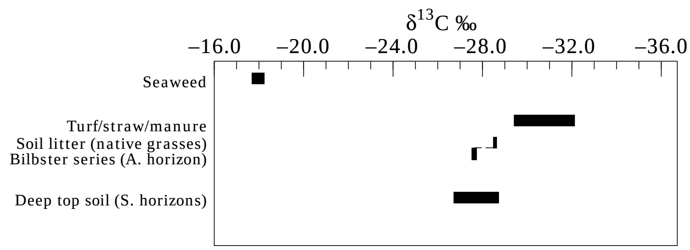

Figure 6. $\delta^{13}C$ values; West Howe deep top soil, Marwick, and control data.

textural pedofeatures observed in thin section (Table 5; Figures 9 & 10). These features are pronounced in the deep top soil at West Howe, but occur only rarely in surface horizons of other Bilbster series soils examined. They cannot, therefore, be attributed to recent cultivation activity but rather are relict features of earlier cultivation practices. Textural pedofeatures of this nature are indicative of cultivated, exposed soils lacking permanent vegetation cover and with declining structural stability to which a reduced organic matter content would contribute. The physical process forming these micromorphological features involves the structural break-up of surface soil peds by cultivation implements, slaking and mobilization of water saturated soil followed by deposition against a barrier or when the soil dries out (Jongerius, 1970; MacPhail, Romans & Robertson, 1987; Courty, Goldberg & MacPhail, 1989). The greatest frequency of textural pedofeatures is to be found in H18 and probably reflects more intensive cultivation activity on the upslope part of the deep top soil in closest proximity to the farmstead.

The observations do not however suggest large scale movement of fine material within the deep top soil; changes in mean and skewness particle size values downslope are small and clay coatings although occasional to many in frequency are not thick and are often discontinuous. Clay coatings are typically *c.* 60–70 μm in thickness (Figure 9) while silty clay textural pedofeatures are up to 150 μm in thickness (Figure 10). This indicates that cultivation activity was moderate in its intensity, an interpretation supported by historical documentation which suggests the Orkney one-stilted plough as the most likely cultivation implement, rather than the spade which was used less frequently in Orkney and only for more intensive garden and kail yard cultivation (Fenton, 1978; Shaw, 1980). Furthermore, any potential decline in soil structural stability arising from this moderately intensive form of agriculture would have been offset by the increasingly intensive application of organic materials.

Conclusions

The deep top soils of Marwick are relict features of infield management between the late Norse period and the agricultural improvements of the late 19th century. Synthesis of the relict soil properties indicates a simple and successful, though labour intensive, process of maintaining and enhancing the fertility of these infield areas. Turfs were stripped from the hill land, causing significant damage to summer grazings, and applied to the infield area together with varying proportions of animal manure. Minor amounts of seaweed were also applied, but there is no evidence to support exploitation of other resources for use in these infield arable areas. Intensity of organic material application was greater with proximity to the farmstead and became greater as the deep top soil developed, perhaps reflecting greater demand for arable produce. It is clear that management of infield areas was not uniform and varied both temporally and spatially, possibly becoming more organized as the deep top soil developed, although earlier detailed patterns may have been lost through post-depositional pedogenesis. The level of cultivation intensity throughout the formation of the deep top soil was moderate as it did not result in substantial downslope and down profile movement of fine material. Historical documentation suggests that the Orkney one-stilt plough was used, minimizing demands on soil fertility.

Despite the inherent fertility of soils derived from Old Red Sandstone, the deep top soils represent areas in the cultural landscape where nutrients were concentrated for the purposes of arable activity. Furthermore, the total phosphate values from West Howe would suggest a continuous and increasing input of nutrients throughout the period of deep top soil formation with no evidence of nutrient decline. The successful maintenance and enhancement of infield fertility would suggest that the land resources of the cultural landscape at Marwick were collectively organized and regulated. From the early 1300s to 1745 such organization may have been achieved through the parish Bailie Court which regulated the movement of livestock and oversaw the maintenance of the turf dykes (Thomson, 1981). Analysis of historical records from the western highlands and islands of Scotland also indicates the organization of land resources for the purposes of maintaining arable land soil fertility, although the degree of success varied in different environmental contexts (Dodghson & Olsson, 1988; Dodghson, 1993). However, after the abolition of heritable jurisdiction the role of the Bailie Courts broke down, yet fertility inthe deep top soil at West Howe continued to increase up to the cessation of formation. This would suggest

