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Bioturbation in Old Arable Soils: Quantitative Evidence from Soil Micromorphology

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Current soils can have attributes inherited from land management systems in the past or previous environmental conditions. An important archaeological question is the extent to which the record of old agricultural practices can be retained in soils. This paper reports the results from examining soil thin sections collected from a range of old cultivated sites in the upper Bowmont valley, south east Scotland. The cultivated horizon was sampled from rigs and cultivation terraces dating from prehistoric to late medieval times. The main finding from microscopic analysis was the considerable impact of bioturbation as expressed in excremental pedofeatures. Results from point counting of these pedofeatures from 10 slides collected from an experimental site at Sourhope provided quantitative evidence on the extent to which bioturbation had occurred over the last 200 years. The rapidity by which micromorphological indicators of previous cultivation can be lost is thus demonstrated.

Keywords: SOILS, CULTIVATION, MICROMORPHOLOGY, EXCREMENTAL PEDOFEATURES.

Introduction

Current surface soils may well contain evidence of cultivation or manuring in the past. The effects of such processes can be reflected in deepened topsoils and enhanced phosphorus, organic C and N levels (e.g. Sandor & Eash, 1995; Leonardi, Miglavacca & Nard, 1998) and distinctive assemblages of multi-elements (e.g. Entwhistle & Abrahams, 1997). The effects of cultivation in producing distinctive microfabrics can be investigated using soil micromorphology (Macphail, Courty & Gebhart, 1990). Experimental studies have also demonstrated that particular soil structures as evident in thin sections are associated with specific cultivation techniques (Gebhart, 1992). Surface soils are thus an important source of evidence for past land management, but a key question is the extent to which such features persist in soils following abandonment of previous management systems.

Many uplands in western Europe display evidence of former cultivation well above current arable areas, the upper altitudinal limit of which can vary from over 350 m OD to almost sea-level as in the northern isles of Scotland. Ancient cultivation can be suggested by the presence of old field boundaries and field drains, stone clearance cairns, or rigs (ridges) and furrows. One interesting question is the extent to which current soils in such marginal localities owe their attributes to arable activity in the past. The effect of cultivation in the past was to mix and deepen soils, to improve aeration and downward movement of mobile components such as clays, silts and organic matter, and to incorporate additions from manuring such as lime, organic residues and other fertilizers. The net effect is an improvement in the soil physical, chemical and biological environment with the aim of enhancing crop yield. Soils can be substantially modified as occurs when anthrosols are formed, distinguished, for example by the presence of a hortic or plaggic horizon (FAO, 1998).

The aim of the project reported in this paper is to evaluate the extent to which micromorphological evidence of cultivation is still present in soils which were cultivated in the past, but which have been abandoned for some time. The Bowmont valley in south east Scotland was selected as the study area. The Bowmont Water rises on the west side of the Cheviot massif and flows north and then east, ultimately joining the River Tweed. The valley was chosen for intensive study for two reasons: (1) the upland portion of its catchment has been the target of a detailed archaeological field survey directed by Mercer (unpublished), undertaken in conjunction with analysis of Holocene landscape evolution by Tipping (1994; (2) an experimental site on Sourhope farm is the focus for an intensive national research programme on soil biodiversity. The current study would have benefited from samples from both cultivated and non-cultivated sites. However, the intensity and extent of cultivation in the Bowmont valley meant that comparable non-cultivated sites could not be found. Instead, emphasis had to be given to determining the presence of micromorphological features known from other studies to be associated with cultivation.

