Processes of post-burial change in soils under archaeological monuments: a micromorphological study with particular reference to the processes of clay and iron redistribution.

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Abstract

The micromorphological examination of soils buried beneath archaeological sites has been an important source of information concerning past pedogenesis, environmental conditions and anthropogenic activity. An assumption inherent in these studies has been that burial preserves the character of the original soil fabric. However, over the past two decades, a wealth of evidence to the contrary has been emerging. This study aims to investigate the nature of changes in the soil micro-fabric that may result from burial; and in particular to examine the causes and implications of post-burial iron redistribution and clay translocation.

Soils were examined that had been buried beneath archaeological sites of different ages, in a number of study regions each with different parent materials. Within these sites profiles with contrasting depths of burial were studied. The micromorphological, and bulk physical and chemical characteristics of the buried soils and their overburdens were determined. Statistical analysis of the results confirms that after burial a wide range of physical, chemical, and biological processes operate resulting in the formation of secondary soil features and the alteration of the micro-fabric of all the buried soils studied.

The nature of the processes operating after burial is influenced by factors of parent material, site age and the depth to which the soil was buried. Two distinctive sets of processes were identified, firstly those related to near surface processes of pedogenesis that result in the biological, chemical and physical welding of relatively shallowly buried soils within the developing surface profile, and secondly those processes distinctive to the burial environment. The second suite of processes includes the redoximorphic redistribution of iron to form pans and nodules, and processes of clay translocation related to the internal slaking of overburden materials. These processes tend to operate in more deeply buried profiles. Soil texture appears to be important in determining the depth of burial required for isolation from surface processes. Time since burial controls the period of time over which processes operate and that pedofeatures have to adjust to the burial environment. Site age also appears to influence the constructional, climatic and parent material burial factors that initiate iron redistribution and clay translocation within buried soils and their overburdens.

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1. Introduction, and a review of the literature.

The research presented in this thesis is based upon the analysis of archaeological buried soils, principally through the application of thin section micromorphological techniques. This first chapter has been divided into two sections. Section 1.1 explains the nature of 'buried soils', core concepts in micromorphology, and its application to archaeology. Section 1.2, examines from a theoretical stance post-burial change in buried soils, reviews the evidence from the literature, and identifies the important processes involved.

1.1 Introducing the concepts of micromorphology and buried soils.

1.1.1 Buried soils.

The notion of a 'buried soil' is one that has profound implications for archaeologists, geomorphologists and geologists. The different ways in which these various disciplines view buried soils, however, necessitates that some consideration is first given to defining and exploring the concept of 'buried soils'.

1.1.1.1 The buried soil concept.

The concept of a buried soil is inherently a simple one – principally that it represents an old land surface upon which the processes of pedogenesis (soil development) have operated and that has subsequently been buried by the deposition of sediment. There are, however, many other processes and scenarios that compromise this simple definition. Related issues involve the definition of a 'soil' and a 'sediment', and the clarification of the possible events that may effect the buried soil after the initial burial event. Many terms are applied to these soils, and although each has a slightly different definition, they have often been used interchangeably.

Pedogenesis.

A soil represents the interface between the atmosphere and the lithosphere i.e. "that part of the earth that has been modified by its proximity to the atmosphere" (Catt, 1987, p.487). A whole range of processes may operate involving the physical, chemical and biological alteration of the surface to cause the development of the 'horizons' characteristic of a soil. The nature of the processes that operate depends upon the environmental factors that the soil is subjected too. These environmental factors were expressed by Jenny (1941) in his universal soil formation equation:

$S = f(cl, o, r, p, t....)$

Where, climate, organisms, relief and parent material, represent the environmental factors which operate over time forming the Soil.

These factors determine the dominant processes which in turn lead to the development of the characteristics (horizonation, deepening and upgrading, and the mixing of mineral and organic components) identified with a soil. More recently the directional, evolutionary nature of soil development suggested by Jenny's model has been adapted so that both progressive and regressive pathways of development are recognised (Johnson and Watson-Stegner, 1987)

$S = f(P, R)$ where P = progressive (horizonation, deepening and upbuilding)
R = regressive (haploidization, surface removal)

In this scenario a soil may be subjected to any number of different developmental pathways, as the processes of pedogenesis respond to environmental perturbations to the system. These pathways may be progressive or regressive and the signatures of many cycles may be retained within the fabric of such a 'polygenetic' soil. For a soil to form, the land surface has to be sufficiently stable so that the speed of soil development and deepening exceeds the effects of erosional or sedimentary processes. If the rate of soil development is exceeded by erosion, the soil will steadily be denuded and eventually removed altogether. If the rate of sedimentation exceeds the rate at which the deposits can be incorporated into the soil profile, then the soil will become buried and pedogenesis will cease (Johnson, 1985). A soil, therefore, can be seen as a substrate at the land surface which has been subjected to the modifying processes of pedogenesis and which exhibits some degree of horizonation. The development of any single soil unit is controlled by its environment and may involve many different phases, the legacy of each phase may be preserved, or partially preserved within the contemporary soil fabric.

Sediments.

The sediments that sometimes bury these soils are differentiated from the latter by the fact that they are clastic, i.e. have been transported and deposited, whereas soils are formed *in-situ*, although often upon sediments themselves. The burying sediment may be an aeolian, alluvial or colluvial deposit, or an anthropogenic deposit including archaeological sediments and constructions. The nature of the sediment and the manner in which it has been laid down varies markedly. Sediments may be organic or mineral in nature, they may be deposited gradually over time, or a single event may deeply bury a soil in a very short space of time. These burial factors have profound implications for the survival of the buried soils, and will be discussed in more detail in section 1.2.2. After deposition, and if stable conditions prevail at the surface, the sediment may then be subject to pedogenesis and a new soil profile may form.

Buried soils and palaeosols.

Buried soils are regularly found within geological columns where they may be termed either buried soils or palaeosols (Kemp, 1987). The term palaeosol has also been applied to archaeological buried soils (Macphail, 1986; Simpson and Davidson, 1997), but is a non-specific term that can be applied to both buried and non-buried soils. The definition of a palaeosol given by Ruhe (1956) is a 'fossil' soil formed during the geologic past. Palaeosols include not only *buried* soils, but also *exhumed* soils (buried soils re-exposed through erosion) and *relict* soils developed upon stable land surfaces in response to changing environmental conditions (polygenetic soils which cover geological time scales). For example, a soil that is buried and then re-exposed by erosion (*exhumed soil)*, or a *relict soil* upon a stable land surface that is neither eroded or buried by environmental change, are both included in the palaeosol definition. There is an implied age limit to this definition of a palaeosol which, has been suggested as logically falling at 10,000 years BP (Catt, 1987). This recommendation is still often ignored however, (Bronger and Catt, 1998) and this may lead to problems in the definition of very recently buried soils relative to their modern unburied counterparts in the landscape (Bos and Sevink, 1975). Here the term 'buried soil' has been taken to include soils formed and buried within the last 10,000 years; all the profiles studied in this thesis fall into this category. In later discussions, however, comparisons with geological buried soils are made and for reasons of clarity these have been termed 'buried palaeosols'.

1.1.1.2 The importance of buried soils.

The importance of buried soils centres upon the evidence of the soils developmental history that is preserved within the soil at both the macro- and the microscopic level. As the soil develops, pedogenic processes modify the fabric of the soil in characteristic ways. The soil may evolve through a number of developmental episodes, each of which has been driven by changing environmental factors such as climate, vegetation and the activities of humans (polygenetic soil). Any alteration of the soil fabric by one developmental episode may partially obscure or destroy the evidence of previous episodes. In this way, the evidence of the earliest phases of pedogenesis may be gradually degraded as the soil adjusts to its changing environment. The severity of this degradation of information will depend upon the nature of the original soil characteristics and the activity of later processes. The soil fabric may contain a number of environmental signals that include resistant relict features of past processes superimposed over which, are the features associated with the modern environmental conditions and their processes. Changes in any one of a number of environmental factors including climate, vegetation or anthropogenic activity can disturb the soil equilibrium and alter the pathway of its development. In this way the buried soil provides evidence of the pedological processes that have led to its formation and in turn provides valuable information about the prevailing environmental conditions that drove these processes. Buried soils have, therefore, been important sources of information for pedologists, palaeoenvironmentalists and palaeoecologists; aiding in the reconstruction of past environments (e.g. Federoff *et al.*, 1990; McCarthy *et al.*, 1998) and providing valuable data upon the development processes of soils (e.g. Conry *et al.*, 1996). Upon geological time scales these soils have been used to elucidate major climatic swings (Catt, 1991). They have even been used to examine the evolution of terrestrial life and to study changes in atmospheric composition (Palmer *et al.*, 1989). The requirement for a stable surface for soil development means that buried soils have been used to study depositional histories and to act as stratigraphic markers within geological and sedimentary profiles. One of the greatest environmental disturbances of the late Holocene has been the influence of humans both directly and indirectly upon the soil. The effects of humans may be preserved within soils buried beneath natural and anthropogenic deposits and these anthropogenically modified buried soils are, therefore, potentially of interest to archaeologists.

1.1.1.3 Archaeological buried soils.

Buried soils are well known to archaeologists and have been a focus of interest for some time. Soils may have been preserved beneath a range of sediments both natural and anthropogenic. Soils buried beneath alluvium are common, but soils within aeolian and colluvial deposits, peat and even volcanic sediments have been identified. Anthropogenic burying deposits include midden and cultivation deposits together with more deliberate constructions such as burial mounds, field banks and cultivation terraces. The investigation of buried soils, often called 'turf lines', as part of archaeological investigation has a long history. At the macromorphological scale, ard marks and rigs preserved in buried soils offer conspicuous evidence of anthropogenic activity (e.g. Barclay, 1989). The bulk chemistry of these buried soils has also been examined as another source of evidence (e.g. Dormaar and Lutwick, 1983; Mattingly and Williams, 1962).

1.1.2 The historical development of micromorphology.

The microscopic examination of geological samples has a long history, but the application of the technique to unconsolidated sediments and soils is a far more recent development. The publication by the Austrian scientist Kubiena of his manual 'Micropedology' (Kubiena, 1938) is widely regarded as the beginning of the micromorphological approach to the investigation of soil fabric. By taking undisturbed blocks of soil from exposed soil faces using 'Kubiena tins', setting these blocks in resin and carefully preparing 30µm thick thin sections for microscopic examination, it is possible to examine soil components *in-situ*. The great advantage of micromorphology over other soil analytical techniques is the undisturbed nature of the samples. This allows detailed examination of the soil constituents and more importantly the elucidation of their relationships both in space and time. These microscopic features are invaluable in understanding the nature of pedological and sedimentological processes, and for determining the chronology of events through the relative spatial hierarchy of the soil's micro-features. Micromorphology, therefore, introduces the concept of a soil as "an ordered system with a construction of its own, particular dynamics (of physical and chemical processes) and a particular biology (of all soil organisms and their activity)" (Kubiena, 1970, pp.3-4).

Since the initial work of Kubiena the fundamental practise of soil micromorphology has changed little, however the approach taken to the analysis and interpretation of the thin sections has seen many developments. Kubiena (1938) set out a morphoanalytical approach devoted to the description and illustration of the soil fabric, but as the applications of soil micromorphology grew, a new approach was needed. The new direction taken by Kubiena (1953) in 'The soils of Europe' applied a morphogenetic approach designed to help classify soil types genetically. For the first time, the descriptive terminology also offered implied, generic interpretations of the soil fabric features. The rapid adoption of soil micromorphology as an analytical tool by a large number of different and varied disciplines led to the development of many descriptive systems, each tailored to their particular applications. Comparability between these disciplines demanded a single, universally applicable, morphoanalytical system. This would concentrate purely upon the description of the soil features whilst allowing scope for subsequent independent and individual interpretation of features, no matter what the application. The first attempt at such a system was made by Brewer (1964), and later the 'Handbook for soil thin section description' was prepared on behalf of the I.S.S.S (International Society of Soil Science) (Bullock *et al.*, 1985). This handbook is now almost universally accepted although disagreements over generic interpretations of soil fabric features still arise. A study by Murphy *et al.*, (1985) has found that a high degree of concurrence exists in the basic descriptions between researchers using the handbook. More recently, Stoops (1998) produced a simple key as an aid to the handbook, this key aims to rationalise some of the terminology used and to provide simple, practical distinctions between the various classifications.

As well as the traditional use of micromorphology in determining soil genetic classification, the potential applications for such information are great. In soil science the investigation of evolutionary pathways of soil formation, including the weathering of primary minerals (e.g. Nater and Boubaid, 1990; Read, 1998) and the elucidation of specific pedological processes (e.g. Aurousseau, 1983; Farmer *et al.*, 1985), are key areas of research. In geomorphology the relationships between erosional and stable periods of landscape development have been analysed (Macphail, 1992; Mucher and Van Vliet-Lanoe, 1997). Whilst the soils associated with periglacial (Van Vliet-Lanoe *et al.*, 1985) and arid environments (Stoops and Poch, 1994) have also been examined in detail. Soil micromorphology has been used in agricultural research to study the effects of tillage practices, crop species, and remedial measures upon soil structure and fertility (e.g. Fortun *et al.*, 1989; Mackie-Dawson *et al.*, 1989a; Mackie-Dawson *et al.*, 1989b). Land management studies can also make use of micromorphological techniques. By providing information on soil fertility and the soil's likely response to tillage, areas of prime agricultural land can be identified. Details of the soil's physical response to compression is needed in civil engineering, whilst a knowledge of soil drainage properties is important to developers, farmers and conservationists alike.

The time scales over which micromorphology has been applied have likewise been diverse. Agriculture is concerned with changes in soil structure that may occur over a matter of days following tillage. Archaeologists on the other hand are concerned with soils and sediments that may date from a few thousand years, although in some cases the anthropogenic influence upon these soils may only cover tens to a few hundreds of years. Quaternary scientists frequently look at the micromorphology of palaeosols to interpret the events of the past 2.5 million years (Valentine and Dalrymple, 1976; Kemp, 1985; Catt, 1991). Geologists have investigated fossil soils covering millions of years (e.g. Buurman, 1980).