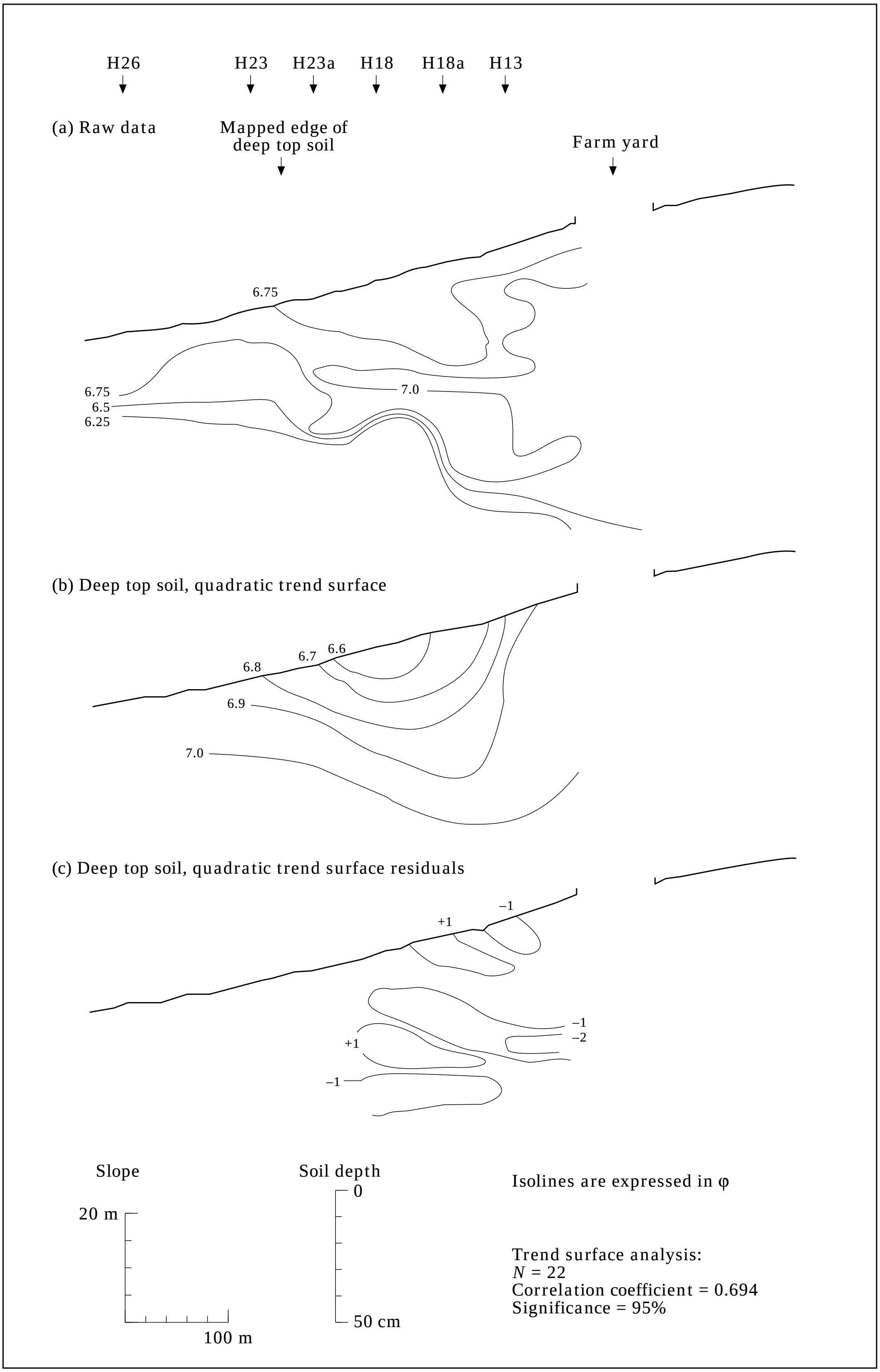

Figure 7. Particle size mean distribution pattern, West Howe deep top soil, Marwick.

