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Micromorphological Evidence of Past Agricultural Practices in Cultivated Soils: The Impact of a Traditional Agricultural System on Soils in Papa Stour, Shetland

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Micromorphological studies of ancient cultivated soils have been heavily reliant on the interpretations derived from the study of modern agricultural soils. There has been a gradual realization that this knowledge cannot be uncritically borrowed and applied to ancient soils. In this paper, a recently abandoned ‘‘traditional’’ agricultural system is used as an analogue of past practice, providing a more appropriate model. The predicted impacts of documented tillage, manuring and cropping methods on soils are tested through the analysis of the micromorphology of nine soil profiles. The results highlight the partial nature of the record provided by micromorphology with large elements of the agricultural system not identified through micromorphology. The most successful results were obtained on manuring practice which can be clearly linked to the recorded techniques on Papa Stour. Soil micromorphology supported by data on particle size and phosphate content were of particular value.

Keywords: MICROMORPHOLOGY, AGRICULTURE, MANURING, PLAGGEN SOILS, SHETLAND.

Micromorphology and the Study of Ancient Agriculture

The study of ancient agricultural practice using micromorphology has progressed from the 1970s, when the potential was first realized (Romans, Durno & Robertson, 1973; Romans & Robertson, 1975). A period of rapid expansion followed in the 1980s (summarized by Courty, Goldberg & Macphail, 1989) leading to the present day when it is accepted that micromorphology has much to offer (Gebhardt, 1993; Dockrill *et al*., 1994). It is increasingly being realized that the use of image analysis techniques can assist with the quantification of certain features in old cultivated soils (Bryant & Davidson, 1996). Interpretations of ancient soils were heavily reliant at first on the conclusions reached in the study of modern cultivated soils (e.g. Jongerius, 1983). There has been a gradual realization that this knowledge cannot be uncritically borrowed and applied to ancient soils. Processes that produce diagnostic features in modern soils may not occur in ancient soils or may be confused with unknown ancient processes (Courty, Goldberg & Macphail, 1989; Macphail, Courty & Gebhardt, 1990). Furthermore, there are issues of major archaeological interest that cannot be addressed from the starting point of modern agriculture. Manuring practice is a clear example of this because, with the advent of inorganic fertilizers, manuring is no longer a key issue in Western European agriculture (Courty & Nørnberg, 1985; Dockrill *et al*., 1994).

Two research strategies are available to break away from the limitations inherent in interpretations of ancient agriculture based on modern agricultural research:

1. the establishment of controlled field experiments using replicated ancient agricultural techniques;
2. the study of recently abandoned ‘‘traditional’’ agricultural systems that provide analogues for earlier, archaeological examples.

Experimental studies in ancient cultivation techniques have been undertaken for some time (Reynolds, 1981; Lerche, 1994) but the micromorphology of these soils has only recently been investigated. Some results have been published (Macphail, Courty & Gebhardt, 1990) but other work is still under way. Those involved with experimental work face two challenges: the need to accurately replicate the method of tillage and to work with soils that resemble their prehistoric counterparts. It is this second issue that may prove more difficult to deal with as it is likely to exert greater control over the development of characteristic soil microfeatures than the precise method of tillage.

The study of recently abandoned traditional agricultural systems as analogues of past practice offers an alternative strategy and it is one that has been adopted for the present study. This approach is based upon the assumption that observed or recorded agricultural practices leave distinctive imprints on the soil record. It is thus necessary to examine ethnographic and other documentary records critically, in order to establish

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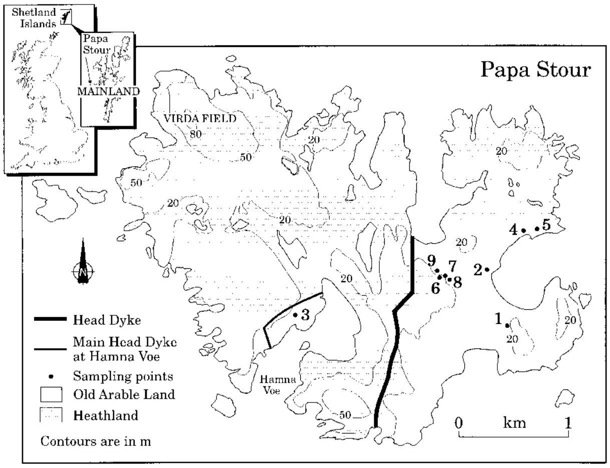

Figure 1. Papa Stour: sample sites.

this relationship between the recorded agricultural practices of a ‘‘traditional’’ system and the nature of soils as they exist today. Of particular importance is the relationship between animal husbandry and arable practice.

Studies of the relationship between agriculture and cultivated soil must assume that the particular practices operated for sufficient time to impact on the soil and erase earlier signatures. The time required for a detectable impact to develop in the soil depends on the practices involved and it is not possible to generalize. Similarly, the soil components, pedofeatures and structural properties display a wide range of persistence. Structure may be re-formed in near-surface horizons through biological activity within a few years whilst some mineral soil components are stable over many millennia. In addition, ‘‘traditional’’ agricultural systems are not static and they evolve over time. It is important to determine the history of this evolution and to evaluate how it has affected the soils. Nevertheless, given the objectives of this study, there are clear advantages in selecting a study area where there has been considerable continuity of agricultural practice; this is the case with the small island of Papa Stour, Shetland.

