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The Soil Micromorphologist as Team Player

A Multianalytical Approach to the Study of European Microstratigraphy

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1. Introduction

Soil micromorphology is one of the major subdisciplines within soil science, with subcommission status in the International Society of Soil Science since 1978. It held its initial working-meeting in London in 1981, where Goldberg (1983) made the first review of the application of soil micromorphology to archaeology. First developed by Kubiena (1938) as a way of studying undisturbed soil in thin sections, soil micromorphology now encompassess a range of ultramicroscopic techniques such as scanning electron microscopy (SEM) that is often linked to

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microchemical instrumental analyses (e.g., qualitative energy dispersive X-ray analysis or Energy Dispersion X-ray Analysis (EDXRA) and microprobe; e.g., Courty et al., 1989).

In Europe, "geoarchaeologist" is broad umbrella term under which are grouped a range of specialists. Many are geographers, pedologists, and Quaternary scientists, who on occasion take on an implied geoarchaeological role when studying sites associated with human activity (e.g., Kemp, 1985; Preece, 1992; Preece, et al., 1995). They also commonly combine geophysical techniques, such as magnetic susceptibility, with standard soil and sediment methodologies, especially when studying wetland sites, although now many archaeological soils are studied in this way (Crowther and Barker, 1995; Oldfield et al., 1985; Taylor et al., 1994). Whereas some are soil micromorphologists, others emphasize the analysis of particle size, tephra, phosphate, river gravels, and the X-ray analysis of sediments (see Barham and Macphail, 1995). Geoarchaeologists are grouped with other environmental archaeologists who study microfossils (e.g., pollen, diatoms, nematode eggs), macrofossils (e.g., seeds/grains, charcoal, mollusks, bones, teeth), isotopes, and human remains, and some notable integrated studies have been published (Dockrill et al., 1994; Maggi, 1997; Matthews and Postgate, 1994). Very broadly speaking, soil micromorphologists, like their soil chemist counterparts, are likely to be asked to focus on the on-site and anthropogenic component of a study. Site geologists and geomorphologists, if present, are more likely to take responsibility for the macro geomorphological setting and the off-site studies. For example, paleosols and colluvium may be identified as macrogeological units, but the soil micromorphologist may confirm these identifications and recognize anthropogenic activities that modified or produced these units. This is not to say that soil micromorphologists cannot also act as competent geomorphologists/geologists, and vice versa. Many workers have been trained in all these fields. As stated as follows, the soil micromorphologist works from the field scale to the microscale, and his/her interpretations may well be of relevance to broad models that reconstruct past landscapes and periods (Crowther et al., 1996; Macphail, 1992; Whittle et al., 1993).

Multidisciplinary environmental studies of archaeological sites that contain a soil science component have been carried out for many years in Europe (Cremaschi, 1985; Dimbleby, 1962; Dockrill et al., 1994; Evans, 1972; Iversen, 1964; Macphail, 1987, Tables 13 and 14, 1994). Such investigations, which involved palynological and land mollusk studies, have contributed enormously to our understanding of past soils, their associated environment, and land use. The specific application of soil micromorphology to European archaeological sites spans the period from the 1950s up to the present day (Castelletti and Cremaschi, 1996; Cornwall, 1958). Nevertheless, one of the constraints that emerged since the late 1950s is a frequent lack of coordination of both sampling and analyses among the various specialists working on a single site or project. For example, when the various specialists sample different parts of the site, conflicting interpretations may result that may be impossible to resolve. This situation is further exacerbated when workers are sampling and analyzing at different scales. Increased dissatisfaction with this situation, which ultimately is a waste of energy

and talent, has led in recent years to a growing acceptance of the need for closer integration and collaboration. This is certainly the view of soil scientists actively involved in the Archaeological Soil Micromorphology Working Group, an ad hoc group meeting biannually in Europe (Arpin et al., 1998; see http://www.gre.ac.uk/~at05/micro/soilmain/intro1.htm).

For their own scientific peace of mind, the present authors have adopted procedures that approach the ideal of multianalytical approaches. Thus, the chief aim of this chapter is to illustrate ways in which the soil micromorphologist may more effectively work within a multidisciplinary approach to microstratigraphic studies.

Consensus interpretations will always be more convincing than interpretations based on one discipline working in isolation. Soil micromorphology employing thin sections is in the middle of a scale of stratigraphical studies that involve fieldwork at one end and scanning electron microscopy at the other (e.g., Courty et al., 1989; Macphail, 1998; Macphail et al. 1998a). Soil micromorphology itself is multifaceted, in that organic matter, mineral components, pedological activity, and sedimentary processes, for example, can all be identified (Bal, 1982; Bullock et al., 1985; Courty et al., 1989). This technique also lends itself to being integrated with other disciplines, as detailed as follows. Bulk physical and chemical, macro-, and microfossil data can be linked directly with the undisturbed microstratigraphy evident in thin sections. Schematic and numerical/seminumerical data presentations from combined disciplines is seen as a way of integrating more specialists in the process of creating consensus interpretations.

2. Methods

2.1. Getting the Sampling Right

It is all very good having ambitions to combine post-excavation data in a multidisciplinary way, but this can only work if correct and thoughtful sampling, subsampling, and sample preparation are carried out in the first instance. For example, if soil monoliths are impregnated they cannot be subsampled afterward for soil chemistry. If only large bulk samples are taken, these cannot be used for pollen analysis. Also, if the pollen column is distant from the soil micromorphology samples, data correlation is less certain.

In the field, good results come from combining Kubiena boxes (8 × 7 cm) and square section plastic drainpipe cut into convenient lengths (e.g., 10–20–40 cm) for undisturbed monolith sampling. These are taken exactly alongside plastic bag samples of the archaeological units and layers within them (20–50–200–1,000 gm). Needless to say, all the archaeological contexts of interest must be sampled, with adequate coverage of the vertical stratigraphy, alongside lateral controls, according to the needs of the site study. At this time there must also be good communication with the site's director/area supervisor/environmental manager, in order that archaeological sampling for artifacts and biofacts is coordinated across the site. For example, radiocarbon dating, phasing by pottery analysis, and contextual interpretation based on charred seed and/or bone analysis can all become crucial elements during the post-excavation phase.

Examination of monoliths in the laboratory allows a second and more relaxed chance to examine the stratigraphy. Monolith cores can be first subsampled for pollen and small chemical samples before being impregnated for thin section analysis. As emphasized throughout this chapter all investigators should regard all techniques as equal approaches. In some situations, the early findings from pollen analysis, for example, may allow better targeting of specific parts of a core for chemical and soil micromorphological studies.