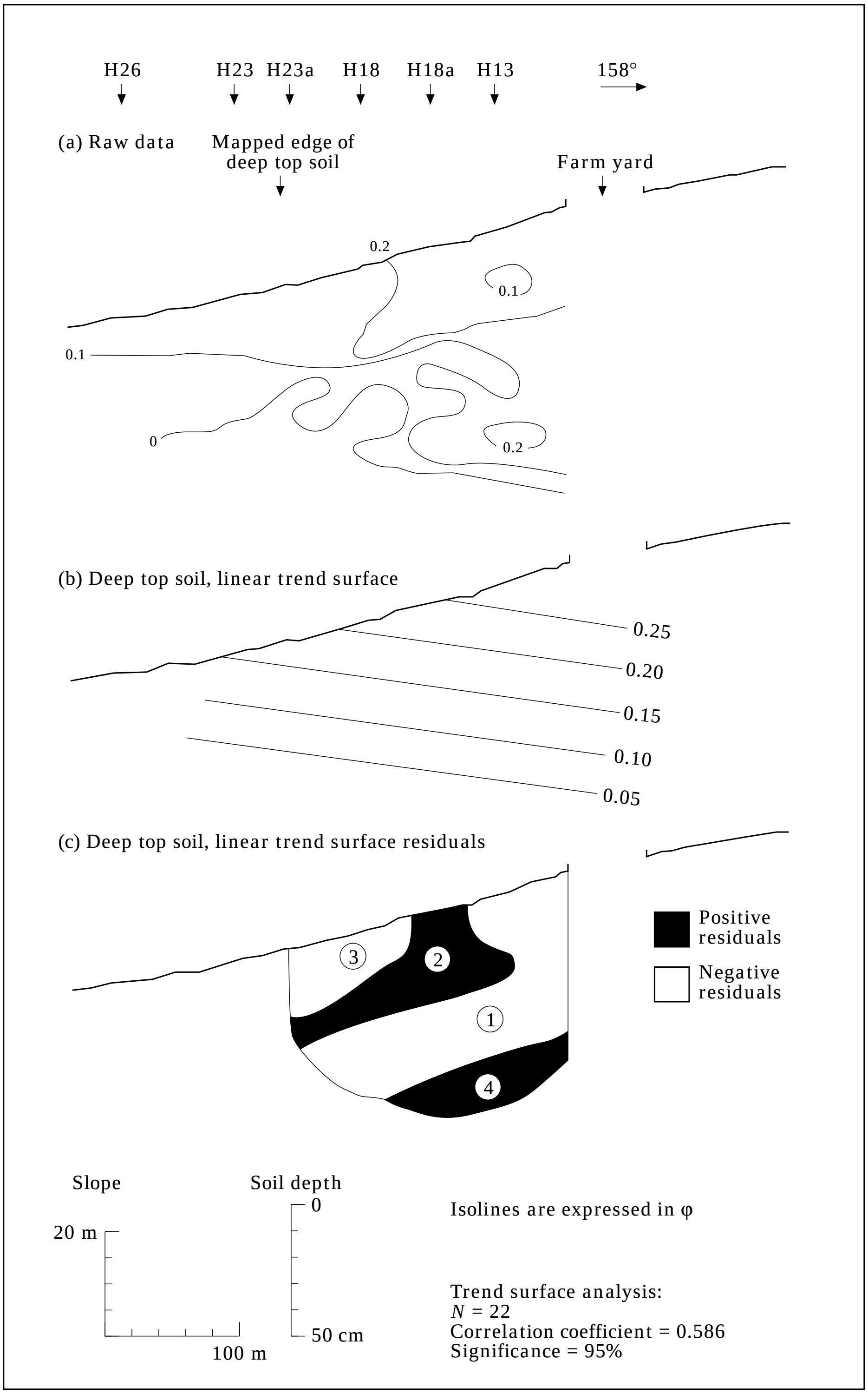

Figure 8. Particle size skewness distribution pattern, West Howe deep top soil, Marwick.

that other forms of land resource management organization were prevalent, particularly in relation to the management of infield areas, and underlay the more formal arrangements documented in the historical literature.

In Marwick turf for the infield came only from the hill land, on which livestock would have been grazed during the summer, and not from the enclosed grassland areas of the township. Although this caused substantial damage to the hill land and gave major

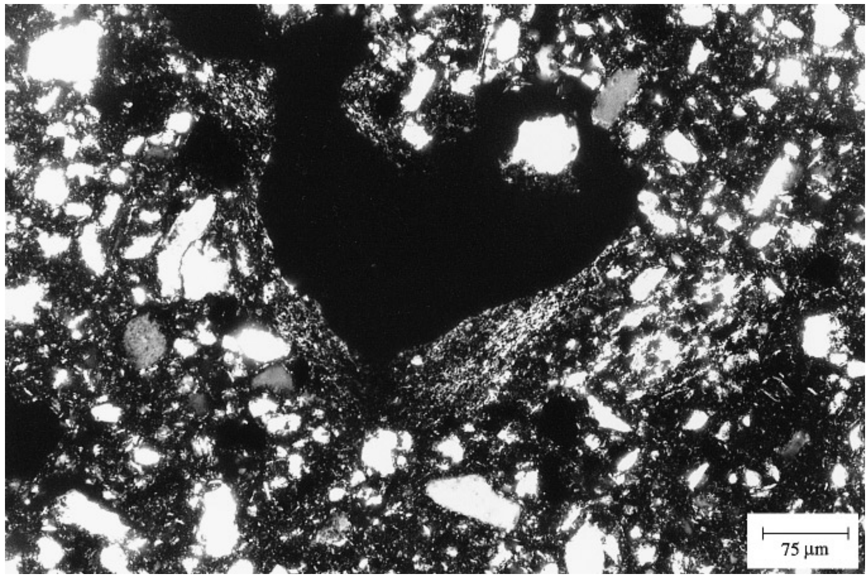

Figure 9. Discontinuous clay coating at 48 cm depth, deep top soil Profile H18, West Howe, Marwick (XPL).