The Study Site: Papa Stour, Shetland

Papa Stour is a small island (roughly 4×3 km) lying off the west coast of the mainland of Shetland (Figure 1). It possesses a highly complex rocky coastline broken by a number of deep inlets; the eastern half of the island is low lying but in the west it rises to 87 m on Virda Field. The island is composed of acid igneous rock of Devonian age (rhyolite and tuff) with some basalt and sandstones at the eastern end (Mykura & Phemister, 1976). There is a shallow stony till over most of the island and in the east this is covered by a variable depth of windblown shell sand. These two superficial deposits are the parent materials for the two Soil Associations mapped on the island (Soil Survey of Scotland 1:50,000 soil map, sheet 3). The till supports gleys, peaty gleys, peaty podzols and rankers of the Walls Association; the sand supports calcareous regosols, brown calcareous soils and calcareous gleys of the Fraserburgh Association. Settlement and cultivated land is currently restricted to the eastern sandy end of the island.

In Papa Stour, the pioneering ethnographic studies of Alexander Fenton in the 1960s recorded the final years of the traditional mixed farming system based on cattle and sheep with crops of cereals, kale and potatoes (Fenton, 1978). Thirty years later, a historically low human population in the island and sheep-dominated agriculture involving a grass-based forage system have ensured that most of the former arable land has gone out of cultivation, thereby preserving substantial areas of cultivation soils unaffected by current agricultural practices. Therefore the island offers the opportunity to study cultivated soils that were the product of a distinctive set of traditional agricultural practices, unaffected by recent changes in farming. Two aspects of this tradition are of particular interest to archaeological studies: spade cultivation and the use of diverse, locally derived manures.

Traditional Agriculture in Papa Stour

The traditional agriculture of Papa Stour was recorded by Fenton in 1967 when elements of it still operated and much more survived in the memories of the older inhabitants (Fenton, 1978, 1985, 1986). These records and memories mostly relate to the century preceding Fenton’s visit. Papa Stour contains an agricultural landscape, formerly common throughout Shetland, of cultivated land and pasture divided from extensive common grazings by an enclosing dyke (Figure 1). Almost all of the settlement was within the one dyke at the eastern end of the island with only the two outsets of Hamnavoe and North Banks forming discrete holdings outside that dyke. The cultivated land was formerly organized into numerous rigs, small strips and blocks of land, with the holdings of the various tenants intermixed. The soil was cultivated with the delling spade and crops of barley, oats, kale and potatoes were fertilized with a variety of materials including turf, byre muck and seaweed. The livestock that produced the muck was stalled at night in the byre with grazing in summer on the hill and, after the harvest, within the town dyke. Turf was cut from the common hill grazings and used in a variety of ways: to make dykes, as house roofs, as a fuel, in the byre as bedding or as a component of muck heaps. In all cases it ended up on the fields as manure as byres and midden heaps were mucked out, houses re-roofed, and dykes demolished or rebuilt. The overall effect was the gradual deepening of the cultivated horizon to a depth of 75 cm. This process of plaggen soil formation has been investigated in the west Mainland of Orkney where the accumulation was initiated in the late 1200s AD (Davidson & Simpson, 1984; Simpson, 1997).

The traditional agricultural system that survived into the middle of the 20th century in Papa Stour had its origins in the Norse settlement of the island after AD 800 (Crawford, 1984). The agriculture practised by the Norse settlers, as interpreted from archaeological evidence in Papa Stour and elsewhere in the Northern Isles, was not dissimilar to that recorded in the earliest surviving documents that discuss agriculture, from the 18th century. It was a mixed system based on livestock and crops with the settlements and arable land separated from common grazings by a town dyke. This means that, in general terms, the soils of the island have experienced the same agricultural practices for as much as one thousand years. From this conclusion it may be suggested that soils are highly likely to reflect the types of traditional practices recorded by Fenton in the 20th century. However, there have been changes which may be summarized as follows:

1. the crops and combinations of crops grown, reflecting the introduction of potatoes in the 18th century and changing demand for cereals;
2. the principle tillage tools, that is the switch from plough to spade in the 18th century as the size of landholdings and rigs was reduced;
3. the extent of arable land relative to pasture within the town dyke, and the proportion of that arable in permanent cultivation, reflecting population pressure and demand for crops;
4. the rate of application of manures, related to the extent of arable land under cultivation and the availability of manure.

Major periods of change have been identified during the second half of the 18th century, with an increasing population and the introduction of the potato, and in the second half of the 19th century with land reorganization, a falling population and the decline of subsistence farming, More recent changes in agricultural practice have had little impact on the island.

Predicted Impacts of Traditional Agriculture on Soils in Papa Stour

The various elements and processes of the traditional agricultural system all have a potential impact on the soil. These impacts may be predicted and analytical methods proposed to detect their effects on soil properties. Three principle elements of cultivation: crops, tillage and manures, have been selected and the potential impacts predicted in Table 1. From this table, it seems highly unlikely that crop type can be directly determined from the cultivated soil other than by the identification of pollen deposited in the soil. Crop type has an indirect impact via the tillage and manuring regime associated with that crop. All three of the possible tillage methods result in the disruption and mixing of the upper portion of the soil profile but the survival of any features that allow for differentiation between them is considered highly unlikely. Indeed, any direct micromorphology evidence for tillage is unlikely to survive in surface soils. It is the gross morphology of the cultivation plots (size, shape, slope, depth stratification) that is most likely to indicate the type of tillage that occurred. The addition of various organic and mineral manures will alter the physical and chemical composition of the soil and promote structural changes. Mineral and carbonized organic components are likely to persist in the soil and therefore provide a permanent record of former manuring practices. Enhancement of soil phosphate content may also persist if it becomes bound into the stable forms in the soil.

On the basis of this summary, attention was focused on the following aspects of the cultivation of soils:

1. depth, stratigraphy and morphology of cultivation plots (impacts of tillage);
2. basic mineral and organic soil components (impact of manures);
3. phosphate content (impact of organic manures).