2.2. Multidisciplinary–Analytical Approach

2.2.1. Chemistry and Palynology

The chemical and palynological methods employed are already well established in the literature (Clark, 1990; Engelmark and Linderholm, 1996; Moore et al., 1991). Within the text we cite proportions of organic and inorganic phosphate as extracted by 2% citric acid, before and after ignition at 550°C, and refer to "P ratios." Several studies demonstrated empirically that soils with P ratios of <1.0 contain inorganic phosphate in the form of neoformed apatite, bone, vivianite, poorly crystallized forms of phosphate and mineralized coprolites, whereas soils with P ratios >1.0 have been manured and/or contain organic herbivore dung (Engelmark and Linderholm, 1996; Macphail et al., in press).

2.2.2. Choosing Techniques

Different archaeological and pedological questions require a flexibility of approach. For example, at the Romano–British site of Folly Lane, St. Albans (UK), it was necessary that archival information from the Soil Survey of England and Wales should be combined with on-site soil micromorphology, microprobe, and diatom studies in order to investigate the composition and archaeological significance of "turf" mound material (Avery, 1964; Macphail et al., 1998b).

During this first stage of soil micromorphological description and identification, some specific features can be analysed by SEM/EDXRA and/or microprobe (see the following sections). It will be seen that such data retrieval then permits the presentation of soil micromorphological data alongside that from other disciplines, such as chemistry and palynology (cf. Preece et al., 1995, Fig. 6).

2.2.3. Soil Micromorphology

In soil micromorphology, descriptive analysis has produced good results (Bullock et al., 1985) in the identification of (1) microfabric types (absolutely essential), (2) structural and porosity features, (3) natural inclusions (e.g., plant remains such as roots, gravel-size flint, and chalk), (4) anthropogenic inclusions (e.g., charcoal, bone, various coprolites, slag, allocthonous stones), and (5) pedofeatures. The presence of fine charcoal, an abundance of phytoliths, or the presence of diatoms, pollen grains, and fungal spores can all be included within the definition of a microfabric type. Pedofeature studies may include the identification of different types of clay coatings, secondary iron, and manganese nodular impregnations, neoformed vivianite, and different types of soil animal excrements.

2.3. Numerical/Semi-numerical Data Gathering

Since 1992, a combination of description of the previously listed components and features and area counting (as opposed to point counting), has been adopted in about 20 studies. The latter can be extremely accurate, and when tested against image analysis of a counted slide from Overton Experimental Earthwork, as little as a 0 to 5 percent difference was found for each of the 13 vertical 0.5 cm deep transects (Acott et al., 1997; Macphail and Cruise, 1996). As the slide was counted at vertical intervals of 0.5 cm, estimates were based on 0.5 cm squares across the slide. Counting of a slide (7.5 × 5.5 cm) at 0.5 cm intervals, however, takes about 8 working hours, and so it is no light undertaking to carry out this kind of analysis where estimates attain numerical validity. On the other hand, where budget and time constraints are factors in a study, area counting may be carried out at a variety of scales, some of which are considerably less time consuming (see the following text). Estimates of clay coatings in order to identify an argillic horizon (*sensu stricto*) produced varied results between operators (see also McKeague, 1983; Murphy et al., 1985). This is why Bullock et al. (1985) wisely chose to keep broad groupings in their Frequency and Abundance scales. Additionally, although coarse mineral grains, void space, major microfabric and faunal excrement types can be accurately estimated, small inclusions such as rare fragments of bone can best be recorded on the Abundance scale of Bullock et al. (1985). Point counting at normal intervals (e.g., 1,000 points per standard geological slide) may well miss very small and rare inclusions. That is why in archaeological studies, where microscopic inclusions may be crucial to an interpretation, area estimation/counting is generally preferred.

In fully funded research projects, thin sections can be counted at practical intervals of 0.5 cm. The Wareham Experimental Earthwork study involves image analysis (by Tim Acott, University of Greenwich), which is being employed to count the amount and shape of voids, mineral grains, organic fragments, and the organic matrix, whereas manual counting (Macphail et al., in preparation) is being used for the numerical analysis of faunal droppings and the different types of plant fragments and their distribution. Traditional descriptive soil micromorphology is also being used to check the accuracy of digitized images, which can then be more accurately and more confidently quantified. The combined soil study also involves chemical analysis of samples from 1 to 2 cm spits taken from the same locations (Macphail et al., in preparation).

Since the early 1990s many archaeological deposits were first described, and then counted, so that the stratigraphical distribution of selected materials and features could be more fully appreciated. Reasonable results have been achieved at the 1 cm scale. Here, a thin section (7.5–13.5 cm) takes some 3 to 5 hours to count. Data may be more rapidly obtained by area counting each archaeological context. These data can be extracted largely from the initial soil micromorphological description and do not require large amounts of extra time. Whichever scale is selected, however, it is essential that the micromorphologist should first examine the slide and gain a general understanding of the soil prior to counting. For example, the soil micromorphologist must be able to differentiate between a natural soil, a washed sediment, and a trampled floor deposit before counting is undertaken. Otherwise counting is a waste of time. Although this basic understanding of the slide may require learned skills and/or advice, it is an absolutely vital step. In fact, numerical data (for its own sake) in soil micromorphology can produce nonsense (Stoops, personal communication, 1997). What is advocated here is the thoughtful gathering of numerical data from thin sections that are already well understood. After counting, slides and counted features can again be analyzed as the understanding of the soil micromorphology deepens. Further benefits arise from the fact that counted data are useful when more than one soil micromorphologist is involved in a single project, because findings can be compared rapidly. Additionally in our experience, during a long-term project, it takes less time to refamiliarize ourselves with our thin section when we have counts than when we have only long descriptions to read.

2.3.1. Presentation of Soil Micromorphological Data (Courty et al., 1989; Romans and Robertson, 1983; Simpson and Barrett 1996)

In 1994, one of the authors (Macphail) presented a seminar paper to the Archaeological Soil Micromorphology Working Group at Rennes University, France. The object was to demonstrate and discuss the many ways in which soil micromorphological data can be presented and to note the views of the members of the working group. For example, full-page descriptions as per Bullock et al. (1985) were compared with tables summarizing data and their interpretation and schematic diagrams to express numbers of features present (per thin section/horizon). Bullet points were employed in the last example. This simple idea came from a paper by Simpson and Barrett (1996) and has been used by other authors (R. Kemp, Royal Holloway University of London, personal communication 1995; A. Gebhardt, Rennes University, personal communication, 1997). At more recent meetings of the working group (Cambridge, London, and Pisa) some soil micromorphological data were expressed as percentages (e.g., Matthews et al., 1997, Fig. 3a-b), with counted data from experiments illustrated as bar graphs, bullet points (Crowther et al., 1996; Macphail, 1998) and on Frequency and Abundance scales.