The main crux of micromorphological interpretation involves the comparative description and analysis of samples within and between different soil units (horizons and pedons). These analyses are based upon the nature and organisation of the soil's microfabric, and interpretation relies upon the collected body of experience and comparison with reference slides. The experience of the researcher and their access to relevant literature and collections of reference samples from known, contexts are, therefore, very important. A study of comparability between researchers found that it was during interpretation that significant differences crept in, these differences being based largely upon the frame of experience of the individual researcher (Murphy *et al.*, 1985). Much emphasis has, therefore, been placed upon the use of micromorphology in conjunction with other micro, and bulk analytical techniques, to bring as much objectivity as possible to the discipline (Brewer, 1972a; 1972b; Carter and Davidson, 1998; Macphail, 1998).

In Britain the first application of soil micromorphology to archaeology was made by Cornwall (1953) to soils buried beneath Bronze Age monuments in England. Cornwall continued to look at archaeologically buried soils, but throughout the 1970s very little attention was given to the discipline as an archaeological tool. Valentine, Dimbleby, Dalrymple and Romans were amongst the few active researchers to keep the discipline alive in Britain at this time. In these early years much of the focus was upon archaeologically buried soils in terms of their pedological or environmental development rather than their anthropogenic history. The 1980s, however, marked a turning point in the archaeological study of buried soils as micromorphology was used to illustrate the impact of humans directly upon the soil became the focus of research (e.g., Courty *et al.*, 1989; Davidson *et al.*, 1992; Gebhardt, 1995; Macphail *et al.*, 1990b).

1.1.3 The role of micromorphology in archaeology.

Micromorphology has become a familiar method of analysis in archaeology. Due to the very generalist standard scheme of description, micromorphology has been successfully applied to a whole range of archaeological materials and helped to provide answers to a few of the perennial archaeological questions when applied thoughtfully and appropriately.

Micromorphological analysis has been applied to the remains of pottery and mortar, but in this thesis the principal concern is its application to soils and sediments. Such substrates, under microscopic examination, reveal clues not only about their sedimentological and pedogenic history, but may also include evidence about the nature of ancient occupation, site activity, and agriculture.

The identification of space use in occupational deposits is a question that has been considered in well preserved Near Eastern 'tell' sites (Matthews, 1995; Matthews and Payne, 1994; Matthews *et al.*, 1997). Exaltus and Miedema (1994) have addressed similar questions on Dutch Neolithic sites. A study carried out upon recently abandoned Scottish sites looking at activity areas including hearths and byres identified microscopic soil features associated with known settlement contexts, supported by ethnographic material (Davidson *et al.*, 1992; Quine, 1995).

Soil pollen, ash, phytoliths, diatoms and molluscs may all be seen in thin section and alongside the pedological features have implications for both environmental landscape scale reconstruction and localised anthropogenic impacts. Anthropogenic sediment origin, the sourcing of constructional materials and the elucidation of monument construction techniques are also archaeological questions for which soil micromorphology is ideally suited. For example, the origin of Roman - Saxon 'dark earths' has been successfully investigated using micromorphology (Macphail, 1983a). Canti (1994) showed a deposit previously assumed to be soil material to actually consist of dumped weathered rock, and Macphail *et al.* (1998) were able to source turves and sediments infilling a 1st century AD funerary shaft.

Finally, soil micromorphology has been used extensively in Europe for the identification of prehistoric agricultural activity. Just as modern agriculture affects modern soil structure and composition, ancient tillage has been assumed to have had similar effects upon ancient soil. Evidence for this assumption comes from experimental work (Gebhardt, 1992; 1995) as well as from the micromorphological examination of soils buried beneath prehistoric sites. However, the absence of structural indicators of agriculture in thin section must be treated with caution as Davidson and Carter (1998) found no such evidence in their study of recently abandoned traditionally cultivated soils on Papa Stour, Shetland. The survival of the evidence within soils over time therefore is by no means guaranteed and may be site, feature, and context specific.

1.1.3.1 The interpretation of the evidence.

Besides determining the anthropogenic history of a site, archaeologists are also interested in the environmental context that this activity has to be placed within. Traditionally, investigations of buried soils through micromorphology and bulk analytical techniques have concentrated upon the pedological and palaeoenvironmental history. More recently, aspects of cultivation practice and site activity have been focused on. Micromorphologists investigating archaeological soils and sediments have had to exploit the experience of many different disciplines in their interpretation of micromorphological soil features. Pedology and agriculture with their long established history of micromorphological research have formed a valuable basis for archaeological research. However, there are issues of applicability when applying research from modern processes of soil development and agricultural practises directly to features observed within ancient soils. Over such time scales can assumptions of uniformitarianism be justified? The application of agricultural experience is particularly problematical as the tools and practices of cultivation are known to have changed greatly since the Neolithic. Will, for example, an ard or digging stick produce the same physical features in the soil as modern cultivation techniques are known to do.

In response to these criticisms, experimental studies by Gebhardt (1992; 1995) have attempted to answer the question of specifically how primitive tools affect the soils microstructure and micro-fabric; and these features have then been identified in archaeological contexts. This approach has undeniably furthered research into ancient cultivation, however there are still accusations of circularity of argument to be addressed. From archaeological finds and environmental evidence, the prehistoric tools used and the crops grown can be confidently identified, but the exact nature of agricultural practice is not so easily investigated. In the face of environmental change can the timing of tillage and sowing, and the nature of manuring, irrigation, weeding and harvesting be understood and recreated accurately?

A further development has been the use of ethnographic material and soils to identify characteristic signatures in the soil microfabric that have been subjected to known traditional cultivation practices (Davidson and Carter, 1998). The regions where traditional practices have continued through to recent times, and are documented or remain within living memory, tend to be marginal areas largely unaffected by the modern agricultural revolution. Are these mainly Atlantic areas good analogues for archaeological buried soils in southern England? In itself, as with the other strands of evidence, this ethnographic work cannot be applied across the board. More recently the universal formation and survival of agricultural indicators has been questioned (Davidson and Carter, 1998; Usai, 1999). In conjunction with modern and experimental research experiences, however, the interpretation of features within archaeological buried soils is rapidly developing, with increasing thought being given to the validity of the assumptions being made.

1.1.3.2 Archaeological soils - the nature of the evidence.

The actions of humans can act to shift the pedological processes acting upon a soil in such a way as to maintain a dynamic equilibrium with the anthropogenic environment. The effects of humans upon the archaeological record, as determined by ethnographic studies and experimental work, can be grouped as clearance and pre-construction site preparation, cultivation and the addition of materials through manuring, occupational functional site areas, and pasturing. The effect of these disturbances upon the soil fabric is explored in table 1.1. The range of features sought is very great indeed and for each disturbance process investigated, the features formed are by no means exclusive. Many different processes may act in similar ways to produce almost identical features, for example dusty clay coatings are thought to be formed through both clearance and tillage activities. The interpretation of these features, therefore, rests upon the identification of a 'suite' of characteristic features, not all of them micromorphological.

Clearance and site preparation (for cultivation or site construction)

Clearance is amongst the most frequently identified anthropogenic disturbance process. If the soil is buried beneath a 'deliberate' archaeological construction, then clearance activity of some sort will almost certainly have been undertaken if only to prepare the land for this building. Soils beneath natural deposits may on the other hand have been 'undisturbed' forest or scrub. At the field level of description, asymmetric tree hollows may result from natural tree throw or from deliberate clearance. These hollows may, if human agency was involved, have rapidly infilled leading to a heterogeneous microfabric with less biological reworking, and including charcoal fragments, phytoliths, burnt red soil and dusty clay coatings (Romans and Robertson, 1975). The effects of clearance of different vegetation types upon the soil were considered by Macphail *et al.*, (1990b), table 1.2. Other site preparation activities may include the truncation of the pre-monument soil profile, sometimes down to a chalk bedrock or bleached Ea horizon (Cornwall, 1953), with the removed turves often being employed within the bank or mound itself.

Cultivation effects

This has been one of the most thoroughly researched areas and this review is only a brief summary of the evidence. Tillage turns the soil, encouraging the homogenisation of the upper soil layers and the loss of surface horizonation. This proisotropic, pedoturbation (Johnson *et al.*, 1987) acts to form a highly disturbed and essentially homogeneous ploughed A horizon (Ap). Jongerius (1970; 1983), looking at modern

Table 1.1: Summary of the effects of anthropogenic disturbances within the soil.

Disturbance activity	Soil characteristics
Clearance	Asymmetric tree hollows with heterogeneous microfabric. Coarse charcoal fragments. Phytoliths Burnt reddened soil. Dusty clay coatings and silt cappings. Profile truncation.
Cultivation	Homogeneous, highly disturbed Ap horizon. Agricutans, dusty void coatings. Reduced organic matter unless manured. Increased surface erosion. Planar voids from implement impact. Decrease in abundance of soil fauna, unless manured. Reduced aggregate size and sorting in Ap horizon – plough pan. Surface crusting. Plough soil washed down cracks in profile – plough pan. Acidification and decalcification of the soil, but with homogenisation of upper layers. Weakening and degradation of soil aggregates
Abandonment	Loss of vughy structure – massive. Intensive reworking by earthworms. Podzolisation / peat initiation.
Manuring	Increased organic matter and charcoal, physically degraded and possibly charred. Quantities of bone, phytoliths, pottery etc. Increased depth of topsoil (plaggen). Increased biological activity relative to non-manured. Improved structure and aggregate stability relative to non-manured. Sterol signatures and increased phosphate levels.
Pasturing	Deep, stable, crumb structure Mull horizon Surface puddling– elongated and platy pores within a dense fabric Fungal rings becoming increasingly birefringent with age and increased numbers of fungal spores. Increased numbers of grass phytoliths. Sterol signatures and increased levels of phosphate.

Disturbance activity	Soil characteristics
Byres	Laminated plant fragments. Phytoliths and moss sporangia. Highly mixed and reworked upper soil horizon. Phosphatic staining and Ca iron phosphates.
Hearths	Highly Heterogeneous and laminated. Relatively high pore space. High carbon content, with charcoal. Reddening of burnt soil. Low organic content and charred organics.
Trampling	Dense compacted fabric with porphyric related distribution Reworked and homogenised upper horizon
Sweeping	Small finely comminuted and sub-rounded components with moderate poor Orientation Enaulic or gefuric related distribution Complex packing void microstructure

Table compiled from existing literature: see text for references.

Table 1.2: Clearance effects within the soil.

Large trees and scrub: Possibility of subsoil hollows with asymmetric infill; moderately deep (20-40cm) to deep (40-100cm); soil mixing – juxtaposed topsoil and subsoil fragments, with fissures infilled by dusty clay; clay coatings, if present in subsoil (Bt horizon) fragments, are often unorientated to present soil surface; coarse wood charcoal often present; possibility of burned red soil with strongly enhanced magnetic susceptibility.
Low shrubs: Shallow (0-20cm) soil mixing; coarse voids infilled with dusty clay or surface soil material; fine charcoal often present; possibility of many phytoliths.

Source: Macphail *et al.*, (1990b, p. 55) agricultural soils recognised surface slaking and the formation of a surface crust.

This may lead to compaction in the upper Ap horizon and causes stratified deposition of soil material in depressions, such as cultivation furrows, and maybe associated with some illuviation (down profile movement) of fine material over short distances. Surface crust formation together with internal slaking of the soil when left exposed to raindrop impact can lead to the break down of the soil's structural units (peds). This releases fine particulates and allows the down profile illuviation of fine silts and clays and their subsequent deposition as void coatings (agricutans) similar in nature to those formed through clearance activities. In lighter textured soils, these coatings tend to be layered. In heavier soils, coatings are formed of relatively homogeneous dusty and impure clays often darkened by organic matter. This is accompanied by a general weakening of soil aggregates and the degradation of the soil structure (Fisher, 1982; Macphail *et al.*, 1990b).

Other physical effects upon the soil may include the washing of pieces of plough soil down cracks in the profile and the formation of ard marks and cultivation ridges (e.g. Barclay, 1989). The physical action of tillage may lead to an overall reduction of aggregate size and a decrease in void space, sometimes producing a massive soil structure. The soil may be sorted with the smallest aggregates at the base of the Ap horizon possibly compact enough to form a plough pan of weakly compacted silt and clay. The larger aggregates and coarser voids occur towards the top of the profile. Experimental evidence has also suggested that the fracture of soil structures under cultivation impact varies according to the nature of the cultivation implement used (Gebhardt, 1992; Gebhardt, 1995; Macphail *et al.*, 1990b). These structural changes to the soil have been shown by studies of modern agriculture to be highly seasonal. The small, fractured soil aggregates largely disappear within the first month following tillage (Mackie-Dawson *et al.*, 1989a; Mackie-Dawson *et al.*, 1989b; Carter *et al.*, 1994; Hall, 1994).

There appears to be a decrease in the abundance of micro- and meso-fauna with cultivation that is only partly remediated by the addition of manures (Gebhardt, 1992). During cultivation, the soil surface may be left exposed for much of the year leading to the possibility of increased surface erosion. This may result in the truncation of the eroding profile and the build up of colluvium in depressions down slope and against banks (Macphail, 1992). If no manure is added to the soil, there may be a reduction in the soil organic matter content, whilst exposure of the soil may lead to increased leaching of bases and an overall acidification and decalcification of the soil.