Samples

Sample soil profiles were chosen to provide a wide variety of cultivation soils within the enclosed land on the island. Nine sites were sampled; their locations are given in Figure 1 and brief descriptions of the nature and histories of these locations are provided in Table 2. Profiles 1, 2 and 8 are within rigs that formed part of the pre-1860 outfield of the enclosed land. Profiles 3, 4 and 5 are from rigs on the land of the two separate outsets, Hamnavoe and North Banks, that adjoin the main town. The remaining three are from contrasting locations at the settlement of Olligarth. Profile 6 is the soil within a planticrue (a small stone enclosure for the raising of seedling kale plants), profile 7 is from the enclosed kaleyard at Olligarth and profile 9 is from uncultivated pasture land adjacent to Olligarth.

Basic Description and Characterization of the Soils

Soil thin sections were prepared in the Department of Environmental Science, University of Stirling using standard procedures (Murphy, 1986). Soil moisture was removed by acetone replacement and a UV fluorescent dye (Epodye) was added to Crystic resin for impregnation. Initial analysis of the thin sections used the descriptive scheme and terminology of the international system (Bullock *et al.*, 1985). This was supported by limited point counting to provide better estimates of abundance of the common components.

Table 1. Predicted impacts of agriculture on soil micromorphology

	Impact on soil	Micromorphological effect	Stability of micromorphological features
Crops			
Barley	Heavily manured soil. Continuous cultivation	High manure inputs, high level of mixing	Depends on manure types
Oats	Manured or un-manured soil	Manure inputs, mixing	Depends on manure types
Potatoes	Manured or un-manured soil. Deep digging?	Manure inputs, deep mixed layer?	Depends on manure types
Kale	Heavily manured soil. Continuous cultivation in yards	High manure inputs, high level of mixing	Depends on manure types
Tillage			
Spade	Inversion and disruption of upper part of profile	Disrupted fabric. Mixing or upper soil horizons in mature profiles. Textural pedofeatures?	Easily destroyed by biological activity
Single-stilted plough	Disruption of upper part of profile (Depth?)	Disrupted fabric. Mixing of upper soil horizons in mature profiles. Textural pedofeatures?	Easily destroyed by biological activity
Mouldboard plough	Inversion and disruption of upper part of profile (Depth?)	Disrupted fabric. Mixing of upper soil horizons in mature profiles. Textural pedofeatures?	Easily destroyed by biological activity
Manures			
Seaweed	Addition of organic matter, marine carbon	Maintenance of structural stability	Easily destroyed
Turf	Addition of organic matter and mineral components	Presence of exotic mineral components, fragments of original turves	Turf fragments unstable, mineral components highly stable
Ashes	Addition of mineral ashes and carbonized organic matter	Presence of carbonized organic matter and mineral ash components	Mineral components highly stable; carbonized organic matter may be fragmented
Dung	Addition of organic matter rich in phosphate	Maintenance of structural stability, presence of phosphatic pedofeatures	Organic matter unstable. Phosphate may be combined in invisible forms

Table 2. Sample sites in Papa Stour and list of thin sections

Site no.	Site name	Nature of site	Thin section	Context
1	East Biggins	A 0·75 m deep cultivation soil within one of a group of pre-division rigs running down slope. Not cultivated within living memory. .	PS1E 13–21 cm	Deepened topsoil
			PS1D 35–43 cm	Deepened topsoil
			PS1C 61–69 cm	Deepened topsoil
			PS1B 78–86 cm	B horizon
			PS1A 92–98 cm	Bg horizon
2	Gardie	A 0·74 m deep cultivation soil exposed through erosion in a low cliff face below Gardie. Not cultivated within living memory.	PS2A 34–42 cm	Deepened topsoil
			PS2B 60–68 cm	Deepened topsoil
			PS2C 90–98 cm	B horizon
3	Hamnavoe	A 0·30 m deep cultivation soil in a small area of rigs within the dyke of this early outset. Hamnavoe has been uninhabited since 1909.	PS3A 16–24 cm	Deepened topsoil
4	North Banks	A 0·48 m deep cultivation soil within an area of pre-division rigs north of the house. North Banks was an outset that lay adjacent to the main town dyke and was occupied until 1960.	PS4B 25–33 cm	Deepened topsoil
			PS4A 37–45 cm	Deepened topsoil
			PS4C 47–55 cm	Basal sand
5	North Banks	A 0·60 m deep cultivation soil within an area of pre-enclosure rigs east of the house, occupied until 1960.	PS5E 4–12 cm	Deepened topsoil
			PS5D 17–25 cm	Deepened topsoil
			PS5C 27–35 cm	Deepened topsoil
			PS5B 37–45 cm	Deepened topsoil
			PS5A 50–58 cm	Basal sand
6	Olligarth	A 0·30 m deep cultivation soil within a planticrue when the crue was built at the end of the nineteenth century and was probably not used after Olligarth was abandoned in 1940.	PS6A 5–13 cm	Cultivated topsoil
			PS6B 16–24 cm	Cultivated topsoil
7	Olligarth	A 0·73 m deep cultivation soil within the kaleyard. The yard was enlarged in the mid-nineteenth century and continued in use for sometime after the house at Olligarth became uninhabited in 1940.	PS7E 11–19 cm	Deepened topsoil
			PS7D 31–39 cm	Deepened topsoil
			PS7C 50–58 cm	Deepened topsoil
			PS7B 57–65 cm	Peaty layer
			PS7A 68–76 cm	Humose sand
8	Olligarth	A 0·25 m deep cultivation soil within a group of pre-division rigs. Olligarth was abandoned in 1940 and the rigs have not been cultivated since that date.	PS8C 11–19 cm	Deepened topsoil
			PS8A 23–31 cm	Topsoil/sand
			PS8B 27–35 cm	Sand layer
9	Olligarth	An uncultivated peaty soil on the hill above Olligarth, within the town dyke.	PS9A 16–24 cm	AH horizon

Particle size analysis was undertaken using an Andreasen pipette (Head, 1980) and total phosphate by the sodium hydroxide decomposition technique (Smith & Bain, 1982).