Nonsoil micromorphologists may examine data from seed, bone, and palynological studies because these are presented graphically, but soil micromorphological findings have generally been obscured by its presentation either in jargon or as interpretation. The present authors have therefore been endeavoring to make soil micromorphology more user friendly to other scientists. This does not mean, however, that they will fully understand the nitty-gritty of soil micromorphology any more than they would the intricacies of pollen taphonomy and mineralized seed identification, but they can at least

see how interpretations are constructed on the logical registration of data as expressed graphically.

The present authors and their colleagues continue to produce soil micromorphological descriptions as the basis of "counted" microfabrics and components. Professor Stoops (University of Gent), although acknowledging the need to summarize data for publication, has also suggested that sufficient data should still be available to enable the reader to judge the scientific merit of the work (Stoops, personal communication, 1997). In papers produced for our peers, this is certainly crucial, but in archaeology we also have to deal with a lay audience. The same must be true for soil micromorphologists reporting to agronomists and to Quaternary scientists. It is therefore up to us to both produce and present data that are both acceptable to our peers and understood by our audience (e.g., archaeologists, paleoenvironmentalists, and field Quaternary scientists).

3. Research Base

Soil micromorphologists working in archaeology need to break new ground because most publications on soil micromorphology have dealt only with natural soils. To achieve this, workers have developed their own specific reference collections, analyzed specific archaeological materials, studied ethnologically interesting sites, and carried out experiments (Courty et al., 1989, 1994; Crowther et al., 1996; Gebhardt, 1992; Goldberg and Whitbread, 1993; Wattez and Courty, 1987; Wattez et al., 1990).

In our case, this approach to archaeological soil micromorphology has been supported by two major strategies, as follows:

First, "counting" has been applied to thin-section studies of deposits formed by ethnoarchaeological experiments, in order to try and identify key semi-numerical microfabric signatures, that may be of significance in the archaeological record.

A second approach has been to identify from our experience some specific components and microscopic inclusions that regularly occur in archaeological deposits and to analyze examples of these intensively. This is a way to identify the archaeological significance of these, especially when recorded semi-numerically, just as counted pollen or seed types may be given anthropogenic weighting according to, for example, established floras and ecological groupings. Where possible, soil micromorphological findings have been combined with chemical data, macrofossil, and palynological studies of the same horizons and components.

3.1. Experimental Findings

The Ancient (Iron Age) Farm at Butser, Hampshire, U. K. is situated on the chalk of southern England, and is well known in Europe for being a focus of experimental studies in agriculture, arable soils, architectural structures, and their floors (Gebhardt, 1990, 1992; Macphail and Goldberg, 1995; Macphail et al., 1990; Reynolds, 1979). To be consistent with the approach to the study of soils at the Experimental Earthwork at Overton Down (Crowther et al., 1996; Macphail and Cruise, 1996) and at numerous current archaeological sites, it was decided to restudy the floors from the Moel-y-gar House (animal stabling) and the Pimperne House (domestic occupation) at Butser, using counted soil micromorphological data. At the same time, bulk samples were run for chemical and palynological analyses. This approach would then provide an experimental example of multidisciplinary microstratigraphic studies as the preferred approach of the authors. Our work at the Moel-y-gar and Pimperne House floors are examples of soil micromorphology counting and how resulting data can be linked to complementary data from chemistry and palynological studies.

At the Moel-y-gar stable house, three distinct layers were identified (Tables 9.1a and 9.2a): an uppermost cemented crust of layered, long monocotyledonous plant fragments, a "stable soil" of phosphate stained chalk and soil, and a phosphate-contaminated buried subsoil (Macphail and Goldberg, 1995, Fig. 2, Plates 3 and 4). The uppermost layer was further characterized by microprobe and X-ray diffraction analyses to confirm the view that this plant-rich layer that is autofluorescent under ultraviolet light, is cemented by calcium phosphate in the form of hydroxyapatite. Key microstratigraphic features were counted (Tables 9.1a and 9.2a).

At the Pimperne House at Butser, a very different kind of microstratigraphy had developed, with an uppermost trampled/beaten floor layer overlying a buried soil (Tables 9.1b and 9.2b). In addition to the soil microfabric differences, complementary studies found, in comparison with the Moel-y-gar "crust," a more strongly enhanced magnetic susceptibility, but less organic matter (LOI 18%) and phosphate (2400 ppm P), the last being dominantly in an organic form (P ratio 2.2–3.4). Furthermore, pollen concentrations were considerably lower but contained a far more diverse herbaceous and weed pollen assemblage.

How do these findings compare with archaeological data? At the Italian Neolithic cave of Arene Candide, Liguria, phosphate-stained stabling layers composed of layered and compacted oak twig wood (leaf hay foddering) can be differentiated from sublamina, massive structured mineralogenic domestic floors (Macphail et al., 1997). At the Roman London site of 23, Bishopsgate, two counted samples from a red charred floor context were composed of semi-layered plant fragments/cattle dung-like material with total phosphate averaging 9,000 ppm, thus indicating that a likely stable layer had been found (an hypothesis now supported by macrobotanical findings; Macphail et al., in press). Sites ranging from prehistoric to recent from Scotland through Switzerland, Italy, and southern France to north Africa have yielded further comparative examples of floors with covered (roofed) stable and domestic areas having microstratigraphic signatures consistent with the experimental findings from Butser (e.g., Boschian, 1997; Cammas, 1994; Cammas et al., 1996; Davidson et al., 1992; Del Lucchese and Ottomano, 1996; Guélat et al., 1998). At the London Guildhall site two types of Anglo–Danish (1060–1120 A.D.) floors were differentiated on the basis of soil micromorphology, chemistry, and palynology. One floor type has a poorly preserved but diverse pollen assemblage in a heterogeneous mineralogenic (LOI 9%) soil with an enhanced magnetic susceptibility (assumed domestic structure).