Both clearance and agricultural disturbance of the soil can result in the formation of dusty or silty void coatings as the soil structure is broken and the soil surface is exposed. These features tend to be poorly sorted and may contain organic matter, fine charcoal and phytoliths compared to the limpid, strongly oriented clay coatings that may have formed naturally under woodland during the Atlantic Holocene phase (Fisher, 1982; Macphail, 1986). The construction of a burial mound or earth bank similarly exposes the soil materials at the surface of the monument to rain splash erosion. This being so, a question that will be considered more fully in section 1.2 is whether illuvial clay void coatings may form post-burial in response to constructional disturbance. If this is so, the discrimination of pre-burial anthropogenic activity may be more complicated than previously considered, and the interpretation of human disturbance within buried soils becomes more complicated.

Manuring

The practice of manuring cultivated soils may produce a further suite of soil features. The increased organic matter content of the manured soil may not be preserved archaeologically unless it is waterlogged, (Davidson and Simpson, 1984; Davidson and Smout, 1996). However, increased phosphate levels (Craddock *et al.*, 1985; Dockrill and Simpson, 1994), amino-acids (Simpson *et al.*, 1997) and lipid signatures (Evershed *et al.*, 1997) in the soil may remain archaeologically visible. These will often be accompanied by artefactual remains in the soil such as pot, bone, flints, burnt stone and increased levels of charcoal all derived from middening.

In some areas there has been a noticeable increase in the depth of topsoil associated with the use of turves to increase soil fertility or plaggening (Davidson and Simpson, 1984). The increased organic matter content of the soil may also help to prevent the degradation of cultivated soil, and the formation of characteristic soil structures.

There may also be an increase in the levels of biological activity relative to non-manured cultivated soils (Gebhardt, 1992).

Abandonment of cultivated land

Following the abandonment of cultivated land, a particular set of soil features has been identified in some circumstances and has been termed destipedocompaction (Macphail, 1983b). This may involve changes to the soil's void structure and reworking of the soil by earthworms.

Functional site areas

These essentially are areas associated with particular human activities, and include hearths, floor layers, threshing areas and streets. These areas fall largely outside of the scope of this thesis, but discussion of their imprint within the soil micromorphology can be found in Courty *et al.* (1989), Davidson *et al.* (1992), Matthews (1995), Matthews and Payne (1994) and Quine (1995).

Pasturing and livestock

The identification of livestock in the archaeological record is also of importance and work has been undertaken, both experimentally and ethnographically, to characterise the evidence. Byres allow the best chance of recognising livestock within the soil record, as it is in this stalled environment that animals will be concentrated. Evidence may include laminated plant fragments, phytoliths, moss sporangia, and a dominance of arthropods among the soil fauna. Allen *et al.* (1995, cf. Matthews, 1995; Matthews and Payne, 1994) noted the presence of phosphatised dung and straw producing a soil strongly strained with black, phosphatic material in drainage cracks, together with a highly reworked and mixed soil fabric.

Land under grass that has been used for grazing may exhibit intense fine rooting, be biologically active and have a deep stable crumb structured, mull A horizon.

Phosphate levels may be increased, whilst in areas where animals concentrate, puddling of the soil surface may form platy structures near the soil surface (Gebhardt, 1995). An association has also been noted between grazing and fungal rings, the fungal spores becoming increasingly birefringent with age (Romans and Robertson, 1975). Many of these features, however, may also be found in any grassland soil and firm evidence of livestock presence may be difficult to find because of the relatively low animal concentrations involved. Elsewhere a pig pasture in an open forested enclosure, has been described as essentially the same as a forest soil (Macphail, 1990c).

In conclusion, however, it must be said that all these anthropogenic soils will also have been subjected to the natural disturbance factors that determine soil development in the absence of human intervention. The action of humans largely acts to modify the extent and perhaps the direction of many of these natural processes. The importance of understanding this principle is that all soils that have been anthropogenically disturbed will have also been affected by past and present environmental conditions. Any attempt to understand anthropogenic activity from the soil micro and macro morphology must first address the questions of soil development and environmental history. Neither must the absence of any or all of these features be necessarily interpreted as an absence of the activity as in many cases ethnographic, experimental and archaeological materials of known context have failed to provide these features. This may be due to post-burial processes destroying the evidence or it may be that these features do not form universally in all soils.

1.1.3.3 The integration of micromorphology in archaeology.

Micromorphology, whilst an undeniably useful analytical tool, can be criticised because of the element of subjectivity involved in the interpretation of thin sections. The integration of micromorphology within a holistic sampling scheme is, therefore, very important. The results of several analyses carried out upon the same material will not only maximise the information that is retrieved, but will usually also help to guide and support the interpretation. Traditional soil analytical techniques with direct relevance for archaeologists including soil phosphate and magnetic susceptibility have been successfully used alongside micromorphology (Allen and Macphail, 1987; Dockrill and Simpson, 1994; Macphail *et al.*, 1998). More recently the analysis of lipids and amino-acids as biomarkers for manuring and cultivation practices (Evershed *et al.*, 1997; Simpson *et al.*, 1997) have been successfully applied alongside traditional micromorphology. Further analysis at the microscopic and sub-microscopic level may also be used. Notably archaeologists are beginning to see the benefits of the application of image analysis techniques (Bryant and Davidson, 1996) and of SEM and EDXRA techniques (Fechner and Kleiner, 1998; Macphail *et al.*, 1998).

1.1.3.4 Useful Summaries.

The most comprehensive volume dealing with micromorphology in archaeology is that of Courty *et al.* (1989) as has already been mentioned. Further summaries that are of use include Cornwall (1958), Goldberg (1983), Fisher and Macphail (1985), Davidson *et al.* (1992), Macphail *et al.* (1990a; 1990b), Exaltus and Miedema (1994), Macphail and Goldberg (1995) and Matthews (1995). More general, but still useful micromorphology texts include Brewer (1972a; 1972b), Bullock *et al.* (1985) and Fitzpatrick (1984; 1993) whilst, texts looking at soils and archaeology in general include Bridges (1978), Limbrey, (1975) and Macphail (1987). The discussion between Carter and Davidson (1998) and Macphail (1998) also provides a good summary of the present day position of micromorphology within archaeology and of the problems that it faces.

1.1.3.5 The present position of micromorphology in archaeology.

Today micromorphology has become a generally accepted practise in archaeology. This acceptance has come about largely as the profile of micromorphology as an analytical tool has risen within the archaeological world, and as its possibilities have been expanded. Micromorphology is often associated with research work as opposed to being widely used in standard archaeological analysis, possibly because the many archaeological applications of this technique are still under development. The work of

English Heritage goes someway towards remedying this, although the sites examined still tend to be heavily concentrated within southern England.

The main research areas continue to include experimental and ethnographic characterisation of features associated with cultivation practices and other site activities, and have increasingly tended to integrate micromorphology with chemical, biochemical and microbiological analytical techniques. The detailed characterisation and interpretation of specific calcitic features associated with dung (spherulites) has been recently carried out by Canti (1997; 1998). Another research area being given attention is the taphonomy of archaeological sediments and buried soils. This interest has lead to greater significance being given to the identification and quantification of post-burial alterations in the microfabrics of archaeological soils (Simpson, 1996a). Experimental work has also been undertaken to better understand this phenomenon (Crowther *et al.*, 1996; Breunig-Madsen and Holst, 1996; Breunig-Madsen and Holst, 1998).

1.2 A theoretical and literary review of the processes of post-burial change in buried soils.

1.2.1 A definition of post-burial change.

Processes of post-burial change are of interest to all those research disciplines that study soils or sediments that have been subjected to burial. Burial is usually considered to be an act of preservation, isolating the buried soil from the surface conditions, halting pedogenesis, and hence preserving the soil in the state that it was first buried. The process of burial, however, is also a destructive one and has been recognised as acting as a double-edged sword. The very act of burial will create a whole new suite of localised chemical, physical and biological conditions that characterise this new 'burial' environment (Simpson, 1996a). As a developing soil will respond to dynamic environmental changes to its pedogenic environment, then so too will a buried soil adapt to the changing conditions within the burial environment. In this way the act of burial will automatically lead to changes within the fabric of the soil, possibly to the detriment of the survival of the pre-burial features formed in equilibrium with the surface conditions during its pedogenic evolution. Burial, therefore, acts as another taphonomic filter upon the features that characterise the prevailing processes and conditions of pedological development. In defining post-burial change therefore, it must include all those process and their effects within the fabric of the buried soil occurring after the initial act of burial. The term 'taphonomy', which is used frequently in archaeology, has been rejected in this thesis because of the recovery and processing filters also assumed by this term, but which fall outside of the scope of this project. Likewise diagenesis, the term favoured by Quaternary scientists and geologists to describe processes affecting sediments after their deposition, has not been applied here. This is to avoid possible confusion in the application to buried soils of a phrase originally intended for sediments as processes of pedogenesis could also fall within the broadest definition of diagenesis (Pipujol and Buurman, 1997).

1.2.2 Burial processes and their influence, with reference to archaeological buried soils.

1.2.2.1 The nature of burial.

As suggested in Section 1.1.1, the processes involved in burial are varied. Natural processes may include the deposition of aeolian, alluvial, or colluvial sediments. Humans may create buried soils either through the construction of earth and stone buildings, banks, mounds, middens and earthworks, or through the promotion of natural processes. For example, agriculture may encourage down slope colluviation, the sediments accumulating up slope of a field bank or wall bury the lower portion of the field. As the processes of burial are varied, so too is the nature of the burying materials. The textural characteristics of the burying sediment will often be determined by the method of, and energy involved in transport and deposition. Sediment particle size varies from fine clays to coarse gravels and will affect how well the buried soil is isolated from the surface environment. If sediments have been carried over long distances, their mineralogy and chemical status may differ from the soil they are burying with subsequent effects upon the burial environment. The nature of anthropogenic sediments depends heavily upon the source of the material.

1.2.2.2 The depth and rate of burial

The depth to which a soil is buried is a crucial factor in the preservation of the buried soil. Depth will determine the isolation of the buried soil from the surface and in this way affect conditions within the burial environment. Whether buried by natural or anthropogenic, mineral, or organic deposits; the depths that these sediments achieve fluctuate widely from only a few centimetres to hundreds of metres with individual circumstances. If a soil is not buried to an adequate depth, it will not be isolated from the surface where, if conditions are stable enough, processes of pedogenesis will continue. In this situation the buried soil is affected by ongoing pedogenesis and will be incorporated into the developing soil profile. Such a buried soil may still retain some features consistent with its history at the surface. The process whereby a buried soil is affected by surface pedogenic processes is known as 'welding' (Ruhe and Olson, 1980). There is no consistent burial depth at which 'isolation' occurs; it is determined by the soil texture and the nature of the pedological processes involved. These depths however may be great with Leigh *et al.*, (1989) finding aspects of welding even at burial depths of over 4.5 metres. In archaeology, depths of burial also differ widely with depths of only a few centimetres beneath some earth banks for example, and up to several metres beneath Silbury Hill (Macphail *et al.*, 1987). Therefore, welding can be expected to be a common occurrence within archaeological buried soils, depending upon the soil's textural status.

A second important variable in the preservation of a buried soil is the rate of burial. A soil that is buried gradually over time, however deeply it is eventually buried, will have effectively been buried by many small depositional increments with surface processes operating between each 'event'. Therefore, for effective preservation of a buried soil, it is desirable that the act of deposition is rapid so that pedogenesis will have no time to act upon intermediate sedimentary surfaces. The rate of deposition is largely dependent upon the mode of deposition, so for example, alluvial buried soils will often have been buried gradually with each flood event. The depth of sediment deposited by each event will depend upon the volume of water and the energy of the flood event. Soils beneath anthropogenic constructions will often have been buried relatively rapidly during a single constructional event, in other cases there may be a more gradual burial for example, where middening is the burial process.

The nature of the burying material, its physical and chemical characteristics, the mode of deposition, and the rate and depth of burial are all complicating factors when considering the processes of post-burial change in buried soils. Each of these will affect the response of the buried soil to burial, and the soil's subsequent preservation.

1.2.2.3 Time as a factor in post-burial change

The time scale over which post-burial changes occur will depend upon the relative permanence of the pre-burial features, i.e. their resistance to change, as well as upon the actual conditions prevalent within the burial environment. Yaalon (1971) grouped features of buried soils affected by pedological processes according to the periods of time required for them to attain steady state into rapidly adjusting, slowly adjusting, and persistent features. More recently it has been suggested that the burial environment is far from steady, but is highly dynamic and depends upon the burial depth and the soils 'isolation' from modern pedogenic processes, as well as time since burial (Schaetzl and Sorenson, 1987). These factors act differently in respect of each of the various soil properties. Bockheim (1980) established that most soil properties were best described by a logarithmic model, with a period of most rapid change soon after burial. He also doubted that soils ever reach a steady-state (dynamic equilibrium) although rates of change may be imperceptibly slow over time. The time scale of change for each soil property was again found to differ according to its relative resistance. This suggests then that soils may react very quickly to the changes in conditions associated with burial, but that these processes will continue to operate over longer time scales, including the archaeological time scales being considered here. Any study of post-burial change in archaeological buried soils, therefore, needs to consider not only the rapid, short-term changes, but also the effect of burial upon these soils over archaeological time scales.

1.2.3 Literary evidence of post-burial change in buried soils.

The literature on post-burial change includes aspects from all those disciplines that study buried soils. The literature splits easily between those papers dealing with modern buried soils (those buried for no more than 50 years), those dealing with archaeological and Holocene buried soils (buried within the last 10,000 years), and finally into buried palaeosols (buried more than 10,000 years ago). This split also serves to highlight the effect of time upon processes of post-burial change.