Results

The description of the soils in thin sections provides an introduction to their composition and stratigraphy and a context for the detailed interpretation of selected components (below). Data from the thin sections are summarized in Table 3. Results from image analysis for the site at Olligarth have already been published (Bryant & Davidson, 1996).

Parent materials. Two types of soil parent materials were sampled in the nine profiles: till and blown sand. The till (samples 1A , 8D and 8E) is characteristically stony with low porosity and lacks organic components. It is poorly sorted: the silt and clay content exceeds 30% but medium and coarse sand contribute less than 50%. Lithology of the rock fragments is variable and includes sedimentary, metamorphic and igneous types. Soils developed in till (Profiles 3, 6 and 9) contain frequent stones and have a dominant fine fraction. The blown sand (samples 1B, 2C, 4C and 8B) is well sorted with dominant coarse/medium sand (more than 85%) and very little silt and clay (less than 10%). It is more or less stoneless and contains very few organic components.

Cultivated topsoils. Cultivated topsoils may be divided into two groups on the basis of the texture of their mineral components. The topsoils in profile 1 (samples CDE), 2 (AB), 4 (AB) and 8 (C) have a dominant, well-sorted coarse fraction and a texture that approaches the blown sand that underlies them. Blown sand is clearly a major contributor to these topsoils. Profiles 3 (sample A), 5 (ABCDE), 6 (AB) and 7 (ABCDE) are poorly sorted with a dominant fine fraction and a texture within the range of values for the till. With the exception of profile 7, where there is some doubt over the pre-cultivation stratigraphy, all of these topsoils directly overlie till.

The distinction between these groups of topsoils is maintained in microstructure. The sand-rich soils (1, 2, 4, 8) have intergrain microaggregate structures with the relatively rare fine fraction forming the microaggregates. The till soils (3, 5, 6 and 7) have complex crumb/granular structures, reflecting the abundant fine fraction, which tends to become a spongy or channel structure at depth as porosity is reduced (samples 5A, 7A, 7B and 7C). In all soils, the aggregates are created from invertebrate excrement, reflecting a high level of

Table 3. Thin-section descriptions

Thin section	Basic mineral components	Basic organic components	Microstructure	Pedofeatures
1A	Sandy silt derived from sedimentary and metamorphic rocks	None	Massive with rare channels	Coatings on channel walls
1B	Pure well-sorted sand with sedimentary banding	None, except amorphous residues in bands at top	Single grain with microaggregates at top	Amorphous organic residues may be excremental
1C	Well-sorted sand with some fine fraction and stones	Few modern roots, few carbonized and humified peat fragments	Spongy/intergrain microaggregate	Microaggregate excrement
1D	Well-sorted sand with some fine fraction and stones	Few modern roots, few carbonized and humified peat fragments	Spongy/intergrain microaggregate	Microaggregate excrement
1E	Well-sorted sand with some fine fraction and stones	Modern roots, few carbonized and humified peat fragments	Intergrain microaggregate	Fragmented link cappings Microaggregate excrement
2A	Dominant well-sorted sand	Carbonized peat fragments and organic fine fraction	Intergrain microaggregate	Microaggregate excrement
2B	Dominant well-sorted sand	Carbonized peat fragments and organic fine fraction	Intergrain microaggregate	Microaggregate excrement
2C	Pure well-sorted sand	Very few carbonized peat fragments	Single grain with rare microaggregates	
3A	Clay silt till with igneous rock fragments	Carbonized and humified peat fragments	Complex crumb/granular	Abundant, various types of excrement
4A	Dominant well-sorted sand with fines	Carbonized and humified peat fragments	Intergrain microaggregate	Microaggregate excrement
4B	Dominant well-sorted sand with fines	Carbonized and humified peat fragments	Intergrain microaggregate and spongy	Microaggregate excrement
4C	Pure well-sorted sand	Organic microaggregates near top	Single grain with rare microaggregates	Excrement microaggregates in channel fills at top
5A	Moderately sorted sand with silt fines and stones	Frequent carbonized peat fragments, few modern roots	Channel, spongy in areas with less fine fraction	Fe hypocoatings on roots
5B	Moderately sorted sand with silt fines and stones	Frequent carbonized peat fragments, few modern roots	Spongy granular	Impregnative Fe pedofeatures, excrement in channels
5C	Moderately sorted sand with silt fines and stones	Few carbonized peat fragments, few modern roots	Complex, dense channel with spongy/granular areas	Fe hypocoatings, more excrement than 5B
5D	Moderately sorted sand with silt fines and stones	Few carbonized and humified peat fragments, few modern roots	Spongy/channel	Excrement in channels. No hypocoatings
5E	Moderately sorted sand with silt fines and stones	Some carbonized and humified peat fragments	Spongy to crumb/granular	Abundant enchytraeid and worm excrement
6A	Poorly sorted with mixed igneous, metamorphic and sedimentary stones	Modern roots, areas of organic rich fabric, few carbonized and humified peat fragments	Dense channel, breaking up into crumb/granular	Enchytraeid excrement concentrated in channels
6B	Poorly sorted with mixed igneous, metamorphic and sedimentary stones, little fine fraction at base	Frequent areas of organic rich fabric, few carbonized and humified peat fragments	Dense channel, breaking up into crumb/granular	Common excrement of various types
7A	Moderately sorted with mixed igneous and sedimentary stones	Common carbonized and humified peat fragments, amorphous organic matter mixed into fabric	Spongy structure with channels	Abundant coalesced excrement
7B	Poorly sorted with mixed igneous and sedimentary stones	Highly organic with abundant large fragments of humified peat only and amorphous organic matter	Massive with few channels and cracks in peat	None noted
7C	Poorly sorted with igneous stones	Common carbonized and humified peat fragments	Spongy	Abundant coalesced excrement
7D	Poorly sorted with igneous stones	Common small fragments of carbonized peat, few humified	Open crumb/granular	Common fresh excrement of more than one type
7E	Poorly sorted with igneous stones	Common small fragments of carbonized peat, few humified	Open crumb/granular	Common fresh excrement of more than one type
8A	Dominant well-sorted sand	Very few carbonized fragments	Sparse intergrain microaggregate	Granules are probably excremental
8B	Dominant well-sorted sand	Very few carbonized fragments	Sparse intergrain microaggregate	Granules are probably excremental
8C	Moderately sorted sand with fines and stones	Common small carbonized peat fragments and few humified	Dense crumb/granular	Enchytraeid excrement clustered in channels, denser fabric may be coalesced excrement
9A	Poorly sorted with mixed sedimentary, metamorphic and igneous stones	Abundant amorphous organic matter and few carbonized fragments of peat, modern roots	Intergrain microaggregate with dominant microaggregates	Abundant, organic matter-rich enchytraeid excrement