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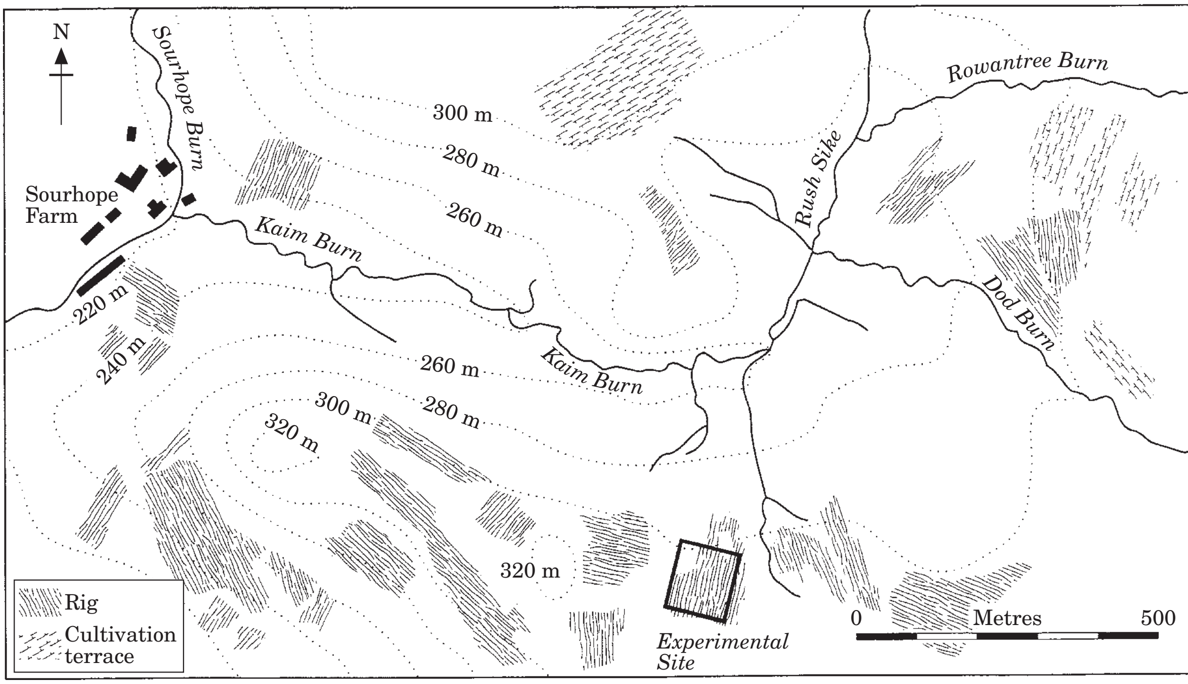

Figure 1. Distribution of rigs and cultivation terraces in part of the upper Bowmont catchment. (Based on an unpublished map provided by R. Mercer, RCAHMS.)

Sampling Contexts and Soil Micromorphology

The Bowmont Valley contains an impressive variety of ancient cultivation remains, including various types of ridging and terracing, that cover large areas of the valley currently used only for pasture (Mercer & Tipping, 1994) An extract of the field mapping is shown in Figure 1. Three broad types of cultivation feature occur within the valley and were sampled: cultivation terraces, broad rig (roughly 3–5 m wide) and narrow or "cord" rig (*c.* 1·0–1·5 m wide). In each case the former cultivated horizon was sampled. The basis to the approach was that these different field system morphologies are a reflection of different cultivation methods. The aim was to establish any relationship between soil micromorphological properties and the form of cultivation remains. Narrow rig is assumed to be the product of spade cultivation and the question is whether this form of management would have produced distinctive soil structures and pedofeatures. In contrast, the wider rigs and cultivation terraces were probably ploughed at later periods to result potentially in different micromorphological features. Cultivation ridges on a low river terrace near Mowhaugh (NT832197) may be placed with some confidence into the 18th and early 19th centuries and other examples of 3–5 m wide ridges may well be post-medieval in date (Mercer & Tipping, 1994). Dating evidence for narrow rig is problematic and it may have been created at any time between 5000 and 1000 years ago (Carter, 1995). The dominant soil type in the Bowmont valley is a brown forest soil of low base status (Sourhope Series) with underlying drift derived from intermediate lavas of Upper Old Red Sandstone age (Ragg, 1960).