1.2.3.1 Modern bulk, soil storage practices as an analogue for post-burial change.

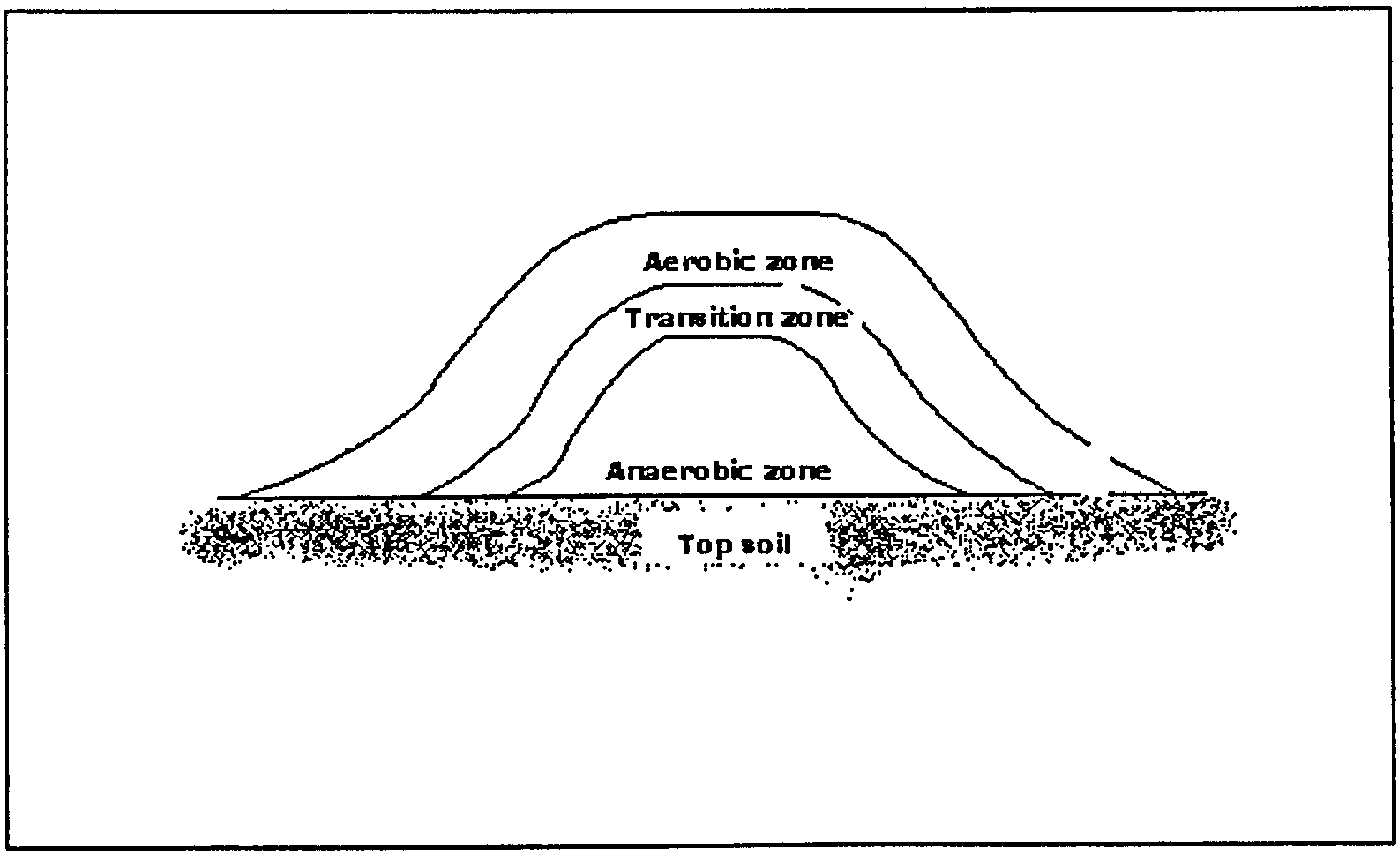
A large body of work exists upon modern, bulk soil stores formed in the course of mining and quarrying operations. These soil stores are composed of topsoils that have been mechanically stripped from quarry sites and stored in heaps for use in restoration work once quarrying operations have ceased. Obviously, these stores are not a direct analogue of the situation within and beneath archaeological sites. Differences exist in both the mode of construction, and the focus of modern studies upon the soils within the store, as opposed to under it. The study of soil stores, however, does provide an insight into short-term, rapid changes in bio-physicochemical soil properties that occur in response to a burial situation.

Evidence of substantial changes in the physical, chemical and biological conditions within the soil stores shortly after their construction, in some cases persisting for many years has been investigated. Physical changes to the soils include an increase in bulk density, a reduction in the coarse porosity, reduced aggregate stability and a breakdown of soil microstructure (Hunter and Currie, 1956; Abdul-Kareem and McRae, 1984). Abdul-Kareem and McRae (1984) found that large aggregates formed deep within the stockpiles as a result of anaerobic conditions. Higher within the store, above the anaerobic zone, shear forces during construction may have broken soil peds making them more susceptible to later compression (Harris, pers. comm.). Some of these physical changes are probably due to trafficking and the mechanical soil handling techniques employed (Ramsay, 1986). At least some of these compressive forces however, could be expected to operate in archaeological mounds, and shear forces will also be associated with the construction of an archaeological monument.

Microbial and chemical changes may also be to blame for these physical soil changes. Immediately after construction there has been observed a massive drop in the fungal and bacterial biomass (Harris and Birch, 1989; Harris and Birch, 1990; Visser *et al.*, 1984). This decline in the soil microflora is accompanied by a drop in earthworm numbers (Hunter and Currie, 1956; Abdul-Kareem and McRae, 1984). Fungal numbers are very severely affected; they decline rapidly and never recover within the deeper parts of the store where anaerobic conditions prevail. Harris *et al.* (1993) likened fungal species to C-strategist competitors performing poorly in disturbed environments. Bacterial biomass initially decreases, but does rise again after the first month, primarily with biomass increases in aerobic bacteria towards the top of the mound (R-strategist ruderals) feeding upon the dead fungal biomass. At the base of the mound anaerobic bacteria also manage to persist by adopting an S-strategist lifestyle as stress tolerators. The rapid and severe decrease in fungal hyphae has important implications for the structural stability of the soils. Fungi are known to be important in maintaining soil structure and aggregate stability in the face of compressive forces (e.g. Molope *et al.*, 1987). Earthworms are almost totally eradicated during construction and numbers are very slow to recover in the face of increased bulk densities taking nearly 15 years to reappear at the surface (Rushton, 1986). If the base of the store is anaerobic, earthworms may never recolonise these areas (Harris, pers. comm.). Chemical changes within the stores include the accumulation of ammonium (Harris and Birch, 1989), carbon dioxide, methane, ethane and ethylene (Abdul-Kareem and McRae, 1984). There are decreases in organic carbon and organic matter and a trend towards neutral pH with depth, together with a greater availability of heavy metals (Harris *et al.*, 1989). Accumulation of iron at the base of the soil stores is also known, possibly becoming visible within three to five years (Harris, pers. comm.).

These changes in soil stores have been modelled by Harris *et al.* (1989) who divided the store into three distinct zones upon the basis of their redox characteristics, (Fig. 1.1). The depths at which each of these zones occur, depends upon soil moisture content and its textural characteristics. Abdul-Kareem and McRae (1984) found visible changes associated with anaerobic conditions at depths of only 0.3m in heavy clayey soils, 1.3m in loam soils and below 2m in sandy soils.

Figure 1.1 Schematic diagram of a soil store.



Harris *et al.*, (1989, p.167)

These changes are rapid acting, and the effects of some appear to be short lived; for example, bacterial numbers recover very quickly. However, despite the time scales involved, the effects of these processes may be great enough to leave their signature within 'older' buried soils, and their effects could include the destruction of pre-burial features in the soil fabric. Structure is one such property, soil structure has been shown to degrade very quickly in storage, and despite a later recovery in the microbial biomass may be permanently affected. Certainly, the recovery of the pre-burial structure is unlikely as the soil adjusts to the new conditions within the burial environment. "Soil is a dynamic system with soil structure being the result of a constant turnover of microbial biomass and the associated cycling of nutrients, once a stable structure has been achieved it is by no means fixed...it may very easily be destroyed by disrupting the microbial community" (Harris and Birch, 1990, p.26).

1.2.3.2 Archaeological evidence of post-burial change in buried soils.

Many archaeological researchers consider that the burial environment has a large influence upon soil micromorphology. Indeed post-burial reworking by worms was blamed for the absence of buried soils from beneath many archaeological structures as long ago as the 1950s (Atkinson, 1957). It has been suggested that post-burial change may have been the cause of, or have led to the destruction and removal of evidence of anthropogenic activity from the soil fabric (Mausbach *et al.*, 1982; Yaalon, 1971).

As an example of post-burial pedofeature destruction, estuarine inundation of terrestrial land in Essex has been shown to result in the removal of clay void coatings through the dispersing action of sodium ions (Canti, 1992a). This is an extreme case but post-burial acidification, sodium inputs in coastal regions, or an increase in other monovalent ions such as potassium from modern or past agricultural activity could be expected to have a similar dispersant effect. The post-burial destruction of structural evidence may be difficult to infer, the nature of the original structure being unknown, however structural changes to the soil in the form of reduced porosity and compression of the buried soil have been observed. Beneath Silbury Hill, for example, the old soil profile has been severely compressed (Macphail, pers. comm.). However, the effects of compression have not been recorded from all sites, and so such processes may be site-specific. The buried soils resistance to compression will relate to its structural strength before burial, and the specific biochemical / hydrological conditions formed after burial.

The study by Cornwall (1953) of two neighbouring Bronze Age barrows illustrates the importance of the overburden material type to the preservation of the buried soil. The soil beneath a gravel dominated barrow was heavily altered, whilst the neighbouring buried soil, beneath a finer textured mound was distinctly better preserved. Simpson (1996a) also found differences between the nature of the overburden to be important in the preservation of the buried soil. At Tofts Ness where a Bronze Age plaggen soil was covered by calcareous, wind blown sand, there was some evidence of post-burial redeposition of carbonates in the underlying plaggen soil. However, in the same profile the mobilisation of fine particles of organic matter was confined 'within and out of the anthropogenic horizon' with no inputs to the buried soil from the overburden. A similar soil buried by peat at South Nesting though, contained significant inputs of fine organic material from the overlying peat, together with evidence for the mobilisation of iron forming an iron pan within the buried plaggen soil. The movement of carbonates from wind blown sand, such as investigated at Tofts Ness, may actually be beneficial to the interpretation of soil micromorphology as it offers protection against leaching and helps preserve fragments of bone and other calcareous materials. Such post-burial preservation was identified at Flixborough and Godmanchester, Cambridge (Canti, 1992a; 1992b). The movement of carbonates into the buried soil has also been noticed at Beeston castle where inputs are assumed to have come from overlying mortar and have raised the pH of the buried soil (Macphail, 1987).

The possibility of the post-burial formation of clay coatings around voids has been raised in a Bronze Age soil beneath the burial mound at Fordhouse Barrow, Scotland (Simpson, 1996b). Considerable illuviation of clay and silt within the barrow after its construction was evident and had formed a diverse mixture of limpid and silty clay coatings. Whether or not this mobilisation of fine particulates had affected the buried soil was unclear, but unless the chemical or drainage conditions at the base of the mound were such as to preclude their forming, it is a distinct possibility. Episodes of clay translocation could relate to illuviation processes operating at the new soil surface. Clays released at the top of the mound would move down profile in the soil water and be deposited lower within the mound or even within the buried soil where 'isolation' was not complete. Surface processes of illuviation have been noted to form yellow limpid clay cutans within mortuary mounds in Virginia after 2000 years (Creemans, 1995). At this American site, there was a difference in the expression of these cutans across the profile of the mound, the cutans being thickest and most abundant at the top, becoming thinner towards the mound sides, and eventually disappearing altogether. Romans and Robertson (1983) also noted the post-burial formation of oriented clay coatings within the mound and associated buried soil at Strathallan, Scotland. They related these features to processes of illuviation initiated by cultivation at the surface of the mound. The spatial distribution of cutans, at discrete depths through the mound, was thought to have formed in response to different cultivation techniques and to different phases of construction of the monument. Another example of clay translocation identified by Gebhardt and

Langhor (1996) concerns a French Medieval motte where the permanently high water table has induced a series of migrations of clay particles and iron to produce a series of linear clay accumulations. No clear trend in the nature of these 'post-burial' clay coatings was identified from the literature. This is in contrast to the limpid coating types interpreted as natural pedogenic features and the silty and impure clay coatings taken to indicate anthropogenic disturbance of the soil surface. The fact that different processes are thought to produce visually very different types of clay coating suggests that the colour, texture and composition of these coatings may potentially be used to infer the processes of their formation. Further discussion on the processes and effects of clay illuviation is given on pp. 16, and 35-36. The effect of hydromorphism upon clay mobilisation could theoretically be related to a decline of fungal numbers under anaerobic conditions, as was noted in modern soil stores. Without fungal hyphae to stabilise soil structure, particularly in a transitional or fluctuating zone where bacteria may rapidly decompose the existing fungal biomass, then the peds may begin to degrade, releasing clays, silts and other soil constituents. The importance of the soil redox potential for the preservation of organics is also highlighted at this site as the reduced, waterlogged conditions resulted in high levels of preservation. In locally aerated situations, however, the organics had totally decomposed leaving only a dusty matrix. Another effect of this *in-situ* hydromorphism upon clay fabrics is that of enhanced magnetic susceptibility, this was identified at Hazleton Down as a result of ferro-manganiferous impregnation and pan formation in the buried A horizon (Allen and Macphail, 1987).