biological activity particularly close the present ground surface.

All cultivated topsoils contain peat fragments, either carbonized or uncarbonized. These are not uniformly distributed and there are particular concentrations of carbonized peat in profile 5 and both types on profile 7. Within profile 7 there are strong differences in peat content between samples 7A, B and C. This is the only clear example of stratification in any of the cultivated topsoils which are otherwise highly homogeneous. The variations in type and concentration of peat are interpreted as the result of different inputs of hearth ash and peaty turf as manure into the soils.

Total phosphate content of the cultivated topsoils is considerably higher than the values recorded from the soil parent materials but displays a range of values in the eight topsoils. Profiles 1, 2, 5 and 7 all have values in excess of 210 mg/100 g whilst profiles 4, 6 and 8 do not exceed 140 mg/100 g. As with the peat fragments, this variation is interpreted as evidence for differential application of manure, in this case organic matter rich in phosphate.

Discussion

The basic description and characterization of the soils has identified a number of components and properties that serve to differentiate the soils. The first of these are the basic mineral components that constitute the bulk of the sediments. From the pattern of variation in texture and sorting it appears that the great depth of at least some of the topsoils (profiles 1, 2, 4, 5 and 7) indicates considerable additions of mineral material. In the context of Papa Stour, turf manuring (the formation of plaggen soils) is indicated. The differing textures and depths of the topsoils suggest that application of turf was variable. The occurrence of peat fragments can be explained in terms of differences in applications of organic manures. The initial results would therefore appear to support the hypothesis that the impact of varying manuring practices will be detectable in the cultivation soils. In view of this positive conclusion, further analysis was undertaken to explore the nature of manuring in greater detail. Two aspects were analysed: 1. the composition and source of the mineral manures; and 2. the composition and source of the organic manures.

Analysis of Mineral Manures

In view of the documentary and ethnographic evidence for turf manuring in Papa Stour, there is good reason to believe that the deep cultivated topsoils sampled in this study are true plaggen soils. The initial analyses, presented above, indicated that the plaggen material was neither uniform in composition or rate of application. Two properties of the mineral components

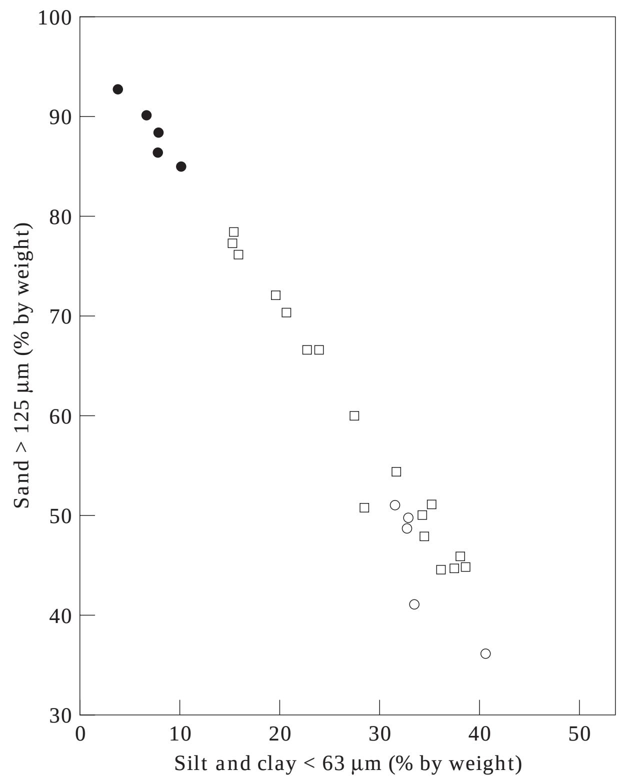

Figure 2. Variation in particle size for deepened topsoils and parent materials. ●, Wind-blown sand; ○, till; □, cultivated soils.

(texture and lithology) were analysed further to determine the composition and source of the turf manure.