Table 9.1a. Counted Microstratigraphy of Floor and Buried Soil of the Moel-y-gar Stabling House 1990 (Center of the House)

a	B	AI 1	AI 2	AI 3	AI 4	AI 6	AI 7	AI 8	NI 2	NI 3	NI 5	NI 6	NI 9	S1	S2	S3	S4	S5	S7	EX 2	EX 3
1	B1(B2)		aa		a	ffff f		aa	f					f	ffff						
2	B1		a	aaa		ffff		aaaa a						f	ffff						
3	B1					ffff f		aaaa						f	ffff						a
4	B1/B2					ff		a		a				ff	ffff				f	a	
5	B2	fff f				ff	a	a		aaaa	a		a	ff	ffff						
6	B2(B1/3)	fff f					aaaa	a	f	a	a	a	aa	ff		ffff	ffff	ffff	ffff f	a	
7	B2(B1)	fff f				f	a	a	f	a	a		a	fff	ff	ffff	f	ffff	ffff f	a	
8	B1/B2					ff		aaaa	f		a	a	a	ff	ffff	ffff	f	ffff f	ffff	a	aa
9	B2/B3 (B1)					f	a	a	fff	a	a	aaa	aa	ff		ffff f	ffff	ffff		aaa	
10	B2(B3)								ff	aa	a	aa	aa	ff		ffff f	ffff	f	f	aa	
11	B2(B3)						a		fff	aa	aa	aa	aa	fff		ffff f	ffff f	f	f	aaa	
12	B2(B3)								ffff	aa	a		aaa	ff		ffff f	ffff f		f	aa	
13	B2(B3)								ffff	aa	aa	aa	aaa	fff		ffff	ffff			aaa	

Table 9.1b. Counted Microstratigraphy of Floor and Buried Soil of the Pimperne House 1990 (Sample from Near Oven Location)

a	B	AI 4	AI 5	AI 6	AI 7	AI 8	AI 9	NI 2	NI 4	NI 5	NI 6	NI 8	S1	S3	S5	S6	S7	S8	FF 1	EX 1	EX 2
1	B4	f	a	f	aa	a	aaa	ff	a	a	a	aa	ff				ffff	f	aa	a	aa
2	B4	f	a	f	aaa	a	aaa	fff	a	a	aa	aa	fff				ffff	f	a		a
3	B4/B5	f	a		aa	a	a	fff		aa	a	aaa	fff	ffff	fff	f	ff	fff		a	aaa
4	B5				aa			fff		aaa	aaa	aaa	fff	ffff	ffff	ffff		f		aaaa	aaa
5	B5				a			fff		aa	aaa	aaa	fff	fff	ffff	ffff f		f		aaaa	aaa
6	B5							fff		aaa	aa	a	fff	f	ffff	ffff		ffff		aaa	aaa

Key to Tables 9.1a–9.1b
a = Depth below surface (cm).
B = Microfabric type.
B1 = Dominantly organic; very dominant pale to dark brown speckled and dotted (PPL), isotic to very low interference colors (weak to strong crystalline b-fabric) (XPL), dill brown (OIL) and high autofluorescence (UVL); dominant amorphous organic organic matter and tissue fragments, with occasional to abundant calcite crystals, occasional to many phytoliths, rare to occasional calcium oxalates (druses) and rare to very abundant patches of <20 μm size spherulites; single-spaced porphyric; C:F 70:30 (limit as 10 μm); Coarse mineral—very dominant, well-sorted silt-size quartz and very few medium sand-size chalk inclusions; Coarse organic—dominant longitudnal sections of *Poaceae* cuticles (tissue remains) and frequent stem cuticle and parenchyma cells (organ remains); much cellulose is poorly birefringent and browned (humified).
B2 = Dominantly mineral very dominantly blackish brown (PPL), very low interference colors (weak crystalline micritic b-fabric) (XPL), pale whitish yellow (OIL) and moderately autofluorescent (UVL); many to abundant amorphous organic matter fragments; single-spaced porphyric; C:F 40:60; Coarse organic—few amorphous fragments; Coarse mineral—common stained chalk clasts (rims autofluorescent under UVL), common silt, very few biogenic calcite (probable earthworm granules) and dark-stained mollusc shell fragments.

B3 = Dominantly mineral—very dominant finely speckled brown (PPL), medium/high interference colors (XPL), pale yellow (OIL) and non-autofluorescent (UVL); occasional to many amorphous organic matter fragments. As B2.
B4 = Dominantly mineral; very dominant speckled and dotted yellowish brown (PPL), low to high-interference colors (weak to strong crystallitic micritic b-fabric), pale yellow to yellowish brown with frequent black specks (OIL), non-autofluorescent (UVL); abundant amorphous and charred organic matter fragments; rare calcium oxalates (druses), <20 μm size spherulites and wood ash crystals, single-spaced porphyric; C:F 60:40; Coarse mineral—dominant silt, common chalk and flint, few mollusc shell and biogenic calcite, very few burned soil and argillic (Bt) sandy soil inclusions; Coarse organic—few charcoal and very few browned (humified) tissue fragments and organ remains.
B5 = Dominantly mineral—speckled, darkish reddish brown (PPL), medium interference colors (XPL), yellowish orange brown (OIL), non-autofluorescent (UVL); abundant amorphous organic matter; single-spaced porphyric; C:F 55:45; Coarse mineral—dominant silt, common chalk and flint, few mollusk shell and biogenic calicite; Coarse organic—very few root traces (organs).
NB: PPL—plane polarized light; XPL—crossed polarized light; OIL—oblique incident light; UVL—ultraviolet light.
Major anthropogenic inclusions
AI1 = stained chalk (with dark UVL autofluorescent rims); AI2 = micrite; AI3 = silty micrite (with well-sorted silt-size quartz); AI4 = burned soil (rubified under OIL); AI5 = soil inclusions (e.g., argillic subsoil clay; daub mixture); AI6 = partially layered plant fragments (>1 mm); AI7 = coarse charcoal; AI8 = amorphous organic matter; AI9 = ash and fine charred fragments.
Major natural inclusions
NI1 = chalk; NI2 = flint; NI3 = sandy soil; NI4 = biogenic calcite; NI5 = mollusk shells; NI6 = plant fragments (<1 mm); NI7 = roots; NI8 = root traces/fragments.
Structure
S1 = voids; S2 = laminar structure; S3 = prismatic structure; S4 = spongy structure; S5 = subangular blocky structure; S6 = crumb structure; S7 = massive structure; S8 = burrows.
Fabric pedofeatures
FF1 = horizontal slickenside/clay smear?
Excrements
EX1 = organo-mineral excrements (>500 μm); EX2 = organo-mineral excrements (<500 μm); EX3 = organo-excrements.
Frequency
fffff >70%, very dominant; ffff 50–70%, dominant; fff 30–50%, common; ff 15–30%, frequent; f 0–15%, very few and few.
Abundance
aaaaa >20%, very abundant; aaaa 10–20%, abundant; aaa 5–10%, many; aa 2–5%, occasional; a <2%, rare.