Sampled Sites

1. Calroust (NT823191)

Five previously cultivated soils expressed as narrow rig and cultivation terraces were sampled to the immediate east of Calroust, yielding nine thin sections (Table 1). At site 1, a thin incipient podzol overlies a previously cultivated dark reddish brown (5YR 3/4) horizons (bAp1 and bAp2) with a very weak fine subangular blocky structure and a sandy silt loam texture. Site 2 is similar, but without the developing podzol. The soils on the old cultivation terraces (sites 3, 4 and 5) have very similar textures, colour and structure to the other Calroust sites. A summary description of the soil thin sections slides is given in Table 2. Basic mineral components are similar for all five locations and consist of very stony, poorly sorted local igneous material. Fresh roots are the dominant organic components. A few small charcoal fragments were noted in the cultivation terrace sites. The microstructure varies from intergrain microaggregate in site 1 to a more complex crumb/granular structure in the other sites. Both of these structures are created from invertebrate excrements; the intergrain microaggregate structure is dominated by excrements considered to be primarily derived from enchytraeids whilst the crumb/granular structures are a mixture dominantly of enchytraeid and

Table 1. Sampling sites in the upper Bowmont valley, south east Scotland. The horizon notation Ap indicates a cultivated horizon (bAp if buried); horizon notation follows the system described by Hodgson (1974)

Locality	Site no.	Sample label	Sampling depth (cm)	Horizon	Cultivation context and rig width
Calroust	1	CAL 1A	2–10	LF, H and E	Very narrow rig on ridge, 0·7 m wide
		CAL 1B	16–24	bAp1	
		CAL 1C	30–36	bAp2	
	2	CAL 2A	8–16	Ap1	Very narrow rig on upper slope, 1·2 m wide
		CAL 2B	20–28	Ap2	
	3	CAL 3A	10–18	Ap1	Front of broad cultivation terrace on lower slope (same terrace as at site 4)
		CAL 3B	30–38	Ap2	
	4	CAL 4A	30–38	Ap	Front of broad cultivation terrace on lower slope (same terrace as 3)
	5	CAL 5A	20–28	Ap	Front of broad cultivation terrace on lower slope
Mowhaugh	1	MOW 1A	28–36	Ap	Narrow rig on river terrace, 4 m wide
	2	MOW 2A	26–34	Ap	
		MOW 2B	43–51	Ap	Narrow rig on river terrace, adjacent to 1
	3	MOW 3A	35–43	Ap	Narrow rig on river terrace, 4·6 m wide (same rig as at 2)
Cocklawfoot	1	COCK 1A	4–12	H, E and Ap	Broad rig on upper slope, 3 m wide
		COCK 1B	16–24	bAp	
	2	COCK 2A	12–20	bAp	Broad rig beside a prehistoric enclosure on lower slope, 2–3 m wide
	3	COCK 3A	14–22	bAph	Narrow cultivation terrace on lower slope, 2 m wide
	4	COCK 4A	10–18	bAp	Narrow rig on ridge, 0·8 m wide
	5	COCK 5A	4–12	bAp1	Narrow rig on upper slope, 1·3 m wide
		COCK 5B	16–24	bAp2	
		COCK 5C	24–32	bAp2	

earthworm excrements. The difference in soil fauna appears to reflect the low base-status of the soil which at sites 3, 4 and 5 has probably been enhanced by recent liming. Only enchytraeids predominate in the more acidic soil.

2. *Mowhaugh (NT832197)*

Four samples were collected from a group of narrow rigs on a river terrace upstream from Mowhaugh. Tipping (1994) considers that this is a relatively recent terrace which formed by the 18th century AD. Three locations were sampled (Table 1). The mineral components are similar to Calroust (local igneous) but the sandy loam texture reflects the fluvial origin of the sediment. Again, the soil structure is a weak fine subangular blocky. Modern roots dominate the organic components but a little charcoal is present. The microstructure at sites 1 and 2 varies from crumb/granular to spongy; this difference is related to the quantity of fresh excrement which is of mixed enchytraeid and earthworm types. At site 3 the structure is much less porous and may be described as spongy/channel; this reflects the relative absence of fresh excrement. Rare textural coatings were noted in slides from sites 2 and 3.

3. *Cocklawfoot (NT853186)*

Five sites above Cocklawfoot on rough grazing land which had been previously cultivated were sampled to yield eight thin sections (Table 1). The sampling contexts varied from broad to narrow rig. At sites 1 and 2 an incipient podzol overlies the formerly cultivated horizon (bAp) which has very similar colour and texture to the equivalent horizons at Calroust. High stone content meant that at sites 2, 3, 4 and 5 Kubiena sampling boxes could not used and large intact irregular blocks had to be extracted. At site 5 the formerly cultivated topsoil (31 cm in thickness) was divided by the presence in the centre of a 2 cm peaty layer, suggesting two cultivation periods separated by an abandonment phase.