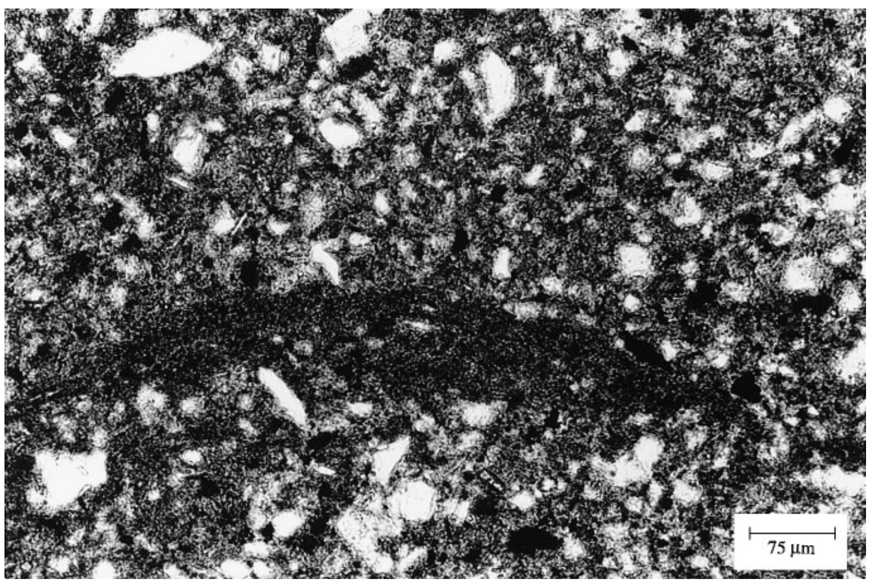

Figure 10. Silty clay textural pedofeature at 29 cm depth, deep top soil Profile H18, West Howe, Marwick (PPL).

problems for reclamation during the subsequent early modern improvements (Willis, 1983), it meant that the enclosed grassland and meadow land areas could be maintained for the provision of winter grazing and fodder. This in turn made available the animal manures that were applied to the infield and which would have been collected by housing the animals, at least overnight if not throughout the winter period. Under such a scenario the ratio of arable to enclosed grazing land becomes important to the maintenance and enhancement of infield fertility levels (Postan, 1993). In Marwick this ratio is approximately 1:4·6 and, on the basis of the relict soil properties, would appear to be at a level which could more than adequately maintain arable land soil fertility where manures were used in conjunction with turf. A further dimension to the maintenance and enhancement of infield fertility levels was the use of the plough. Spade cultivation would have yielded significantly greater arable returns (Shaw, 1980), but at the cost of being a greater drain on fertility and requiring a larger labour force. Population densities in West Mainland were generally less than those of other parts of Orkney during the period of deep top soil development (Simpson, 1994) although clearly they must have been at a sufficient level to permit the paring and movement of substantial volumes of turf.

This study emphasizes the spatial and temporal variability of relict soil properties evident in early infield systems, overturning the notion that such areas of land were static and uniformly managed features in early cultural landscapes. Relict soil properties clearly have an important role to play in establishing and explaining the complexities of both manuring and cultivation in infield areas together with the associated patterns of cultural landscape organization. For these objectives to be achieved it is clear that fine grained sampling strategies are required. Such approaches will be equally relevant in both historic and prehistoric contexts.

Acknowledgements

Professor Donald Davidson is thanked for his continual support throughout the lifetime of this project. Mr and Mrs I. Moar of West Howe and the other farmers of Marwick are thanked for their kind hospitality and for allowing access to their land. Dr D. D. Harkness of the Natural Environment Research Council Radiocarbon Laboratory, East Kilbride kindly provided facilities for radiocarbon and stable carbon isotope analysis where the technical support of Brian Miller is gratefully acknowledged. Bill Jamieson and David Aitchison produced the tables and figures. Fiona Chrystall and Rhiannon Hart commented on an earlier draft of the manuscript.

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