Table 9.2a. Key Microstratigraphic Features at the Moel-y-gar House

Depth and layer	Soil micromorphology	Some complementary studies
1–3 cm ("crust")	Very dominant partially layered plant fragments >1 mm in length (grass stems, AI6) and abundant amorphous organic matter (humified dung, AI8) set in a specific, chiefly autofluorescent (under UVL) microfabric (B1) with little evidence of small animal mixing (EX2 and EX3).	Dominant grass stem fragments (W. Cazrruthers, personal communication, 1995), high amounts of organic matter (LOI 41%) and inorganic phosphate (6000 ppm P; citric acid P ratio <1.0; 0.5–1.3% elemental P), and unexpectedly high concentration of pollen 822 (grains × 1000) per cm^3 dominated by grass pollen, compared to only 77 (grains × 1000) per cm^3 in the subsoil.
3–9 cm ("stable soil")	Dominant dark stained chalk clasts (AI1) and microfabric type B2, with chalk clast rims and soil ped edges autofluorescent under UVL; dominant subangular blocky structures and burrows within an overall prismatic structure (S3, S5, and S7) (Fig. 14.1).	Organic (LOI 32%) and phosphatic (2840 ppm P; citric acid P ratio <1.0).
9–13 cm ("buried subsoil")	Only rare anthropogenic inclusion (AI) occur in an unstained chalk (NI1) dominated, increasingly by calcareous soil (B3), with a subangular blocky and spongy structure associated with many very thin to thin organo-mineral excrements (EX2).	Comparatively less organic (23% LOI) and phosphatic (1460 ppm P; citric acid P ratio >1.0).

Table 9.2b. Key Microstratigraphic Features at the Pimperne House

Depth and layer	Soil micromorphology	Complementary studies
1–3 cm ("trampled floor")	1–3 cm ("trampled floor"): few burned soil fragments (AI4), with many coarse charcoal (AI7), ash and fine charred materials (AI9) and rare amorphous organic matter (dung, AI8) fragments, set in a highly heterogeneous mineralogenic soil (microfabric type B4) with a dominant (but now cracked) massive structure (S7) (Fig. 14.2).	Moderately humic (LOI 20%) and phosphatic (2430 ppm P; citric acid P ratio >1.0). Highest magnetic susceptibility (47 Si units SiKg10-8, 4.7% MS conversion at 550 °C) compared with Moel-y-gar floor (16–27) and surropunding fields (mean 22).
3–6 cm (buried soil")	3–6 cm ("buried soil"): only rare to occasional anthropogenic anthropogenic inclusions (AI) in calcareous soil (microfabric type B5) containing many natural inclusions (NI), and featuring first prisms (S3) and increasing amounts of subangular blocky (S5) and crumb (S6) structures, associated with many to abundant organo-mineral excrements (EX1 and EX2).	Similarly humic (LOI 20%) and phosphatic (2310 ppm P; citric acid P ratio >1.0), with magnetic susceptibility at 28 Si units (SiKg10-8).

Figure 9.1. Butser Ancient Farm, Moel-y-gar stabling floor layers; center of floor; uppermost 3 cm—crust of calcium phosphate cemented layered monocotyledonous plant fragments and dung; middle 4 cm—stable floor of phosphate stained chalk and soil; lowermost 6 cm—phosphate stained buried colluvial rendzina soil (for detailed soil micromorphology see Table 9.1a). Computer-enhanced image of 13 × 6.5 cm thin section.

In contrast, other *in situ* floors and floor deposits have well-preserved grass- and cereal-dominated pollen assemblages in highly organic (LOI 30%) and phosphatic (e.g., 6,000 ppm P) deposits characterized by layered plant fragments or probable cattle dung (Cruise and Macphail, in press; Macphail and Cruise, 1995). The latter contexts are interpreted as stable floors and deposits. In order to begin the process of interpreting soils, individual microfeatures need to be characterized.

Some of these are better understood than others. For example, at Overton Down much was made of the apparent transformation of earthworm-worked soils (1–5 mm wide mammilated excrements) into soils featuring 100 to 500 μm thin Enchytraeid-like excrements as a result of changed soil conditions induced by burial (Crowther et al., 1996). The relationship between the excrements of soil fauna and soil conditions is well understood in general (Babel, 1975; Bal, 1982). Equally, the presence of vivianite and related features are seen as indicative of the presence of phosphate, and such features occur in bog ores, occupation deposits, and floors (Landyudt, 1990; Macphail, 1983, 1994). In the following sections, we give two examples of how two important anthropogenic soil components, "dark clay coatings" and "phosphatic nodules" were characterized in order to determine their composition and their implied archaeological significance.

3.1.1. Dark Clay Coatings

A feature common to archaeological sites, but which is poorly understood, is dark-reddish brown clay coatings. For many years it was suspected that these were

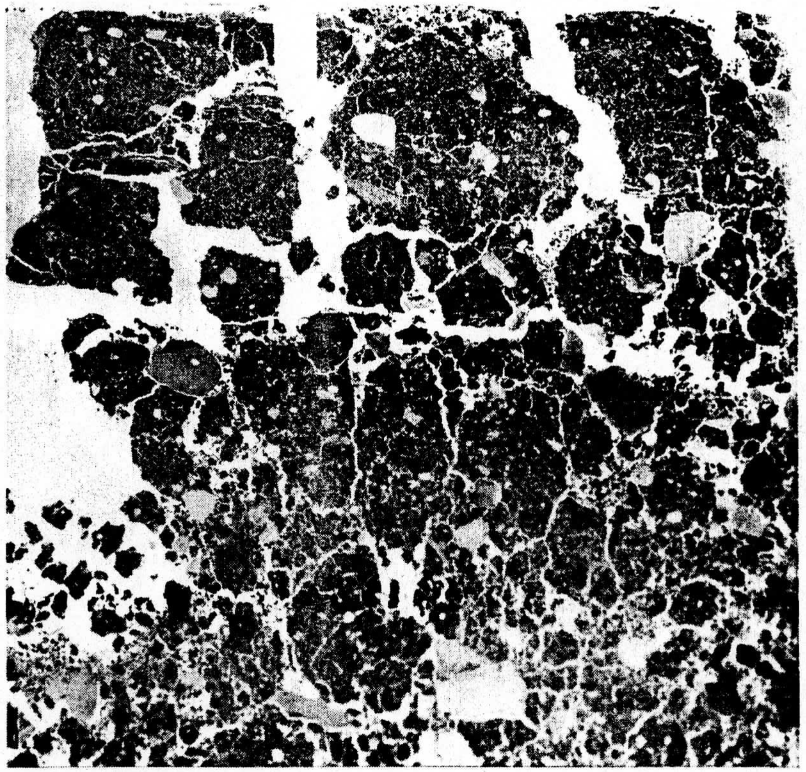

Figure 9.2. Butser Ancient Farm, Pimperne House floor; center, juxtaposed to hearth; uppermost 3 cm—massive, dry trampled crust containing various anthropogenic inclusions; lowermost 3 cm—prismatic structures of soil underlying the trampled crust, give way to subangular blocky and crumb structures, relic of the natural buried colluvial rendzina soil. Computer-enhanced image of 6.5 cm long thin section.

of an organic/phosphatic character and were associated with animal concentrations, (Nörnberg and Courty, 1985, plate 5). The present authors have also found them while counting urban soils in London and at rural sites in Northamptonshire and Bedfordshire (see Figs. 9.5 and 9.7). The long-term study of the important site of Raunds, Northamptonshire—where large numbers of these dark clay coatings are present in the counted microfabrics—permitted a detailed study of these features (Courty et al., 1994, photo 6; Windell et al., 1990). They were counted alongside coarse textural features such as micropans and impure clay coatings and infills in soils that featured one barrow burial of a hundred cattle skulls and another buried soil that contained dung beetles.