Basic mineral components as evident in the thin sections closely match the Calroust samples, consisting of local igneous rocks occurring as stone sized clasts. Modern roots dominate the organic components but the slides from site 3 contain significant levels of amorphous organic matter (reflected in a 33% loss-on-ignition result). The slide from this site also contains amorphous iron and iron depletion pedofeatures indicative of gleying. This contrasts with the other samples from the Bowmont which are all freely draining. Apart from site 3, the Cocklawfoot samples display the same range of invertebrate excrement derived microstructures, intergrain microaggregate in sites 1, 2 and 4, and crumb/granular in 5. Two of the sections from site 5 contain what may be fragmented, cemented cappings. These could be derived from an underlying indurated horizon by cultivation disturbance.

4. *The experimental site at Sourhope (NT855196)*

The experimental site (120 × 100 m) belongs to the Macaulay Land Use Research Institute (MLURI) and

Table 2. Summary of soil micromorphological attributes of samples from a range of previously cultivated contexts in the upper Bowmont valley

Sample label	Basic mineral components	Basic organic components	Microstructure	Pedofeatures
CAL1A	Local igneous, more stones towards base	Frequent organic fragments at top, amorphous organic matter in B horizon	Intergrain microaggregate	Excrement, depletion features in E horizon
CAL1B and C	Local igneous, very stony	Modern roots	Intergrain microaggregate	Whole fine fraction in excremental pedofeatures
CAL2A	Local igneous	Modern roots including bracken rhizomes	Complex crumb/granular	Abundant enchytraeid and possible earthworm excrement
CAL2B	Local igneous	Modern roots including bracken rhizomes	Similar to CAL2A but less granular	Enchytraeid and possible earthworm excrement
CAL3A	Local igneous, stony	Modern roots	Complex crumb/granular	Discrete excrement, concentrated in voids, earthworm excrement also
CAL3B	Local igneous, stony	Few roots, 1 fragment of charcoal	Complex crumb/granular	As in CAL3A but less obvious excrement
CAL4A	Local igneous, stony	Modern roots, very few charcoal fragments	Complex crumb/granular	Abundant enchytraeid and earthworm excrement
CAL5A	Local igneous, stony	Modern roots	Complex crumb/granular	Enchytraeid and earthworm excrement
MOW1A	Local igneous, sandy moderately sorted	Modern roots, very few charcoal fragments	High porosity crumb/granular	Enchytraeid and earthworm excrement
MOW1B	Local igneous, sandy moderately sorted	Modern roots, very few charcoal fragments, including carbonized grain?	Crumb/granular to spongy	Enchytraeid and earthworm excrement, very few coatings
MOW2B	Local igneous, sandy moderately sorted	No roots ?, very few charcoal fragments	Crumb/granular to spongy	Enchytraeid and earthworm excrement, very few coatings
MOW3A	Igneous, sandy moderately sorted	No roots, very few charcoal fragments	Spongy/channel	Less obvious excrement, very few coatings
COCK1A	Local igneous, very stony	Modern roots especially at top, very few charcoal fragments	Intergrain microaggregate	All fine fraction is enchytraeid excrement
COCK1B	Local igneous, very stony	Modern roots and very few charcoal fragments	Intergrain microaggregate, more coalesced	All fine fraction is enchytraeid excrement
COCK2A	Local igneous, very stony	Modern roots and very few charcoal fragments	Intergrain microaggregate	All fine fraction is enchytraeid excrement
COCK3A	Local igneous, very stony	Abundant roots and amorphous organic matter	Dense fabric of coalesced excrement and root channels	Excrement, amorphous Fe and Fe depletion pedofeatures
COCK4A	Local igneous, very stony	Modern roots and amorphous organic matter. Very few charcoal fragments	High porosity intergrain microaggregate	All fine fraction in enchytraeid excrement
COCK5A	Local igneous, very stony	Abundant modern roots including bracken rhizomes	Crumb/granular	Some excrement
COCK5B	Local igneous, very stony	Abundant modern roots including bracken rhizomes	Crumb/granular	Some excrement, fragmented cappings?
COCK5C	Local igneous, very stony	Fewer roots than above	Denser fabric than above	More visible excrement, fragmented cappings?