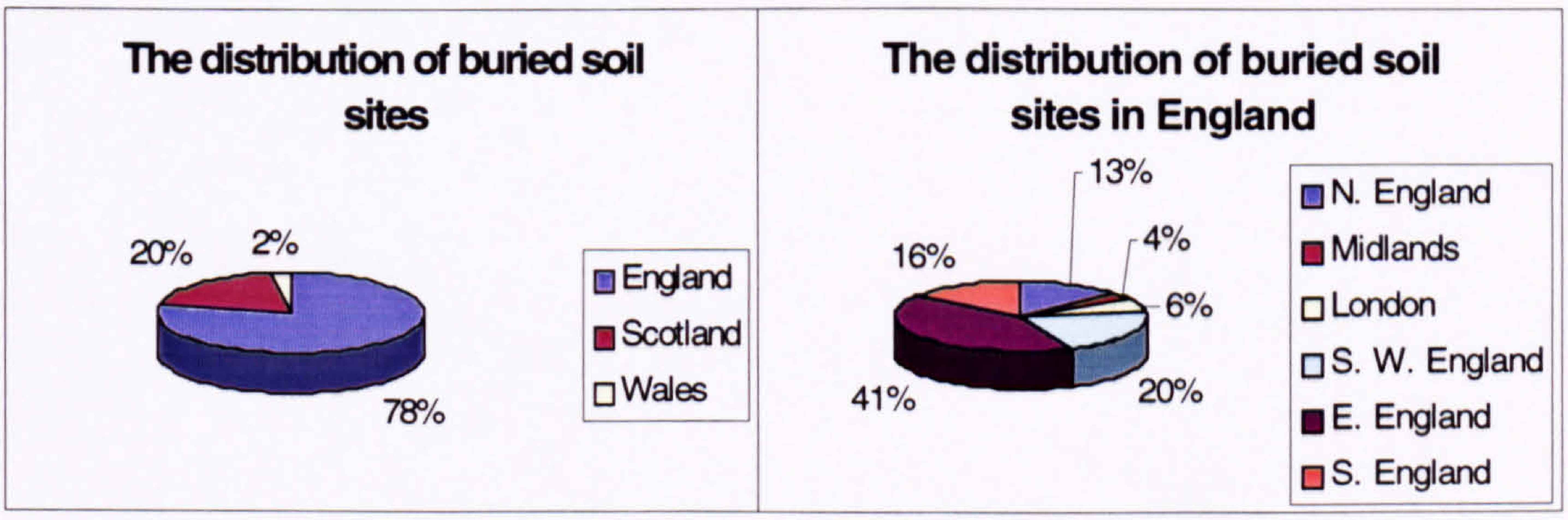
The formation of pans and iron rich nodules and segregations within buried soils has been well documented (e.g. French, 1994; Limbrey, 1975) and the consequent reddening of soil field coloration was noted by O'Kelly (1951). Some of the most spectacular pan features have been found within the Bronze Age barrows of South Jutland, Denmark where pans have sometimes formed enclosing the entire core of the monument (Breunig-Madsen and Holst, 1996; 1998). These pans may form in both clay and sand rich soils and, on the evidence of the survival of the organics enclosed by these pans, form very quickly after burial. Iron pans at the base of barrows, at the interface between the buried soil and the overburden, are commonly associated with Bronze Age barrows in southern England and elsewhere (French, pers. comm.). However, Holst (pers. comm.) also notes that there have been pans found at both earlier and later sites in Denmark and across Europe. Redox processes have been implicated in post-burial, iron pan formation by Breunig-Madsen and Holst (1996; 1998). Buried soils and the overlying material may become anaerobic following burial as the soil is isolated from the aerated atmosphere and bacterial breakdown of organic matter rapidly depleted the soil atmosphere of oxygen. In these conditions of low Eh and pH, the ferric form of iron is reduced to its more mobile ferrous form, allowing it to move through the soil water until more oxygen rich conditions are encountered. Here the ferrous iron oxidises leading to its deposition as concretions of amorphous iron and in some cases an iron pan. The possibility of secondary, post-constructional podzolisation as a mechanism for iron redistribution and the formation of iron pans and nodules has also been investigated (e.g. Runia, 1988; Runia and Buurman, 1987). This theory suggests that iron at the surface and in turves within the overburden may complex with organic matter and these relatively mobile chelates may then migrate down through the profile in the soil water. When chemical conditions that favour the release of the iron from the chelate, such as raised pH, are encountered the iron is deposited. Runia (1988), and Runia and Buurman (1987), however, found no evidence to support this hypothesis, and they suggest that at most only slight secondary enhancement of a pre-existing podzolised profile may occur. Further discussion about the processes of iron redistribution is given in section 1.2.4, pp. 36-37.

Some of the most comprehensive experimental work undertaken has been the experimental earthwork of Overton Down, which has investigated short-term changes following construction, including those in soil micromorphology, over a period of 32 years to date (Bell *et al.*, 1996). The Overton Down study has shown the potential effect of earthworm activity upon the buried soil structure with almost total reworking of the buried soil since the monument's construction (Crowther *et al.* 1996). The movement of carbonates, iron and manganese has also been noted since burial, together with large reductions of up to 80% in horizon thickness and a concomitant increase in bulk density. The overall thickness of the Ah horizon dropped by as much as 50% in places, with a drop to only 3% porosity, (Crowther *et al.*, 1996). The degree and speed of compaction was found to relate not only to the weight of the overburden, but also to the nature and chemical composition of both the buried soil and the overlying material. The effects of change within the soils were locally heterogeneous in response to these two burial variables. The initial results from Wareham seem to suggest that these changes are soil specific with a much lesser degree of faunal reworking occurring within these more acid buried soils (Bell, 1996). The level of microbial activity, indicated by glucose initiated respiration, at the Wareham earthworks has been shown to be significantly lower than that of the surrounding soils, and a similar effect has been identified within a Bronze Age buried soil (Hopkins, 1999). An experimental mound has also been built in Denmark, and has been used to study iron pan formation. Within seven days of construction anaerobic conditions had developed in the core of the mound and within a month the mobile, ferrous form of iron had been detected (Breunig-Madsen and Holst, 1998).

1.2.3.3 A database of archaeological buried soil sites in Britain

The literature presented above was harnessed in order to help guide the research plan eventually formulated. This was achieved through the construction of a Microsoft Access 97 relational database of British archaeological buried soil sites, which have used the microscopic technique of micromorphology in their analysis. This database is presented and explained in appendix 1. The relational nature of this database allows for easy cross-tabulation and comparison between aspects of the soils developmental and burial history, and its fabric characteristics. The trends that emerge from this database, which includes many of the sites identified in the previous section, are briefly outlined here. One limitation of the sites already studied is their regional distribution, which reflects the areas of interest to the few researchers using soil micromorphology (figure 1.2).

Figure 1.2: The spatial distribution of buried soil sites



English sites have been most studied, particularly in east, south-west and south England. Another problem is the relative paucity of information concerning processes of post-burial change within the references and sources consulted in the building of the database. Only 68 of the 198 soils included mention evidence of post-burial change. The nature of change most frequently mentioned (53 sites) is that concerning the formation of iron pans, iron nodules and mottles after burial. The presence of void coatings associated with the post-burial translocation of clay and silt is noted at 13 sites. Biological processes of change, mostly the reworking of the buried soil by earthworms, are also mentioned from 13 sites, and structural changes from compression are noted at 12 sites. Table 1.3 shows the processes of change that have been identified and the number of sites at which they have been recorded.

Table 1.3: Processes of post-burial change that have been identified in archaeologically buried soils in Britain.

Process	**Number of sites identified**
Iron redistribution	53
Clay translocation	13
Biological reworking	13
Structural alteration	12
Calcification	4
Vivianite formation	2
Gypsum formation	2
Calcium iron phosphate	2
Pyrite formation	1
Sodium carbonate	1
Acidification	1

Iron redistribution, clay translocation and biological reworking appear to be the most prevalent processes of post-burial change affecting buried soils in Britain, although regional biases and the relative paucity of information should mean that the results are treated with caution.

1.2.3.4 Quaternary and geological evidence of post-burial change processes.

As well as being of archaeological significance, buried soils assist with environmental reconstruction. The potential time scale for studies of this kind is far greater than the five thousand or so years with which much of British archaeology is principally concerned. Palaeosols in geological sections are frequently examined, and when considering geological time scales and processes (compaction, cementation, neomorphism, authigenesis, dissolution, replacement, dehydration, reduction, base exchange and carbonisation), understanding changes after burial is obviously very important (Catt, 1996). The destruction of primary features of soils and imposition of metamorphic foliation, schistosity and crystalline texture limit the interpretation of palaeosols (Retallack, 1990; 1991). Many of the processes of interest to geologists are related to increasing lithification of the soil in response to high temperatures and pressures outside of those generally encountered in archaeological contexts. With such extreme alterations it may also be difficult to separate those processes of 'diagenesis' which occur relatively soon after burial from those pedogenic processes which formed the soil (Porter *et al.*, 1998; McCarthy *et al.*, 1999). To combat this problem, Valentine and Dalrymple (1975) suggested using palaeocatenas wherever possible as the logical pedogenic slope sequence could then be differentiated from any later diagenetic effects.

Soil welding however, is one area that is of interest to archaeologists and Quaternary scientists, and includes the 'welding' of the older buried soil within the lower parts of a younger, developing surface soil. If the buried soil is not sufficiently isolated from the surface it takes on chemical and some of the physical properties associated with its position within the developing surface soil profile. However, relict features consistent with its history at the surface may also survive depending upon the stability of the features and the processes of soil development. Welding is usually the result of the movement of base cations and fine particulates from the surface soil into the buried soil. This may affect the texture, porosity, and the content of soluble salts of the buried soil (Olson and Nettleton, 1998). The deposition of cations and particulates at the surface and buried soil interface may also occur if the two soils present a textural discontinuity. The movement of clays down profile and into the buried soil is a recognised part of this welding process; many clay void cutans have been attributed to such post-burial movements (Graef *et al.*, 1997). The depth to which welding occurs will be dependent upon the texture of the overburden, its landscape position and the nature of the processes. However, Schaetzl and Sorenson (1987) found pH stabilised below 1.5m and organic matter at 1m in a soil buried beneath loess. The decomposition of organic matter and the process of burial gleization are also relatively rapid alterations and have been observed in buried palaeosols. Burial gleization is a "distinctive feature of many paleosols" (Retallack, 1991, p.185) formed through the anaerobic decomposition of organic matter by bacteria reducing iron (hydr) oxides as the buried soil is affected by the water table. These gley features are commonly found overprinting pedogenetic features (Buurman, 1980; McCarthy *et al.* 1999; Pipujol and Buurman, 1994; 1998). Kemp *et al.* (1998) also found hydromorphic, ferrimanganiferous nodules and segregations forming in response to contemporary hydrological conditions in a buried palaeosol.

1.2.4 The theory of post-burial change in archaeological buried soils.

Using examples of previously observed alterations in soil structure, microstructure and fabric, it is possible to propose a theoretical model of post-burial change in buried soils. This model would help to explain the nature of the processes involved, the way in which they may act, and the time scales over which change may occur.

1.2.4.1 The actions of post-burial processes in archaeological buried soils.

The processes that may operate after burial and their effects in the soil fabric are discussed in Section 1.2.4.2. Many different processes of change may be involved, but these processes can act within the buried soil and the overburden in one of only three ways.

1. *In-situ* processes operate over localised distances within buried soils, overburdens or at the interface between the two. Such processes include, for example, the processes of mineral weathering, which although slowed by burial, may still be ongoing after burial. Other processes of post-burial change acting *in-situ* include the

reworking of the soil fabric by meso-fauna particularly through the localised actions of enchytraeids, and the nutrient cycling activities of the soils microbiota. Structural degradation resulting from lowered pH and / or an altered microbiota may also occur upon a localised scale, particularly within the transitional and anaerobic zones of the overburden material. Chemical redistribution over small areas may also be included here, so although leaching and podzolisation processes are excluded, localised iron diffusion in response to localised redox conditions may be considered.

2. Net down profile translocation processes are generated towards the surface of the overburden and act in a net downward direction. Soil welding processes are included here, whereby ongoing processes of pedogenesis at the new land surface impinge upon the buried soil. This may include, for example, the addition of base cations to the buried soils transported down profile, through leaching from the upper horizons of the surface soil. Processes of secondary podzolisation, the adjustment of pH in-line with the buried soils isolation from the atmosphere, and depth related biological processes (e.g. the sinking of artefacts, pollen and fungal spores) will also be considered in this section.

3. Net upward processes of translocation act in a reverse manner to those explained above i.e. the processes originate deep within the profile, but their effects impact higher within the profile. Ground water fluctuations and changes in perched water tables are the main mediators of these processes. Ground water levels may both fluctuate seasonally and over periods of many years either because of anthropogenic drainage of surrounding land, or through climate change. The effect of monument construction may also be to raise the groundwater level, as forces of cohesion and tension operate in such a way that the ground water surface mimics the topographic land surface. Changes in bulk density and porosity together with possible textural differences at the buried soil/overburden interface may also result in a perched water table at the base of the mound which may respond very quickly to changes in precipitation. These fluctuations in water levels at the base of the monument, and within the buried soil, can cause the upward translocation of cations. Deep plant roots are another method by which nutrients from the base of the profile may be cycled upwards.

1.2.4.2 Processes of post-burial change in archaeological buried soils.

As has been discussed in the literature, post-burial change may involve physical, chemical and biological processes.

Physical processes

The physical effects of post-burial change may include structural alterations resulting from the physical mass of the overburden, or they may involve physical changes in the nature of the soil matrix and the possible formation of textural features. The effects of compaction are known to include decreased porosity and even the formation of a massive soil structure, with an increase in bulk density, and the possible deformation of stratigraphic features. Acid, poorly drained soils under anaerobic conditions appear to be most vulnerable to compressive forces. Analysis of geological profiles has shown that compaction is initially most rapid with a large response to relatively light loads after which reductions in horizon thickness require comparably much greater loads (Retallack, 1991).