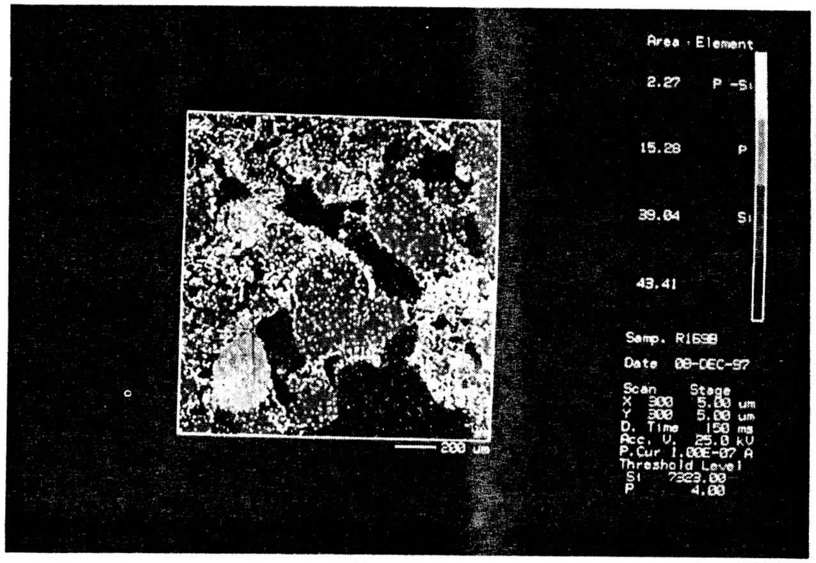

Figure 9.3. Raunds prehistoric barrow cemetery (example from West Cotton, Barrow 5, sample 9); Bronze Age barrow-buried subsoil; example of elemental mapping of dark clay coatings by microprobe; dark clay coatings, 50–100 microns thick, coat sand grains of diagonal void; elemental P averages 0.2%; such features are coincident with enhanced levels of organic phosphate and may be indicative of animal concentrations (see text). (Analysis by Kevin Reeves, University College London). Computer-enhanced image.

We tested the hypothesis of a link between these dark clay coatings and animal management at Raunds. First, total phosphate analyses of bulk soil samples revealed an association between these features and phosphate, a simple finding consistent with the literature on phosphate and animal activity (Proudfoot, 1976; Quine, 1995). Moreover, the dark clay coatings are most abundant in layers dominated by concentrations of organic matter and organic phosphate (P ratio 2.3–3.5; Engelmark and Linderholm, 1996; Macphail et al., in press). The dark reddish colors of the clay coatings already implied that they were humic in character. Finally, the concentration of phosphorus within the dark clay coatings themselves, rather than the soil matrix surrounding them, was confirmed by microprobe studies of numerous examples from two uncovered thin sections. Data from two examples are presented in Table 9.3, with Fig. 9.3 illustrating the mapped presence of P in Sample 9. We can therefore conclude that organic matter and organic P are apparently concentrated in these dark clay coatings.

Dark clay coatings in natural Bt horizons of Alfisols have long been known to contain organic matter and phosphorus, which are related to natural clay

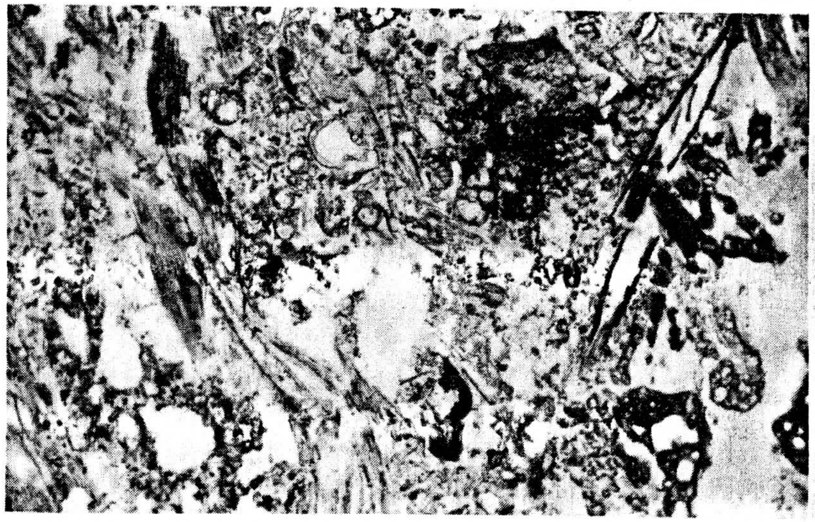

Figure 9.4. Potterne Early Iron Age "Deposit"; Sample 21b, reference fused amorphous material; "fused ash," composed of a colorless to dark gray non-birefringent cement, that is autofluorescent under ultraviolet light and has a siliceous and calcium phosphate character; inclusions include vesicular silica (from melted phytoliths) slag (left-hand corner), residual phytoliths (center), blackish (rubified under oblique incident light) burned soil and charred cereal awn fragments (right); plane polarized light (PPL), frame length is ~0.33 mm. (see Table 9.4).

translocation with fulvic acid under conifer woodland (e.g., Gray forest soils of Duchaufour, 1982:301; e.g., boreal paleosols of Fedoroff and Goldberg, 1982). Thus any link between dark clay coatings and animal management has to be argued carefully. At Raunds, humic topsoils of Spodosols and acidic Alfisols were present in prehistory, and liquid animal waste passing through these may have mobilized fulvic acid to produce these dark reddish brown clay coatings, which occur alongside other textural features indicative of animal trampling (M. A. Courty, CNRS, Paris, personal communication, 1992). Obviously, this hypothesis of a process active at the microscale is worthy of further testing. But, as fieldwork, bulk chemistry, and soil micromorphology studies have yielded comparable interpretations from nine barrows dating from the Neolithic to the Bronze Age, proxy soil landscapes and their land use can be reconstructed on the scale of kilometers for this part of the Nene river valley. As similar paleosols have been analyzed in the nearby Ouse valley, such findings have implications for regional proxy soil landscape and land-use reconstruction. Past soils of the chalk downlands of southern England have already been modeled in this way (Allen 1992; Evans, 1972; Whittle et al., 1993).