Texture

Results of the particle size analysis show that there are two soil parent materials on the island with strongly contrasting textures: blown sand and till. If the texture of all samples are plotted (Figure 2), they all lie on a straight line with the two parent materials at the ends. The intermediate texture of any cultivated topsoil may be interpreted as a mixture of these two materials. The relative contribution of the two sediments can be determined but four assumptions must be made in order to undertake this calculation:

1. there is a single value for the texture of the two parent materials;
2. the only possible parent materials of the cultivation soil are the blown sand and the till;
3. the cultivation soil will include a component derived of *in situ* soil. The composition of this sediment is assumed to be the same as the sediment that currently underlies the cultivation soil;
4. 15 cm of this *in situ* sediment was incorporated into the soil (this depth is derived from Fenton's estimates of the depth that a Shetland delling spade was worked).

Table 4. Papa Stour, estimated depths of topsoil accumulation in nine soil profiles either from sand-blow or turf manuring

Site	Depth of topsoil (cm)	Soil parent material	Depth of sand accumulated (cm)	Depth of turf added (cm)
1	75	Sand	44	16
2	74	Sand	39	20
3	30	Till	0	15
4	48	Sand	9	24
5	60	Till	0	45
6	30	Till/sand	0	15
7	73	Till/sand	0	58
8	25	Sand	0	12
9	16	Till	0	0

Accepting these assumptions and caveats the calculations were performed for the nine soil profiles and the results are given in Table 4. For the purposes of the calculations, samples 4C (sand) and 1A (till) were used to provide textures for the two parent materials. In the case of profiles 6 and 7 at Olligarth it is assumed that the cultivated soil included a shallow layer of sand that was entirely incorporated into the cultivation soil. Only two profiles are dominated by additions of sand: 1 and 2; the remainder either have no sand, or small amounts. Six profiles contain between 12 and 24 cm of added till but two (profile 5 and 7) stand out above this with 45 and 58 cm respectively.

It has been assumed up to this point that all deepened topsoils are the product of turf manuring; however, the results in Table 4 suggest that this assumption should be challenged. If sand was used in manuring, why only in these two locations? Furthermore, the traditional source of turf was the hill land to the west, an area without blown sand. So, use of sand would imply turf cutting within the town dyke consistently over a considerable period of time. This seems highly unlikely and an alternative explanation is needed. It is suggested that the results for profiles 1 and 2 reflect natural sand accumulation contemporary with the cultivation of these rigs. The location of profiles 1 and 2 places them close to the principle source of blown sand: the Kirk sand. Sand comes on shore at the Kirk sand and accumulates in dunes, periodically blowing further north over the site of profile 1 as far as Housa Voe, the location of profile 2.

If it is accepted that profiles 1 and 2 have been augmented by windblown sand, a clearer picture emerges:

1. Total additions of till-derived turf to cultivated soils are generally in the range 10 to 25 cm (profiles 1, 2, 3, 4, 6, 8). All soils, except profile 6, were within outfield rigs prior to 1860 and therefore received relatively low levels of manure. Profile 6, the Olligarth planticrue, is also expected to have been lightly manured as planticrues were traditionally maintained in a relatively infertile condition.
2. In two locations: a rig in North Banks (profile 5) and the kaleyard at Olligarth (profile 7) considerably more turf was applied. Kaleyards, like that at Olligarth, are known to have been heavily manured but the result from the rig at North Banks does not conform to the manuring model. This result is discussed further below.

Lithology

The lithology of rock fragments in turves used as manure varies according to the area of the island from which the turf was cut. This reflects the complex lithology of till deposits on the island. Ice from the mainland of Shetland carried till in a north-westerly direction over Papa Stour (Mykura & Phemister, 1976). Therefore till deposited on the south-east part of the island is dominated by metamorphic and sedimentary rocks from the mainland. The contribution of local acid igneous rocks increases until it dominates over the western part of the island.

This variation has been used to investigate the source of the mineral materials added to the cultivation soils. The lithology of all rock fragments larger than 2 mm in thin section was recorded in three classes:

1. Sedimentary (sandstone, siltstone, mudstone);
2. Metamorphic (quartz/mica/feldspar schists with occasional amphibolite);
3. Igneous (rhyolite with occasional tuff and basalt).

A summary of the results is presented in Table 5 which allows comparison of rock fragment lithology from the till and from the cultivated topsoils.

Samples of till and *in situ* till-derived soils provide information about the natural variation in till lithology. Sample 1A for the south-east of the island is dominated by metamorphic rocks with subordinate

Table 5. Lithology of rock fragments >2 mm

Sample types	Site numbers	Sedimentary %	Metamorphic %	Igneous %
Till (Bg horizon)	1A	28	64	8
Till derived soil	3A	8	6	86
Till derived soil	9A	29	32	39
Deepened topsoil	2, 4, 5, 7A, 8	42	12	45
Deepened topsoil	1B–E, 7B–E	20	16	64
Deepened topsoil	6	40	27	33

sedimentary. At Olligarth, only 600 m to the north-west, sample 9A is characterized by roughly equal proportions of metamorphic sedimentary and acid igneous rocks. At Hamnavoe, 2 km to the west of profile 1, sample 3A is dominated by acid igneous rocks with very few others. Results for samples of windblown sand show that they contain almost no rock fragments larger than 2 mm. Therefore it can be assumed that all stones in mixed sand/turf cultivation soils derive from the turf (till) component.