The translocation of fine particulates either into or out of the buried soil profile may result in the infilling of voids and the formation of new textural features. Besides the formation of clay coatings following burial, clay translocation may lead to the development of limpid (pure), strongly oriented clay coatings in natural soil profiles, and also to the more organic and silty (dusty) coatings associated with clearance, cultivation and trampling of a soil. Separating the post-burial features from their pedogenetic or disturbance initiated counterparts may be difficult as different processes following burial may potentially form different types of cutans, and relies upon the study of the relative spatial hierarchy of these features. The formation of features associated with the movement of clay depends upon three processes, mobilisation, transportation, and deposition of clay minerals. For mobilisation to occur, dispersion of the clay from the soil aggregates is first required. As Heil and Sposito (1993, p. 35) note, the "release of clay particles from aggregates results from the interaction of physical (texture, hydraulic conductivity), chemical (cation exchange capacity, organic carbon, pH, exchangeable sodium) and mineralogical (nature of the clay fraction, lime, secondary iron and aluminium phases)". The phenomenon of clay dispersion has been extensively investigated; recent summaries can be found in (Banin and Borochovitch, 1983; Buhmann *et al.*, 1996; Kretzschmar *et al.*, 1993; Keren and Sparks, 1995; Levy and Torrento, 1995 and Stern *et al.*, 1991). Soil aggregation is a complex process that is still not fully understood, but clay mineralogy and biological activity are crucial. The effect that a particular cation species has upon the soil clay distribution is related to its valency. Monovalent cations, including sodium and potassium, have a dispersive effect upon the clays. This is because their adsorption on the surface of the clay micelles is insufficient to overcome the electronegative charge of the clays, and because their single charge is unable to bond with more than one particle at a time. The electronegatively charged clay particles therefore repel each other. Divalent and trivalent cations such as those of calcium, magnesium, aluminium and iron are more strongly adsorbed on the clays and are capable of forming ionic bridges between adjacent particles causing clay minerals to flocculate. Organic residues also promote flocculation, especially the polysaccharides, which are large, flexible molecules capable of forming multiple bonds with several particles at once (Chaney and Swift, 1984). Clay mineralogy is also important as certain clay minerals including smectite are known to be more dispersive, whilst illite and kaolinite are less so (Stern *et al.*, 1991). Flocculation is only part of the process however, and on its own is insufficient to cause aggregation. Microbial hyphae form a cohesive network of fine filaments; organic polymers may form protective capsules around soil aggregates, while others act as cementing agents and the action of plant roots in terms of localised compression are all important factors. The transportation of particulates requires the presence of water and the macroporosity of the soil will determine the route taken through the soil. Deposition depends upon either flocculation of the clay particles because of pH or high levels of Fe and Al, or the retention of the suspension by the paralysation of the water front because of reduced macroporosity (Aguilar *et al.*, 1983). Retention of the water front may allow the adsorption of the water into the soil matrix or the settling out of fine material (Sullivan, 1994); textural boundaries within the soil, therefore, are important areas of deposition.

Chemical processes

This may involve the inwashing and loss of solutes and particulates, changes in redox conditions, or the transformation and weathering of soil constituents. Changes in the level of aeration and availability of oxygen are expressed as changes in the redox potential of the soil; this redox potential is probably fundamental to many processes of post-burial change. In anaerobic conditions, ions such as iron and manganese will be reduced as they act as electron receptors for anaerobic respiration. In their reduced form, ions of iron and manganese are more readily mobile and their subsequent oxidation and deposition gives a mottled appearance to soil. Strongly reducing conditions may develop after burial if there is a rise in the water table or if a perched water table develops. The pH of buried soil is a localised and dynamic soil condition. Under anaerobic conditions the direction of change will be towards more acidic conditions unless permanent waterlogging occurs in which case it may become neutral. At Overton Down, inwashing of calcium ions from the overburden actually increased the soil pH over the 32 years of the experiment (Crowther *et al.,* 1996). The soil pH may affect not only the preservation of other environmental data, but also the composition of the soil biota, the soil response to changing hydrology and compaction, and the mobility of other soil constituents. Calcium and other bases are known to stabilise soil aggregates and so act to resist compressive forces and prevent the dissolution of peds releasing clay, silt and fine sand for translocation.

The dissolution and precipitation of salts in soil are affected by the hydrology and drainage (Eh) of the soil and, by localised pH, and the degree of weathering and ped stability. These latter three are in turn, partially determined by the concentration of base cations. Some of the most common movements include gypsum, calcium carbonate, and iron and manganese. The precipitation of gypsum and calcium carbonate may act to obscure pre-existing soil features. Iron and manganese may be redeposited as pseudomorphs, nodules, and iron pans within the buried profile, impeding drainage and affecting the soil hydrology. The deposition of Fe and Mn may also have a strong obscuration effect making the discrimination of pre-burial pedogenic features difficult. The mobilisation of iron and manganese is intimately linked with the aeration and pH of soil, as under reducing conditions the ferrous iron and manganese are more soluble at more moderately acid pH (Collins and Buol, 1970). Within the overburden, secondary podzolisation was also thought to occur. Runia and Buurman (1987) and Runia (1988) suggest that the observed laminae of sesquioxides and humus are a secondary enhancement of podzolisation and that buried podzols may have been further enhanced by such illuviations.

Transformation in the chemistry of particular features may also occur. Notable examples are the formation in root cells of pseudomorphs of calcium carbonate, iron and manganese, and the replacement of calcium carbonate by pyrites in shells within estuarine soils. Neoformations involve recrytallization of particular soil constituents and in buried soils are essentially related to drainage conditions (Stoops, 1997), whilst authigenesis is the term applied to the formation of new minerals in the soil after burial. The chemical and physical weathering of minerals will continue at a rate determined by the conditions of the burial environment and vary vertically through any profile (Birkeland, 1984). Although chemical changes in composition cannot be seen microscopically, the weathering of minerals such as the feldspars can be estimated by the degree of pitting and alteration of their surfaces (Bouabid *et al.*, 1995; Ferrari and Magaldi, 1975, 1983; Read *et al.*, 1996; Read, 1998)

Biological processes

The direct effect of macro-flora upon buried soils is confined to root penetration, which causes localised changes in porosity and bulk density, and soil chemistry and redox potential. Indirectly, surface humus accumulations may affect the chemistry of both the overburden and buried soil, for example, the formation of acid mor humus can exacerbate leaching and translocation and intensify illuvial activity. Macrofauna on the other hand can burrow into the soil, breaking the 'seal' of the buried soil, allowing pedogenic development, and reducing the integrity of the fossil features.
Mesofauna may intensively rework the soil fabric through the gut until the groundmass may be totally excremental and all evidence of earlier soil development is destroyed (Courty and Federoff, 1985; Courty *et al.*, 1989). Both earthworms and enchytraeid worms cause pedoturbation which may be either proisotropic or proanisotropic in nature (Johnson *et al.*, 1987); in either case, however, valuable archaeological and pedological evidence may be destroyed and small items displaced

(Armour-Chelu and Andrews, 1994). Indicators of mesofaunal activity come in the form of excreta (which may coalesce with time), channels and chambers, vermiform features and calcitic granules.

At Overton Down, a degree of mixing of the overburden with the Ah of the buried soil was noted (Crowther *et al.*, 1996). The degree of mixing varied according to the nature of the overburden and the type of biota it encouraged. The most intensively mixed area was under the earthworm worked chalk rubble as opposed to that beneath the enchytraeid rich turves. Overall, a decrease in earthworm activity had occurred after burial although it had not altogether stopped and an almost complete reworking of the soil fabric was the result. Under conditions of burial, soil ecology changes and where acidity increases then enchytraeid may be favoured over earthworms and *vice versa*, the excreta of which are easily distinguished (Dawod and Fitzpatrick, 1993; Crowther *et al.*, 1996). Enchytraeids may rework earthworm excreta and obliterate evidence of their earlier activity. The identification to species of excrement is made difficult by the fact that their form and size are dependant upon the size, age and diet of the individual organisms, but certain known diagnostic characteristics can be used (Fitzpatrick, 1984).

Micro-organisms regulate many of the chemical transformations that occur in the soil including the decomposition of soil organic matter. They also play an important role in stabilising the soil through the formation of soil aggregates. Their ecology is intimately related to aeration and saturation. Degradation of fresh organic matter and its incorporation into the soil structure involves the separation of the insoluble residues from the soluble organic substances, and the gradual mineralisation of the latter (Courty *et al.*, 1989). Within the burial environment, the decomposition of organic matter may be slowed as microbial action is partially inhibited by waterlogged conditions. In prehistoric soils the process may be well advanced with no fresh identifiable organics, only calcium carbonate, iron, and manganese pseudomorphs remaining.

The effects of these physical, chemical and biological processes upon some of the soil features outlined in section 1.1.3 of this chapter as of importance in archaeological interpretation are given in Table 1.4 below. This table shows how the processes of post burial change may act to preserve, obscure, confuse or destroy those soil features formed prior to burial. The importance of microscopic soil features to archaeologists was outlined previously in section 1.1, and so the way in which they are affected by post-burial processes is of importance. Iron redeposition for example, may obscure the nature of the underlying soil fabric, whilst the post-burial formation of clay and silt void coatings could both obscure earlier features and confuse interpretation.

The examples of post-burial alterations that have been given indicate that within any soil there may be changes in the chemical, physical, and biological characteristics in response to conditions prevailing within the burial environment. However, many processes that operate both before and after burial exhibit a high degree of inter-dependence. The soil biota, for example, will be strongly affected by the soil's physical and chemical conditions; different species will be able to survive under different conditions of soil density, hydrology, pH, and mineralogy. A change in any of these factors therefore will result in a concomitant shift in the composition and activity of the soil biota. Conversely, the structural characteristics of the soil and soil pH are heavily influenced by the actions of the soil fauna and flora. The results of this strong inter-dependence between soil variables and burial processes means that any study of one variable must always be mindful of the more general soil and burial environment and of the possible influence of other processes.

1.3 A summary of post-burial change in archaeological buried soils.

The soil features that are of importance to archaeologists, pedologists, and palaeoenvironmentalists include soil structure and microstructure, the presence of particular 'artefacts' and pedofeatures within the soil, and the level and nature of biological activity. The artefacts considered by archaeologists cover artificial inputs to the soil including, flints, bone, charcoal and organics, all of which may suggest manuring, clearance or occupation activities. Dusty clay void coatings and silt cappings are often seen as being indicative of agriculture and clearance activities (Courty *et al.*, 1989). The interpretation of the soil fabric by archaeologists is made more complicated, but also more interesting, by the fact that the soil will still contain evidence of its previous sedimentological and pedological history. Many of the features formed by anthropogenic activity may also be produced by the natural, sedimentary and pedological processes that operate before the disturbance of the system by humans. For example, clay void coatings may form naturally by illuviation and through clearance and agricultural activity, whilst silty features can also be associated with periods periglacial activity. These possible sources of confusion have been long recognised and investigated so that the likelihood of misinterpretations has been reduced. However, it has been only relatively recently that the potential impact of processes acting after burial upon the soil fabric has been considered.

From archaeological observation, experimental studies and research into change in modern bulk soil stores and geological buried palaeosols a number of important processes can be highlighted. Anaerobic conditions at the base of the mound and the buried soil may establish very rapidly if the depth of burial, the textural characteristics of the buried soil and the overburden, and groundwater levels are appropriate. These anaerobic conditions are one of the key preservational processes as these conditions are not conducive to decomposing bacteria and fungi that may otherwise attack organics within the buried soil. The actions of microfauna are important in stabilising the soil structure and so anaerobism may add to structural changes in the buried soil under compression from the overlying material. It may be that if anaerobic conditions are established quickly enough, the reworking of the soil by earthworms observed at the experimental sites, would be averted. Under these conditions of anaerobism then localised redoxymorphic redistribution of iron may also occur even to the extent of forming pans at the surface of the buried soil and there is some evidence of clay movements in these waterlogged conditions. Over longer time scales the influence of surface pedological processes have also been implicated. The down profile illuviation of clays and iron mobilisation through secondary podzolisation has been interpreted as the cause of particular features within some buried soils and their overburdens. Even over geological time scales buried soils have been shown to react to fluctuations in the contemporary hydrological conditions. The key processes, therefore, can be

Table 1.4: Summary of soil features, processes of post-burial change and their potential effects.