Figure 9.5. Colchester House, London: microlaminated dark reddish clay void coatings in brickearth subsoil beneath 3rd Century truncated. 1st–2nd Century Roman occupation: dark coatings are coincident with enhanced levels of organic phosphate; the authors have argued for a possible phase of animal activity on site predating 3rd century constructions (see text). PPL, frame length is ~1.3 mm. Computer-enhanced image.

3.1.2. Phosphatic Nodules

Three enigmatic materials with specific features under PPL, XPL, OIL, and UVL, were identified in thin sections of an occupation deposit at Potterne (Late Bronze Age/Early Iron Age, Wiltshire; Lawson, 1994). Individual fragments were made into thin sections, with residues being studied under microprobe, through bulk chemistry, and through macroplant remains and pollen analysis. These materials, termed for convenience as "pale nodules" (possible cess-pit nodules), "fused ash" (burned and fused cereal processing waste), and "burned and cemented soil" (often burned, possible stable soil floor deposit), were all autofluorescent under ultraviolet light and contained around 12%, 7%, and 1% P, respectively. Table 9.4 shows an example of how one of these components was defined and then interpreted to become an established microscopic indicator of the presence of domestic cereal processing waste at a site. This description and characterization is a crucial step before such counted components can be given any significance in site reconstruction.

Subsequent to this work, fused ash, cess-pit nodules, and dark clay coatings were found at a number of midden and occupation sites, their semi-quantified presence added to the collage of information available for the interpretation of sites with complicated site formation processes.

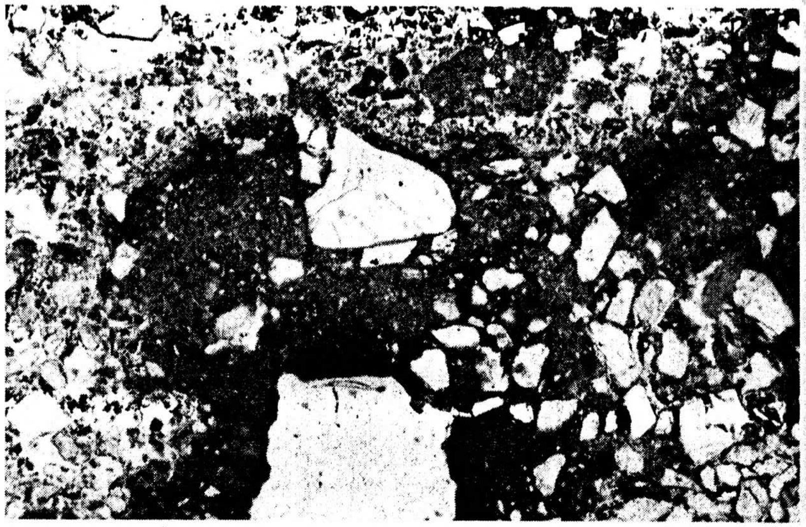

Figure 9.6. Haynes Park, Bedfordshire; Roman to Norman rural activity on a catena; "water hollow" location at base of slope, upper fill; humic sandy soils with very abundant phytoliths impregnated with probable poorly crystalline iron compounds, forming a nodule around a void that is coated by fibrous crystalline material (goethite or Fe/P compound), all indicative of dominant waterlogging; layer is coincident with enhanced amounts of inorganic phosphate; other micromorphological features and palynology indicate the presence of animals and inputs of dung (see text). PPL, frame length is ~3.4 mm. Computer-enhanced image.

4. Discussion

How successful has this fully integrated microstratigraphical approach been? We have already cited our study at Folly Lane where soil micromorphology and microprobe studies were combined with the identification and semi-quantitative analysis of diatoms in thin sections, as one example of a multi-disciplinary investigation of rural Romano–British soils (Macphail et al., 1998b). Such an approach allowed us to go further with our interpretations than would otherwise have been the case if only single or non-integrated techniques had been applied. A consensus understanding of what happens to soils when buried at the Overton Down Experimental Earthwork drew on palynological, microbiological, chemical, soil micromorphological, and archaeological excavation data, and again this led to confident extrapolations when discussing archaeologically buried soils such as at nearby Easton Down (Bell et al., 1996; Crowther et al., 1996; Cruise and Macphail in Whittle et al., 1993). Many other cases have yet to be published, but they can be briefly cited here. As examples, we summarize relevant findings from the Roman site of Colchester House, London, and the Roman to Norman site of Haynes Park, Bedfordshire. At Haynes Park we show how we have graphically

Figure 9.7. Haynes Park, Bedfordshire: Roman to Norman rural activity on a catena; colluvial Roman soil below lynchet; major soil micromorphological features are burrowing and mixing by soil fauna and abundant dark, microlaminated dusty void clay coatings (illustrated) and likely amorphous phosphate infills; layer is also coincident with 1,000 ppm P (2% citric acid extract)—a maxima in these slope soils; this layer is interpreted as an animal trampled soil, leading down to the waterhole. PPL, frame length is ~1.4 mm. Computer-enhanced image.

presented summarized soil micromorphological, chemical, and pollen data to illustrate and support our arguments as reported to the archaeologists working on the site.

A number of mechanisms were identified that accelerate weathering of Roman to medieval urban stratigraphy and the formation of a cumulative anthrosol termed "dark earth" (Macphail, 1994). One atypical urban land use is the stocking of animals, the trampling and rooting-up of soils that could homogenize earth-based (timber and clay) buildings. At Colchester House, London, the coincidence of organic phosphate in subsoils with counted dark clay coatings (Fig. 9.5) allowed the hypothesis that a phase of animal activity could have contributed to the reworking of clay and timber buildings believed to have been on the site before construction of a stone-founded structure in the third century A.D. (Macphail and Cruise, 1997b).