Results for the cultivated topsoils reveal contrast both within and between profiles. The lithology of the samples divides them into three groups:

1. Profiles 2, 4, 5 and 8 all contain equal numbers of sedimentary and igneous rocks with fewer metamorphic fragments. This composition is not matched by any of the till samples but is most likely to occur away from the south-east of the island where mainland metamorphics are dominant but not too far west where acid igneous rocks dominate. Sample 7A at the base of profile 7 also conforms to this composition.
2. Samples 7B–E are dominated by igneous rock fragments. In profile 1, the sand-dominated lower parts of the topsoil have low concentrations of mixed lithology but the top sample 1E is also dominated by igneous rock fragments as in profile 7. Turf dominated by igneous rock fragments apparently derives from the west of the island.
3. The final lithological group contains the two samples from profile 6 which contain equal proportions of the three rock types in high concentration. This closely matches the composition of the till derived sediment of profile 9, only a few metres to the north-west of profile 6.

The lithology results from the cultivated soils can be used to make a number of observations about manuring practice:

1. Only profile 6 (Olligarth planticrue) can be shown to contain exclusively locally obtained turf. This planticrue is a late addition to the landscape (*c*. 1900–1940) and therefore post-dates the creation of consolidated holding in the island. The strict prohibition on turf cutting within the town dyke had ceased by this time and tenants were able to utilize turf from within their own holdings.
2. In all other soils, turf manure has been obtained at some distance to the site. Two lithologically distinct areas have been exploited: an igneous rock-dominated source that must be the common grazings in the west of the island and a more easterly source of uncertain location, probably on the North Ness beyond North Banks. This result confirms the documentary evidence that the source of turf was the common grazings and that individual holdings exploited different areas for their turf.
3. The origin of turf manure used in the Olligarth kaleyard (profile 7) changed from the eastern to the western source. Evidence presented below will indicate that this shift correlates with the creation of the kaleyard in an existing arable rig. Therefore it may reflect the change of function, and hence choice of manure. More probably it relates to a change of ownership and therefore access to manure.

Analysis of Organic Manures

Introduction

There were three sources of organic manures in the traditional agricultural system of Papa Stour: peat and peaty turf, seaweed and animal dung. Fragments of carbonized and uncarbonized peat, noted in thin section, must relate only to the first of these three. There is no thin-section evidence for either seaweed or animal dung manures. The presence of carbonized residues reflects the use of peat and peaty turf as fuel with the ashes subsequently used as manure. Uncarbonized residues could derive from the direct use of peaty turves as manure or some more complex route via the byre or midden. Detailed analysis was undertaken to address the following questions: 1. What are the composition and sources of these manures? 2. What evidence is there for spatial or temporal variation in the nature and abundance? 3. Can composition and variation be related to agricultural practice?

Methods

All fragments of peat (carbonized and uncarbonized), larger than 1 mm, were measured and classified according to their internal structure, percentage mineral content, maximum mineral grain size and mineralogy/lithology. Fragment area was calculated as the square of the fragment length, assuming that all fragments were approximately equi-dimensional. Results are summarized in Table 6 and are given as averages per thin section in order to permit easy comparison.

Discussion

Composition. All of the fragments consist of organic matter or dominantly organic organo-mineral mixtures. In all profiles the dominant structural type (carbonized and uncarbonized) is amorphous organic matter with randomly arranged mineral grains. A substantial minority of fragments in all profiles are structured, in most cases this comprised parallel, convoluted layers of highly degraded plant tissue. In all cases with one exception, tissue fragments are very rare. The proportion of mineral to organic matter in the fragments differs between carbonized and uncarbonized material. The majority of uncarbonized fragments contain less than 2% mineral components but for carbonized material there are roughly equal numbers of fragments with less than 2% and 2–20%. Very few fragments contain more than 20% mineral

Table 6. Summary statistics on peat fragments >1 mm recorded for each complete soil thin section (4500 mm²)

Sample	Carbonized		Uncarbonized		
	Number of fragments per slide	Area per slide (mm^2)	Number of fragments per slide	Area per slide (mm^2)	Total area per slide (mm^2)
Deepened topsoils ($N=16$)	3·1	121·9	14·1	47·5	169·4
Kaleyard sample (PS7B)	10	29·0	190	1099·3	1128·3
Planticrue topsoil (PS6A and PS6B)	3·5	11·3	13	42	53·3
Heathland AH horizon (PS9A)	3	10·6	0	0	10·6

components. The mineral grains are angular and most fragments contain grains up to fine sand size. Very few coarse grains are present.

With the exception of the rare carbonized plant tissue fragments, all of this material may be interpreted as fragments of amorphous to semi-fibrous peat, that is, derived from the O horizon of a soil rather than an Ah horizon. The low concentrations of mineral grains indicate that this peat was shallow and in an area where mineral sediments were exposed on the surface. The higher mineral content of the carbonized fragments is thought to be the product of shrinkage of the organic matter during combustion. Therefore the carbonized and uncarbonized material is essentially the same. The rare carbonized tissue fragments derive from woody plants and probably result from the burning of heathy turves. These observations raise the following points:

1. The dominance of highly organic peat contradicts evidence for an acute shortage of peat for fuel on the island.
2. There is no difference between peat used for fuel (carbonized) and peaty turf applied as manure without prior burning.
3. There is very little evidence for the presence of organo-mineral mixes indicative of turf stripping, i.e. fragments of soil Ah horizons and vegetation. The clear evidence for significant turf manuring provided by the deep topsoils suggests that mineral-rich turf has not survived as discreet fragments.

Source. The composition of the organic fragments indicates that they derive almost exclusively from peat with sufficient mineral content to indicate proximity to mineral sediments. Analysis of the mineralogy and lithology of the mineral grains indicates that all of this peat could have been dug on the island: almost all fragments with mineral grains contain only quartz or rhyolite which dominate the geology of the island. For fragments with more than 2% mineral content and grains larger than silt-size (i.e. those peat fragments where positive identification of minerals is feasible), rhyolite is present in 82% of carbonized and 79% of uncarbonized fragments. Exposures of rhyolite in this part of Shetland are almost entirely limited to Papa Stour (Mykura & Phemister, 1976) and therefore these fragments must derive from the island. In view of the documented shortages of fuel in the island, it remains possible that the peat with less than 2% mineral grains (which are largely unidentified) could have been imported from the mainland. However, the overall similarity of the assemblages of carbonized and uncarbonized peat fragments argues against this interpretation. In view of the difficulties and high cost of importing fuel, it would not have been spread unburnt on the fields. Therefore a local source seems more probable for all of the peat.