Features	*Processes*		
	natural	*anthropogenic*	*Effect of time and burial*
pedofeatures (excremental, textural and depletion) Determinants: Soil biochemistry. Soil texture and structure Biota Soil composition Hydrology After burial the nature of the overburden and the structural, chemical and biological changes in the burial environment.	excremental: Of particular importance are the Oligachaetae whose excremental structures are common in soil thin sections. Particular genera can be identified on the basis of the excremental morphology. The species composition of the soil is in turn affected by the soil pH in acid conditions Enchytraide worms are more common than earthworms and vice versa.	tillage: Disturbance of the soil and depletion of soil organic matter tends to decrease the overall number of Oligachaetae, although manuring will in part rectify this, in consequence the density of excremental features will decrease. Pasturing: The grazed grass sward are often very intensively biologically worked.	Over time excremental features have been shown to age and fuse together to form a ground mass, to a greater or lesser degree excrement can be expected to be reworked, the intensity of which will relate to the soil conditions after burial.
	textural (silt and clay cappings, coatings and inter-calations: disturbances such as windthrow and devegetation and erosional surfaces, they may also form in recent depositions of alluvium, colluvium etc. The process of lessivage forming limpid clay coatings in argillic rich B horizons may occur under woodland. Superpositioning of such features can give clues to the temporal sequencing of events.	Clearance, cultivation, pasturing all cause soil disturbances resulting in the anslocation of silts and clays which may be deposited as dusty clay void coatings or cappings. Cultivation may also lead to a process of internal slaking and the formation of agricutans.	Following burial such features may both continue to form and to be destroyed. Destruction may be through biological reworking, or under particular hydrological conditions by remobilisation of fine particles which may then be redeposited elsewhere to form new features. Alternatively fine particles mobilised in the overburden after burial may be deposited within the buried soil profile.
	depletion: Form when certain soil constituents have been mobilised and removed, leaving behind depleted regions. On a horizonal scale podzolisation, lessivage and leaching all leave depleted horizons but this may also happen on a micro- scale also, where the soil chemistry and hydrology allows. Inparticular areas adjacent to pores and voids may be prone as they are subjected to repeated wetting and drying, hydration and dehydration.	The tendency of cultivation to increase the mobilisation of soil constituents will therefore increase the severity of depletion and possibly also the frequancy of micro-depletion zones.	The survival of areas of depletion will depend upon the balance between loss of material downward and the immigration of material from the overburden and from deposition by fluctating water levels where the buried soil has become waterlogged. The survival of individual depletion features will be dependant upon the local pH, drainage and porosity, and Redox potential of the soil and the changes brought about in these after burial.
Organic Matter Determinants: Biota Disturbance soil biochemistry soil hydrology / aeration.	The nature of the soil organic matter may be seen in soil thin sections and this is determined by the nature of the biota from which it originates. The organic matter particles can also be seen to have been subjected to biological attack through comminution by the mesofauna and decompositon through the actions of the microfauna and flora.	Cultivation may lead to a net decrease in soil organic matter in many cases, and that which is present may be more homogeneously distributed throughout the Ap horizon. The physical disturbance of the soil can be seen in the degree of physical destruction of the organic particles while turnover of the soil can cause inclusions of fine sand silt and clay within the organic fragments.	Over time the degree of comminution and decompositon of the organics will increase. Within the burial environment however anaerobic conditions may actually help to preserve the organics as in the case of some Dark Earth deposits. In-situ decomposition may be evident through organic staining, while transformations to form pseudomorphs may also occur.
Charcoal and humified organic matter Determinants: prevelance of fires pedoturbations soil biochemistry	Charcoal may enter the soil after natural fires started for example after lightning strikes and then be incorporated through the action of earthworms and other organisms. While the presence of humified material may suggest decomposition by the soil microorganisms	domestic and clearance fires greatly increase the amount of charcoal entering the soil and as with organic matter, anthropogenic soil disturbance will result in it being homogeneously distributed throughout the A horizon and in its physical fragmentation. manuring may add quantities of already partially humified material to the soil.	Charcoal is a relatively resistant material and so may undergo very little change over time, reworking of the soil may alter its distribution somewhat however. Humification will continue except under extreme conditions of waterlogging. While the soluble and fine products of humification may be susceptible to mobilization.

Feature	*Processes*		*Alteration over time and with burial*
	natural	anthropogenic	
Soil macrostructure Determinants: Parent material. Soil composition (base saturation, pH, organic status, clay mineralogy) Exposure to compressive forces, pedoturbations. Hydrology.	Describes the size, shape and arrangement of soil peds and pores. The tendency to form peds is affected by pH, base concentration, the quantity and nature of organics and clay minerals, and the particle size distribution of the soil. There formation and/ or destruction therefore is controlled by all of the above properties and their concomitant processes, while waterlogging of the soil or excessive compressive forces can cause the collapse of these peds and result in a massive soil structure.	Impact of implements during tillage can cause the break up of soil peds into smaller units, which may then sort within the Ap horizon so that finer peds concentrate at the base of the horizon. The tendency to shatter will be greater if the base concentration of the soil has been lowered through cultivation. A platy structure or plough pan may form at the base of the Ap horizon through the concentration of finer particles and peds and the action of compressive forces during working. Slaking and puddling resulting from the activities of cultivation or pasturing can also cause the collapse of soil peds leading to a massive structure and also to the formation of a surface crust.	The effect of time on soil structure can be seen in the rapidity of soil reworking by Oligachaetea and other meso-fauna which increase porosity and can help to create a more crumb structured soil. The amount and nature of the soil biota will depend largely upon the soil chemistry and the availability of organic material. An obvious effecy of burial will be that of compression, whereby bulk density will increase and porosity decrease to form a more 'massive' structure. The severity of this change will depend not only upon the weight of overlying material, but also upon the nature of the soil and the overburden itself as they affect ped stability. Hydrological changes and gleying of the buried soil may also lead to the collapse of soil structure. From experimental work the effects of compression seem to be relatively immediate.
Field morphology (horizonation, panning etc.) Determinants: Biochemical nature of the soil. Parent material. Soil structure, hydrology and climatic regime.	The main processes determining field morphology are those of mobilization and deposition (leaching, translocation, podsolization) which result in discernible zones of depletion and enrichment, and processes of pedoturbation (physical, chemical, biological), horizonation etc. will be encouraged by proanisotropic turbations and prevented by proisotropic ones. The factors involved in these processes are those already discussed.	Cultivation in creating a deep Ap horizon, and through deep ploughing can be seen to simplify a naturally more complex series of organic horizons. Conversely aggravated leaching, podzolisation, panning etc. can be seen as encouraging horizonation.	The effect over time will depend upon the balance of the other processes operating. Within the burial environment a decrease in biological activity in particular their reworking of the soil can be anticipated, while the potential formation of Fe pans could produce a more complex buried soil morphology compared to that when freshly buried.
Structure and micro-structure Determinants: as for macro-structure, but on a more localised scale.	porosity, microporosity, ped shape etc. The formation processes will be largely similar to the soil macro structure but on a more localised scale.	As for macrostructure, in thin section it may be possible to recognise and type ped fractures caused by implement impact. Soil microporosity may be less affected by human disturbance than the macro-pores	Change in the nature and orientation of porosity and microporosity may occur after burial and will have a crucial role in affecting the stability of other soil properties. Reworking by soil organisms may have a particuarly detrimental effect upon soil microstructure. And compression will usually affect soil macropores before the micro ones.
Ground Mass, Course:Fine Determinants: Parent material (mineralogy, particle size distribution) weathering intensity biochemical soil environment local hydrology	Coarse: Fine; particle size distribution related to the parent material and to the nature and intensity of weathering. Relational distribution will depend upon soil structure, biological activity and the soil hydrology. Coarse; physical and mineralogical alteration Fine mass: Colour and texture dependant on chemical environment and the mineralogy. Homogeneity and orientation dependant upon the mode of formation / deposition of the groundmass, whether in situ or through translocation.	Overall tillage may act to increase the homogeneity of the ground mass through tillage, which may also disturb original orientations, colour etc.	Change over time and after burial may include reworking of the soil groundmass, destroying original orientations to create a more homogeneous matrix. Continued alteration of the 'coarse' particles should also occur. In washing of fine materials from the overburden could potentially, if they weren't deposited in concentrations or were reworked after deposition, alter the nature of the groundmass (mineralogy, coarse:fine, distribution). The ageing and fusing of excremental features can alter the groundmass

seen to include the onset of anaerobic conditions, the destabilisation of soil peds, remobilization of iron compounds and clays, and the biological reworking of the buried soil.

Understanding the effects of these processes within the buried soils, and their implications for thin section interpretation is very important. The alteration of the soil's microstructure has implications for the survival of those structural features that have been noted to form following tillage of the soil. The survival of soil organics and evidence of soil biological activity are important in the interpretation of manuring activities. The possibility of secondary formation of clay and silt void coatings within the buried soil could result in confusion with either natural, or anthropogenic coatings and cappings. In a similar manner post-burial redistribution of iron may obscure and confuse the evidence of pre-burial processes. Therefore, the destruction, alteration and obscuration of the soil fabric may all occur after burial of a soil with profound implications for the micromorphological interpretation of that soil. In chapter 2 the specific processes and soil features identified in this chapter are combined to form a theoretical model of post-burial change in archaeologically buried soils.

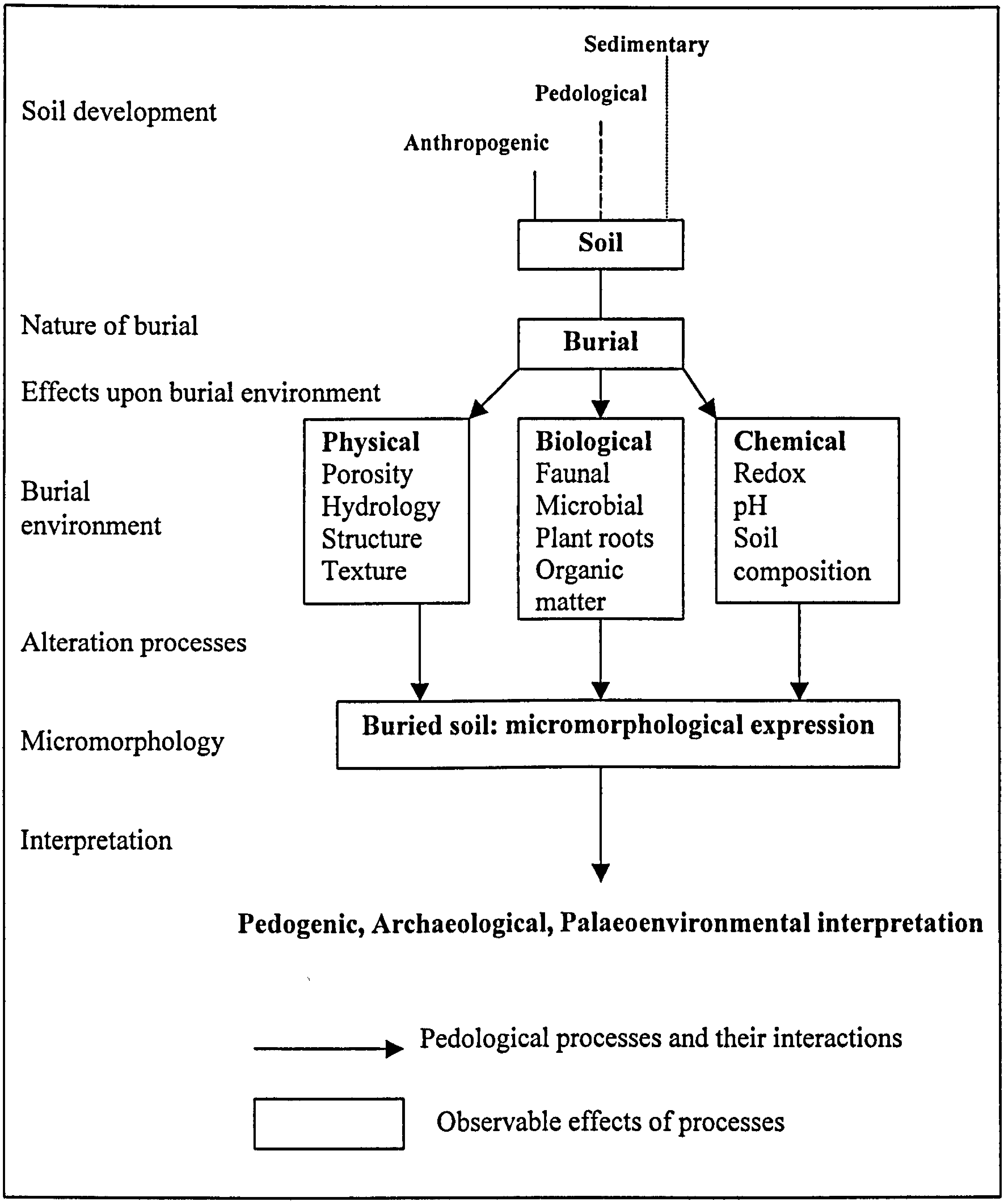
2. Research framework and aims

The literature review of the previous chapter identified a number of key processes and variables involved in the alteration of soil fabric within the burial environment. Post-burial change includes structural soil changes, biological reworking and the movement of materials into and out of the buried soil. This chapter develops a theoretical model of post-burial change in archaeologically buried soils, and sets out the research aims based upon recognised gaps in our knowledge of these processes, and the research hypotheses which the field, laboratory and analytical elements of this study attempt to address.

2.1 A theoretical model of post-burial change in buried soils.

It has been shown in chapter 1 how post-burial change in buried soils involves the interaction of numerous physical, biological and chemical processes. These processes operate according to the specific conditions within the burial environment, these conditions are themselves largely dependent upon the manner of burial and the nature of the buried soil. The soil itself is the sum of its developmental history, including sedimentological, pedogenic, and possibly anthropogenic disturbance phases. The evidence of many or all of these phases will be retained within the soil's fabric and micro-fabric, but the processes associated with each subsequent development phase will have a deleterious effect upon the surviving evidence of any former phases. The evidence of the earliest phases of development will therefore be gradually filtered. This filter will be dependent upon the nature and resistance of the original evidence, the nature of the subsequent processes and the time over which these processes have been allowed to operate. The final developmental phase for a buried soil, assuming it has not been exhumed, is that of adjustment within the burial environment. After burial, the soil will adjust to the conditions prevalent within the burial environment with which the buried soil will establish a new dynamic equilibrium. These systems can be simplified to provide a theoretical model of change within buried soils that can then be used as a framework

Figure 2.1: A simplified model of post-burial change in archaeological buried soils.



for the subsequent examination of these processes. This simple, schematic model is given in figure 2.1. The model shows the development of soil prior to burial as well as the effect of independent burial 'variables' upon the subsequent onset of post-burial processes and their effects within the micro-fabric of the buried soil. The post-sampling taphonomic filters of analysis and interpretation are also illustrated although they are not of prime concern in this thesis.

In summary the model presents a sequential series of events, defining environmental conditions and governing the nature of the processes operating within the soil and so determining the development of the macro-fabric and micro-fabric of the buried soil. The events within the development series of a buried soil are those relating to sedimentological, pedological, and anthropogenic disturbances, which govern the development of the soil and determine its eventual properties prior to burial. Burial is the key event of interest to this study and it is the mode of burial, the nature of the burial, and the properties of the soil immediately prior to burial, that are hypothesised to affect the nature of the burial environment. These burial variables are discussed further in section 2.1.1. The burial environment, therefore, establishes in response to a number of burial variables (section 2.1.2.). The particular set of conditions within the burial environment of any buried soil will then determine the suite of processes that operate, the effects of which may be visible within the soils fabric and micro-fabric (section 2.1.3).