At Haynes Park, Bedfordshire, a catenary sequence contains wet hollows at the bottom of the slope (Macphail and Cruise, 1997a). Fieldwork, excavation, and macrofossil studies suggested that the Roman to Norman deposits were likely the result of dominant arable activity, as indicated by the presence of a Roman corn dryer, charred cereal grains, and substantial lynchet. Soil micromorphology was

Table 9.3. Mean Values of P in Dark Clay Coatings (Microprobe Line Analysis) and Background Bulk Chemistry at Raunds (see Fig. 14.3)

Sample	Context	% LOI	Total P ppm nitric acid	Po ppm citric acid	Ptot ppm citric acid after ignition at 550 °C	P ratio	Coating P ppm (probe)
11	buried soil upper	3.8	1410	n.d.	n.d.	n.d.	570 (17 points)
9	buried soil lower	3.3	n.d.	130	350	2.6	2380 (9 points)

linked to chemical studies of the dry soils, whereas in the wet hollows, pollen cores were first evaluated before sampling for thin sections and chemistry. Although cultivated soils were broadly identified, the preserved presence of dung fragments and anthropogenic inclusions such as chalk, ashes, and igneous rock (grindstone), along with the magnetic susceptibility and phosphate chemistry additionally implied that manuring had taken place. Furthermore, the palynological study indicated inputs of fresh manure in a landscape where animals grazed on herb-rich grasslands, acid heath, and wet valley bottoms. Microscopic crust and pan fragments alongside phytolith and diatom-rich microfabrics that featured amorphous organic inputs (dung) and concentrations vivianite and poorly crystallized iron phosphate (Fig. 9.6), further implied the on-site presence of animals (Fig. 9.8). Drier soils up slope also contained dark clay coatings (Fig. 9.7) and other features of trampling. When reconstructing the site's past land use and proxy vegetation history, it became clear from modern studies of the same soil type at nearby Woburn that a probable mixed farming regime had been practiced at Haynes Park to offset the susceptibility of the soils to erosion (Catt, 1992; Macphail and Cruise, 1997b).

It may be considered that the wetter the site, the better pollen may be preserved, but the less potential there is for soil micromorphology and chemical analysis, and few peat bogs have been studied using our preferred combined approach. Nevertheless, at Bargone, Liguria, Italy, the colluvial peat bog edge of mountain peat bog was studied in this way in 1994 (Cruise et al., 1996). The site had already been cored several times in its center and fully analyzed for pollen in the late 1980s. Here again, the palynological evaluation of the new cores from the trenched excavation of the bog edge guided the multidisciplinary investigation. Layers of interest within the cores were subsampled for chemistry and soil micromorphology, as well as being chosen for radiocarbon dating. Of particular relevance to this chapter is the discovery that changes in vegetation as recorded by palynological analysis are coincident, for example, with different chemistry and soil micromorphological indications of the peat bog drying out or animal trampling or colluviation. We also have archaeological and diatom data to add to the debate. Such a multidisciplinary approach is a great advance on traditional palynological investigations.

Table 9.4. "Fused Ash": An Example of Potterne's Components and Microfabrics

Material	Sample number examples	Soil micoromorphology (SM), bulk data (BD) SEM/EDXRA (XR), microprobe (probe) and elemental map (EM)	Interpretation and comments
Fushed ash	SM20, SM21b (2673/2227)	SM: (a) colorless to pale yellow to dark grayish brown with fine black dots (PPL), non-birefringent (XPL) (rarely crystallitic), very pale gray, with few fine red material (OIL), with extremely abundant (siliceous) plant fragments up to 800 μm and phytoliths in general, occasional plant pseudomorphs and occasional long charred fragments; common vesicular areas; occasional charred and amorphous organic matter; frequent quartz silt and very fine sand; contains pale yellow, cloudy (PPL), non-birefringent patches, except for fine blackened (XPL) and whitish grey (OIL) areas; all matrix is generally highly UVL autofluorescent; includes patches of silt and fine sand, whereas areas of plant remains contains only a few fine silt-size quartz. fine sand, whereas areas of plant remains contains only a few fine silt-size quartz. (Macroremains: awn fragments of *Triticum* sp.; Carruthers, personal communication) (Pollen preparation: microscopic fragments of uncharred organic matter, charcoal and unidentifiable nebulous "ghosted bodies"; Wiltshire, personal communication) (b) associated material is dark grayish with black specks (PPL), nonbirefrinent (XPL) and gray (OIL), with coarse and fine vesicles; material is non-UVL autofluorescent). XR and Probe: Si (10.5%), Al (0.73%), Fe (1.4%), Ca (14.8%), P (6.8), K (0.4%), Mg (0.15%) Ti (0.007%), S (0.19%), and Mn (0.007%)	(a) probable product of moderately low high-temperature burning (500–600°C) of cereal-rich Poaceae material, with loss of calcitic ash, partial melting of the phytoliths (high Si) in places and their (yellow) staining probably with phosphate (hence high Ca and P and UVL autofluorescent appearance—calcium phosphate); blackish dots are probably composed of carbon; (b) totally melted (above 650°C) silica (Poaceae phytoliths) to produce a vesicular glasslike material with staining by pure carbon; high temperature has probably driven off K found in lower temperature ashes (Courty, personal communication); Straker (personal communication) suggests such fused ashes probably formed under reducing conditions.

4.1. A Final Cautionary Tale

Working within a team can have its own complications. For example, while working on the 500,000 year old site of Boxgrove, West Sussex, UK, findings from the widest imaginable environmental team were debated openly (Roberts and Parfitt, 1999; Roberts et al., 1997; Stringer et al., 1998). Soil sediments with cold formation signatures were associated with cold faunas, and marls contained pond-living mollusks and alluvial deposits had amphibian and fish faunas. On the other hand, Unit 4c, which had all the micromorphological hallmarks of a sediment, was the focus of human activity and full of mammal bone remains and was considered to be a land surface. The described soil microfabric, including that from several thin sections through "chipping floors," initially led to an interpretation of Unit 4c as a sediment. It was only after repeated study that some small residual pedological features were identified, and this together with reference to analogues from drowned coastal sites in the UK and ripened polders in Holland allowed the overturning of the original strictly sedimentary hypothesis. Thus, Unit 4c could safely be identified as a bona fide ripened soil (Macphail, 1996). This was not a compromise interpretation to meet the other specialists halfway, but a soil micromorphological contribution from an equal. Counting of soil micromorphological features for its own sake will not yield interpretations, and at Boxgrove because of postburial transformation, less than 5% of the microfabric contained clues to Unit 4c's pedological history. There is therefore always the danger that the counting of "identifiable" features, components, and the like may become a mechanical substitute for accurate, thoughtful analysis of a thin section and its interpretation.

5. Conclusions

1. Soil micromorphology can produce extremely accurate semi-quantitative data that is most convincing to non-specialist soil micromorphologists when expressed graphically.
2. Experimental soils when characterized through counted soil micromorphology have specific signatures that are replicated in the archaeological record.
3. The specific analysis of individual microscopic components and pedofeatures that are counted can lead to the identification of features of archaeological significance.
4. The multidisciplinary approach has shown that specific microstratigraphies can have coincident and related chemical and fossil signatures that immensely aid the task of arriving at convincing interpretations of archaeological sites.

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