Spatial and temporal variation. Average figures are given in Table 6 for deepened topsoils which demonstrate the overall dominance in thin sections of carbonized rather than uncarbonized fragments. Similar amorphous to semi-fibrous peat was applied to all of the cultivated soils. Most samples of cultivated soil have values of carbonized peat less than 200 mm^2 and uncarbonized peat less than 100 mm^2. There is no correlation between the concentration of carbonized and uncarbonized fragments although in most cases carbonized fragments are more abundant. The slides from the topsoil in the planticrue are exceptional through having low concentrations of organic fragments and with the dominance of uncarbonized peat. This matches the documented practice of only manuring planticrues with fresh turf and only to a limited extent. Striking variation can be found with depth. Slide PS7B from the kaleyard at Olligarth records a considerable concentration of uncarbonized material (Table 6). In contrast the basal slide (PD5A) from the North Banks rig has the greatest concentration of carbonized material (600 mm^2). These two profiles are exceptional because of their greater accumulation of turf manure compared with other cultivated soils. The following points may be made about the distribution of peat fragments:

1. Carbonized and uncarbonized peat fragments are the result of independent processes: the use of hearth ashes and turf as manure.

2. The concentration of uncarbonized peat is highly variable, indicating that turf used as manure does not always possess a surface peat layer i.e. only some turves are peaty.
3. Hearth ashes contribute to the manure for all cultivated soils with the exception of the planticrue where the contribution of ash is negligible. Profile 5 (North Banks rig) received exceptionally high levels of hearth ash early in its development.
4. Profile 7 (Olligarth kaleyard) received an exceptional deposit of pure peaty turf early in its development. This layer survives 8 cm thick (7B) and was probably over 20 cm thick before cultivation of its upper surface. It buried an existing manured soil (PS7A) that was 13 cm deep. The deposition of the peaty turf is interpreted as the deliberate deepening of the soil within the newly created kaleyard which had been located in an area of existing fields.

Conclusions

Analysis of the thin sections, and the collection of other data, have allowed many site-specific interpretations to be made concerning the functioning of the traditional agricultural system in Papa Stour and its impact on the soils. It is not the purpose of this paper to focus on these specific interpretations and impacts. Instead, they may be used to illustrate more general conclusions about the role of micromorphology in the study of past cultivation practice.

Tillage

In the present study, no micromorphology evidence was obtained relating to tillage. The history of changing tillage methods over the past three centuries from single-stilted plough, through spade to mouldboard plough is not detectable in soil thin sections. It is widely recognized that characteristic microstructure and textural pedofeatures, which are the principle source of evidence for tillage, will only develop in certain soils and are then susceptible to destruction by bioturbation (Courty, Goldberg & Macphail, 1989; Macphail, 1992). The former cultivated soils in Papa Stour have a high level of biological activity and their structure and fabric has been totally re-worked by invertebrates. In fact, the biological activity has been promoted by the long history of soil manuring and is therefore positively correlated with cultivation.

If attention is shifted away from pedology to the wide field of agriculture, it is clear that valuable information about tillage practice can be gained from the recording of field shape and size, tool marks surviving at the bases of cultivated soils and from the tools themselves. Micromorphology appears to have little to offer in the study of tillage compared with these other sources of information.

Manuring

The positive results obtained from the micromorphology study of manuring practice in Papa Stour are, in part, due to the exceptional geological circumstances of the island and cannot be assumed to apply more widely. However, because in any circumstances it involves the addition of mineral and organic components to the soil, manuring is inherently more likely than tillage to have a lasting impact on the soil. The impact on the soil in any specific case will be determined by the stability of manure inputs. Mineral components are more likely to survive than organic components but carbonized organics and biogenic silica (phytoliths) may be as persistent as any other mineral materials.

A study of manuring practice will derive additional benefit from techniques other than thin-section micromorphology. The presence of artefact scatters in fields has long been recognized by archaeologists as evidence for manuring and is of particular value in determining the extent and duration of manuring. The linking of results from these two contrasting scales of observation has clear benefits.

The agricultural system

The central aim of this study was to take a well documented system and to test the ways in which known agricultural practices have impacted on the micromorphology of the cultivated soils. Attention has been focused in this study on tillage, cropping and manuring practice. The results of the analyses, presented above, highlight the partial nature of the evidence that survives for this system in the cultivated soils. No information was obtained about the nature or impact of tillage, other than confirmation that it had occurred in soils known to have been cultivated. No information was obtained about cropping, despite the documented complexity in this aspect of agriculture. The most successful results were obtained on manuring practice which can be clearly linked to the recorded techniques in Papa Stour. Soil micromorphology supported by data on particle size and phosphate content were of particular value.

The key conclusion is that micromorphology will only elucidate certain aspects of agriculture. The study of the micromorphology of ancient cultivated soils must be set into a wider analysis of ancient agriculture; the physical infrastructure of fields and settlement remains: evidence for tillage from surviving tools and tool marks; evidence for crops and field ecology from carbonized of waterlogged plant remains. The micromorphology of cultivated soils must be viewed as one element in the study of agriculture and this requires greater integration with a range of soil analysis combined with other archaeological data.

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