is situated at c. 305 m OD on land sloping at *c.* 5° to the north. The soils in the vicinity are brown forest soils belonging to the Sourhope Series with pH generally in the range 4–5. Table 3 gives details of a soil profile from the centre of the experimental enclosure. The organic horizons in the first 8 cm have developed subsequent to abandonment of cultivation. Palynological evidence from a local site suggests cereal cultivation until *c.* AD 1650 (Tipping, 1998); the effect of cultivation was the formation of rigs 1·5–2·0 m in width, still very evident within the experimental enclosure. A well homogenized and manured topsoil would have been formed, now expressed as the Ah horizon in Table 3.

The experimental site is laid out with 5 blocks arranged downslope with each comprising 6 plots (12 × 10 m). The main treatment to plots has been a substantial application of lime (600 g/m^2) at the start of the experiment (May 1999) with subsequent treatments in 2000 and 2001. Soil thin sections were sampled at the start of the experiment and of particular relevance to

Table 3. Soil profile description for the Soil Biodiversity experimental site on Sourhope farm (from baseline data provided by Carolyn Kenny as part of the NERC Thematic Programme on Soil Biodiversity)

Altitude	308 m
Slope description	7°
Soil drainage	Free
Series	Sourhope
Major soil subgroup	Brown forest soil
Rock type	Andesite and undifferentiated intermediate igneous

Horizon	Depth (cm)	Soil description
LF	0–1	No identifiable mineral grains; fibrous; moist; no stones; clear smooth boundary.
FH	1–3	Dark grey, 10 yr 4/1 matrix colour; no identifiable mineral grains; fibrous; moist; abundant very fine fibrous roots; common fine fleshy roots; no stones; sharp wavy boundary.
H	3–8	Very dark grey, 10 yr 3/1 matrix colour; loamy peat; amorphous; moist; weak medium subangular blocky structure; abundant very fine fibrous roots; common fine fleshy roots; no stones; sharp irregular boundary.
A h	8–26	Dark reddish brown, 5 yr 3/2 matrix colour; sandy silt loam; no mottles; moderate medium angular blocky structure; moist; friable; many very fine fibrous roots; common fine fleshy roots; common medium subangular undifferentiated intermediate igneous stones; common large subangular andesite stones; clear smooth boundary.
AB	26–37	Brown, 7·5 yr 5/2 matrix colour; fine sandy silt loam; no mottles; weak fine subangular blocky structure; moist; friable; many very fine fibrous roots; common fine fleshy roots; many very small angular undifferentiated intermediate igneous stones; few small subangular undifferentiated intermediate igneous stones; clear irregular boundary.
Bsh	37–55	Yellowish red, 5 yr 5/6 matrix colour; fine sandy silt loam; no mottles; weak fine subangular blocky structure; moist; friable; common very fine fibrous roots; few fine fleshy roots; abundant very small angular undifferentiated intermediate igneous stones; common small subangular undifferentiated intermediate igneous stones; sharp wavy boundary.
BCx	55–78	Reddish brown, 2·5 yr 4/4 matrix colour; strong brown, 7·5 yr 5/6 mottle colour; sandy clay loam; common fine distinct clear mottles; massive structure tending to moderate medium platy structure; moist; moderate induration; few very fine fibrous roots; very abundant very small angular andesite stones; common medium subangular andesite stones; clear wavy boundary.
C	78–90	Reddish brown, 5 yr 5/3 matrix colour; sandy silt loam; no mottles; massive structure; moist; firm; no roots; very abundant very small angular undifferentiated intermediate igneous stones; common medium subangular andesite stones.

this paper are the attributes of the Ah horizon. Standard Kubiena boxes were used to collect undisturbed blocks from the base of the L/F horizon and including H and Ah horizons; in some profiles the H horizon was subdivided into two (H_1 and H_2).

Results

Microscopic study of the thin sections (Table 2) from the range of former cultivation contexts as expressed in rig morphology at Calroust, Mowhaugh and Cocklawfoot detected almost no feature of soil composition or structure that could be linked to former cultivation of these soils. No relationship is apparent between rig type and soil micromorphology. Instead, the major finding seems to be the high degree of excremental pedofeatures in the former cultivated horizons, indicating substantial change through biological activity. The experimental site at Sourhope provided the opportunity to investigate this hypothesis in greater detail.

Quantification of excremental pedofeatures as well as other micromorphological attributes was thus necessary and a subsample of 10 slides (two from each block) was selected for detailed point counting. Slides were subdivided into horizons and then point counts made on a 2 mm grid with *c*. 350 observations being made per slide. Observations were made at each grid intersection on the presence of particular types of excremental pedofeatures or, if not present, other features. A classification of excremental pedofeatures was evolved based on size, shape and degree of fusion and guided by Babel (1975) and FitzPatrick (1993). The classification system and results when combined for the 10 slides are given in Table 4.

Overall, these results highlight the extent to which excremental pedofeatures dominate the upper horizons of an upland soil in a cool maritime environment. Of particular interest is the nature and extent of excremental pedofeatures in the Ah horizon. The dominant type (1) of excremental pedofeature is derived primarily from enchytraeids with an average of 29% of the Ah horizon comprising this type. Rock fragments (type 10), dominantly of andesite, occupy 24% and appear randomly distributed within the excremental pedofeatures. Excrement of type 1 varies in occurrence from separate features to high degrees of coalescence. Undifferentiated excrement identified as type 7 could well have been derived from enchytraeids. The effect of

Table 4. Occurrence (%) of different excremental types and other features based on point counting (total of 3653) of 10 slides for the upper 4 soil horizons. The H_2 horizon occurs in certain areas of the Sourhope experimental site and is distinguished by a concentration of phytoliths

	Excremental types							Other features			
	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9	Type 10	Type 11
LF	18	6	1	0	1	0	31	16	14	0	12
H1	24	5	0	0	5	1	25	17	7	1	15
H2	24	2	0	0	1	0	33	17	5	6	13
Ah	29	2	0	0	4	0	12	14	5	24	11

Excremental pedofeatures
Type 1: up to 100 µm, spherical/oblong (dominantly from enchytraeids, but also mites).
Type 2: 100 to *c.* 250 µm, spherical/oblong (from tipulids *inter alia*).
Type 3: >250 µm, varying shapes, dominant mineral content (from beetles).
Type 4: >250 µm, varying shapes, dominantly plant fragments (from diptera larvae).
Type 5: >500 µm and with a channel or mamilated morphology (from earthworms).
Type 6: >250 µm, spherical. (unknown origin).
Type 7: organo-mineral material with evidence of excremental origin.
Other features
Type 8: Organo-mineral material with no evidence of excremental origin.
Type 9: Plant fragment.
Type 10: Rock/mineral fragment.
Type 11: Void.

earthworms seems comparatively minor (4%), but is likely to be underestimated since earthworm excrement can be rapidly consumed by enchytraeids as well as by other soil animals.

Conclusions

The results from sampling a wide range of cultivation contexts within the Bowmont valley as well as from more intensive sampling of a small area of rigland indicate the extent to which the former cultivated horizon is dominated by excremental pedofeatures. In many ways this is a result to be expected. The aim of cultivation through mixing and the addition of manure is to maintain or enhance soil fertility which also has a positive effect on soil animals. The burrowing, mixing, eating and excreting activities of these animals result in the almost total loss of structural features characteristic of cultivation within an Ah horizon. At the Sourhope experimental site, this would have happened within *c.* 200 years. A similar project on Papa Stour in Shetland indicated that total reworking by soil animals could have happened within 40 years (Davidson & Carter, 1998). The effect of bioturbation on soil pollen distribution has also been demonstrated for another upland site (Lour) in the Scottish Borders (Davidson *et al.*, 1999). In this case it was shown that biological activity was the most important factor in the incorporation and redistribution of soil pollen dating to *c.* AD 1840 though the net effect of enchytraeids on overall movement was probably neutral. The results from the current and these previous projects demonstrate that micromorphological features diagnostic of cultivation will be lost within decades unless such soils are very quickly sealed within archaeological contexts. In cool temperate upland environments, the micromorphological investigation of past cultivation processes from modern surface soils is thus likely to be unrewarding though evidence for previous manuring may well persist.

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