2.1.1 Key variables affecting the burial environment.

As has been discussed, the study of the burial environment is complicated by the interconnected nature of the system. However, a number of crucial, controlling variables can be isolated. The nature of the buried soil will be important as the chemical, physical and biological properties of the soil immediately prior to burial will affect the response of that soil to the conditions of the burial environment. Time since burial may affect both the nature of the processes operating, as different processes operate over different time scales, and also the 'severity' of the physical effects seen in thin section where processes continue to operate over time. Other factors will affect the nature of the burial environment and therefore the nature of the processes that may act under these conditions. The depth of burial, for example, will determine the isolation of a buried soil from the surface. Not only will this include isolation from the effects of ongoing surface pedogenesis, but depth will also isolate the buried soil from the atmosphere, altering the redox potential of the soil with significant implications for the processes that operate thereafter. The nature of the burying material and the way in which it is laid down will also affect the buried soil, generally, the more rapid the burial, the better the preservation of the soil could be expected to be. The texture and composition of the overburden will also affect the physico-chemical conditions of the burial environment. Finally, there is a whole range of climatic and environmental conditions that may affect the buried soil. A very wet phase, for example, may allow the illuviation of material from the new surface down into the buried soil and could also raise the water table level, leading to waterlogging of the buried soil. Conditions that encourage the erosion of the overburden, whether through the activities of humans or climatic change may also impact upon the buried soil. Upon the basis of the literature examined in section 1.2 three key variables will be identified in this section. These variables are (1) the nature of the buried soil, (2) the depth of burial, and (3) the time since burial; it is these three variables that determine the sampling strategy.

(1) Parent material

The importance of parent material upon the development of soil was recognised by Jenny (1941) in his universal equation of soil formation and is further reflected by the incorporation of parent material within the soil classification systems of Scotland, and England and Wales. In these classifications soil associations are defined by the parent material upon which that soil has developed. Those properties of the buried soil most significant in soil development are its textural characteristics and its mineralogy. Soils formed upon coarse materials will tend to be free draining and significant pedological processes may include leaching and podzolisation. Soils developed upon finer textured materials will be less freely draining and may be prone to waterlogging resulting in gleying and processes of organic accumulation. Textural characteristics of the parent material may also affect the soil structure, those upon coarser soils tend to be less cohesive than upon finer, clay rich soils and so the strength and development of soil peds in the former may tend to be less. The mineralogy of the parent material will influence the base status of the soil, although this may be augmented, for example, by aeolian or alluvial inputs. Parent materials with a mineralogy including significant quantities of ferro-magnesium or calcareous minerals will tend to produce base-rich soils, whilst soils dominated by siliceous minerals will produce more acidic, base-poor soils. In this way podzols will tend to develop upon coarser textured parent materials and gley soils upon finer parent materials, whilst calcareous soils and brown earths will preferentially develop upon a base rich parent material.

The soil's physical and chemical properties will help to determine how that soil responds to compression beneath the mass of the overburden and the chemistry will effect the chemistry of the burial environment. If a site is constructed from local turves, soils, and geological materials, the parent material will also determine the nature of the overburden. For example, a very sandy overburden material will, at any given depth up to the depth of isolation, isolate the buried soil less well from the surface atmosphere and surface pedogenesis, than an overburden with a heavier, clayey texture. Accordingly an anaerobic zone would be expected to form at shallower depths under an overburden with a finer particle size than beneath one with a coarser texture, the affect of this zone was examined in section 1.2. The nature of the overburden will also affect the availability of materials for translocation down-profile, from the literature post-burial movements of clay and iron would seem to be important in this respect.

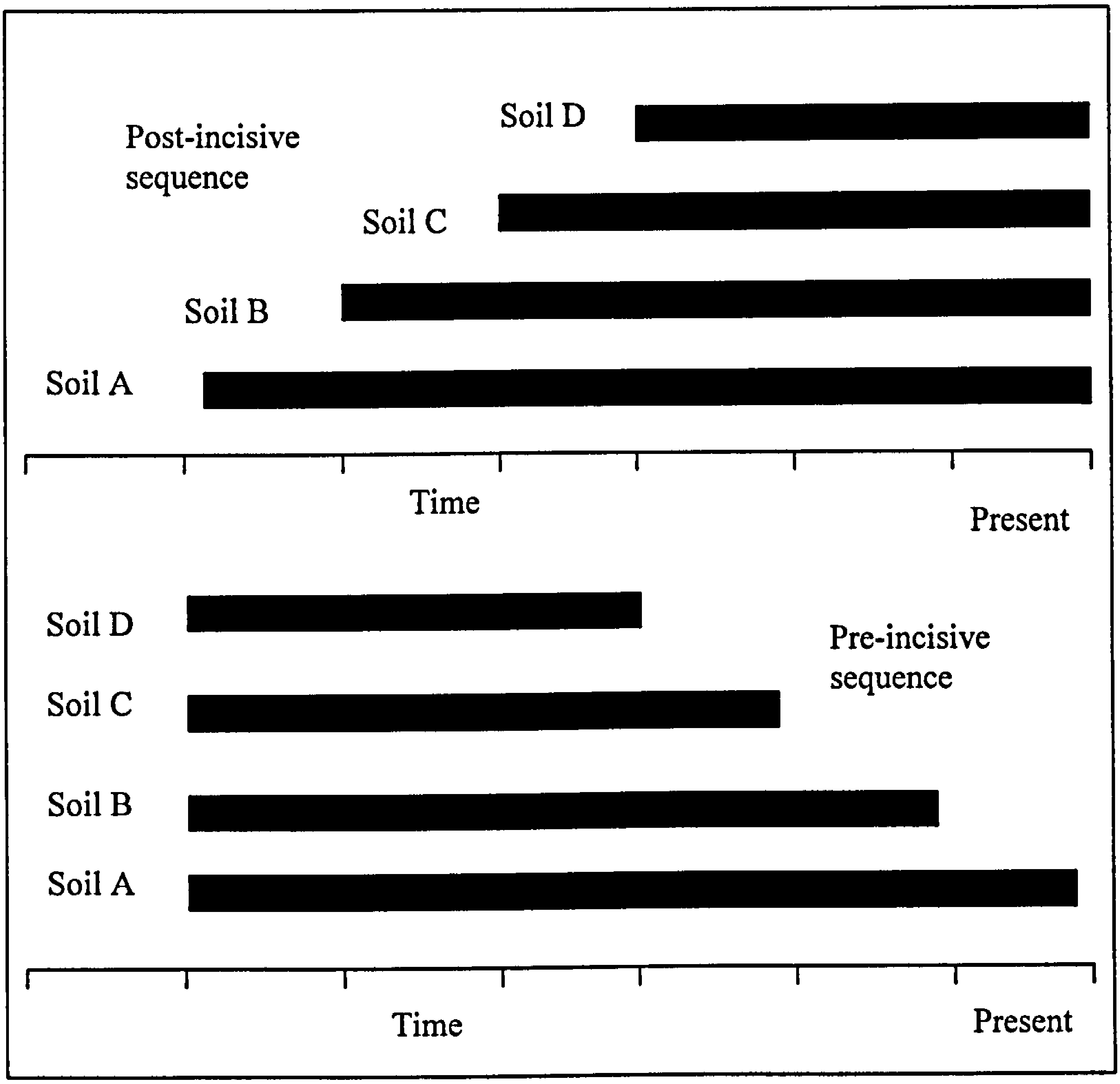
(2) Time since burial

Time since burial is the second key variable, but rather than being seen as a soil forming factor, the time variable should be considered as a continuum against which change takes place. Different responses of the soil to burial occur at different rates according to the resistance of the affected features. These rates will also be influenced by the nature of the soil environment, and importantly pedogenic and burial processes may change direction in response to environmental and anthropogenic perturbations. The time variable, therefore, should not be seen as a way of determining an absolute chronology of events after burial as any individual point in time represents a unique suite of environmental conditions. By viewing time as a continuum forming a background against which change takes place, the problem of environmental perturbations is alleviated whilst allowing room for statements about the relative rates and sequences of events to be made.

Chronosequences

Time sequences, or chronosequences (the sequence of change over time in any given landscape), have a number of forms defined by Vreeken (1975; 1984), these consist of pre-incisive, post-incisive, and time transgressive with and without historical overlap. The series are illustrated in figure 2.2.

Figure 2.2: Potential time-series (chronosequences) in pedological research.



Source: Vreeken (1975, p.381)

Vreeken (1975) suggests that the pre-incisive sequence of soils, those which all began their development at the same time and were then sequentially buried at intervals throughout their history, is the ideal form of sequence. Soils in this series will have been subject to the same macro environmental conditions, whereas for the other schemes it has to be assumed that all the soil profiles used have evolved along the same pathway.

(3) Depth of burial

The depth of burial under most British monuments is too shallow, even at their deepest to isolate the buried soil totally from the effects of surface pedogenesis according to the findings of Schaetzl (1987). The depth of burial is a key variable in determining the degree of isolation from surface processes of pedogenesis. If the depth of burial is insufficient to isolate the buried soil from the effects of these surface processes, the buried profile may become 'welded' with the developing surface soil. Depth of burial will also affect the isolation of the buried soil from the atmosphere so that with depth anaerobic conditions can develop, dependent upon the textural characteristics of the overburden material. Gleying of the buried soil (burial gleization) will also be encouraged by a deep burial in which the water table level will rise with the surface topography to a point where it may affect the buried profile.

2.1.2 Properties of the burial environment.

The model of post-burial change states that the burial variables outlined in the previous section will affect the nature of the burial environment. This burial environment then presents another set of factors that form in response to the burial variables and which will affect the response of an individual soil to burial. These 'burial' factors include soil pH and redox potential, the soil's textural and drainage properties, the soil biota, and the compressive forces that the buried soil is being subjected to. The physical, chemical and biological properties outlined are also, of course, associated with any unburied soil environment and only comparison between these two environments upon a local scale would enable their differentiation.

2.1.3 The effects of burial

The eventual effects of burial, as expressed in the soil macro-fabric and micro-fabric, completes the theoretical model. The expression of these effects within thin section is determined by the nature of those post-burial processes that have operated within the profile, themselves a product of the conditions within the burial environment. It is the features that are produced by post-burial alteration processes, which can affect archaeological interpretation of soil thin sections through the obliteration, alteration or obscuration of the pre-burial soil fabric. The features of interest, upon the basis of the literature could include the illuvial void coatings, the result of movements of solutes and particulates within and between the buried soil and the overburden. This movement of material may have the effect of destroying pre-burial features or, if new textural pedofeatures are formed, may obscure and interfere with pre-existing anthropogenic / pedogenic soil features. Soil biota may alter in response to disturbance and altered physico-chemical conditions to effect the biological reworking of the soil, including its anthropogenic and pedogenic features. The redistribution either locally or down profile of iron, manganese and other soluble base cations may also occur either destroying or obscuring pre-existing features.

2.2 Research aims and hypotheses

2.2.1 Research Aims

The central aims of this research are as follows:

(1) To study the effect that the burial environment has upon the micro-fabric of archaeologically buried soils as expressed in thin section,

(2) To understand and elucidate the processes of change that may produce the features observed in thin section,

(3) To assess the implications of the visible macro- and microscopic burial alterations for future interpretations of the micromorphology of archaeologically buried soils.

In particular this research aims to investigate:

(4) The prevalence and, cause of post-burial translocation of fine particulates within the buried soil, and between the buried soil and the overburden,

(5) The prevalence, and cause of the redistribution of iron within the buried soil, and between the buried soil and the overburden.

The information that the results generate through tackling these aims will add to the body of knowledge of the burial environment and the processes that may operate over archaeological time scales. Particularly this thesis should provide a greater understanding of the processes of post-burial clay, silt and iron redistribution, as well as expanding knowledge of the burial environment in general. With a greater understanding of the nature and activity of post-burial alteration processes in archaeologically buried soils, future sampling strategies could be devised which would take account of these processes and ensure that any samples taken have the least possible amount of burial disturbance. This is a particularly important issue in sites where conditions are such as to encourage the processes of iron and clay redistribution; these processes have the possibility of obscuring and confusing details of the pre-burial soil fabric.

2.2.2 Research hypotheses

As stated the broad aim of the research was to study the effects of post-burial change in archaeologically buried soils, and in particular to investigate the possibility of textural and solute movements within and between the buried soils and their overburdens. However, to achieve this aim requires the testing of specific hypotheses. These hypotheses relate to the influence of the key variables upon the nature of the burial environment, the effect of the burial environment upon the post-burial processes operating, and consequently the effects of these processes upon the fabric of the buried soil. Three main, testable hypotheses are presented:

1. The parent material from which a soil is formed influences the response of that soil to burial and the subsequent development of the buried soil micro-fabric.
2. The time for which a soil has been buried influences the nature of the post-burial processes affecting it and the severity of their effects in thin section.
3. The depth of material burying a soil affects the nature of processes of post-burial change and the development of the buried soil micro-fabric.

Besides these three main hypotheses concerning the effects of the key burial variables upon the processes of change and their expression in thin section, this study throws up a number of far more specific hypotheses and questions.

Typically these hypotheses will relate to the effects of the burial factors upon specific properties of the burial environments, for example grain size and chemical composition, and the effects of these properties upon particular processes of change. It can be hypothesised that where coarse grain sizes occur the burial environment will remain aerobic to greater depths of burial than those soils with a finer, clay rich texture. It could also be suggested that where the burial environment is anaerobic, then structural degradation is more likely to occur than in aerobic conditions. This being so, within an anaerobic environment clays, iron and other fine particulates and solutes will be available for mobilisation and redeposition within the overburden or the monument. However, within an aerobic burial environment one hypothesis might be that soil fauna will persist within the buried soil, eventually reworking the soil fabric. Time can also be hypothesised as an important factor in the realisation and actual effect of each of these processes upon the buried soil as the effects of biological, physical and chemical processes will be to some extent, rate and time-dependent. Similar hypotheses can be made for any one of the many potential post-burial processes operating within these buried soils.

2.2.3 The research framework as a model of post-burial change in archaeological buried soils.

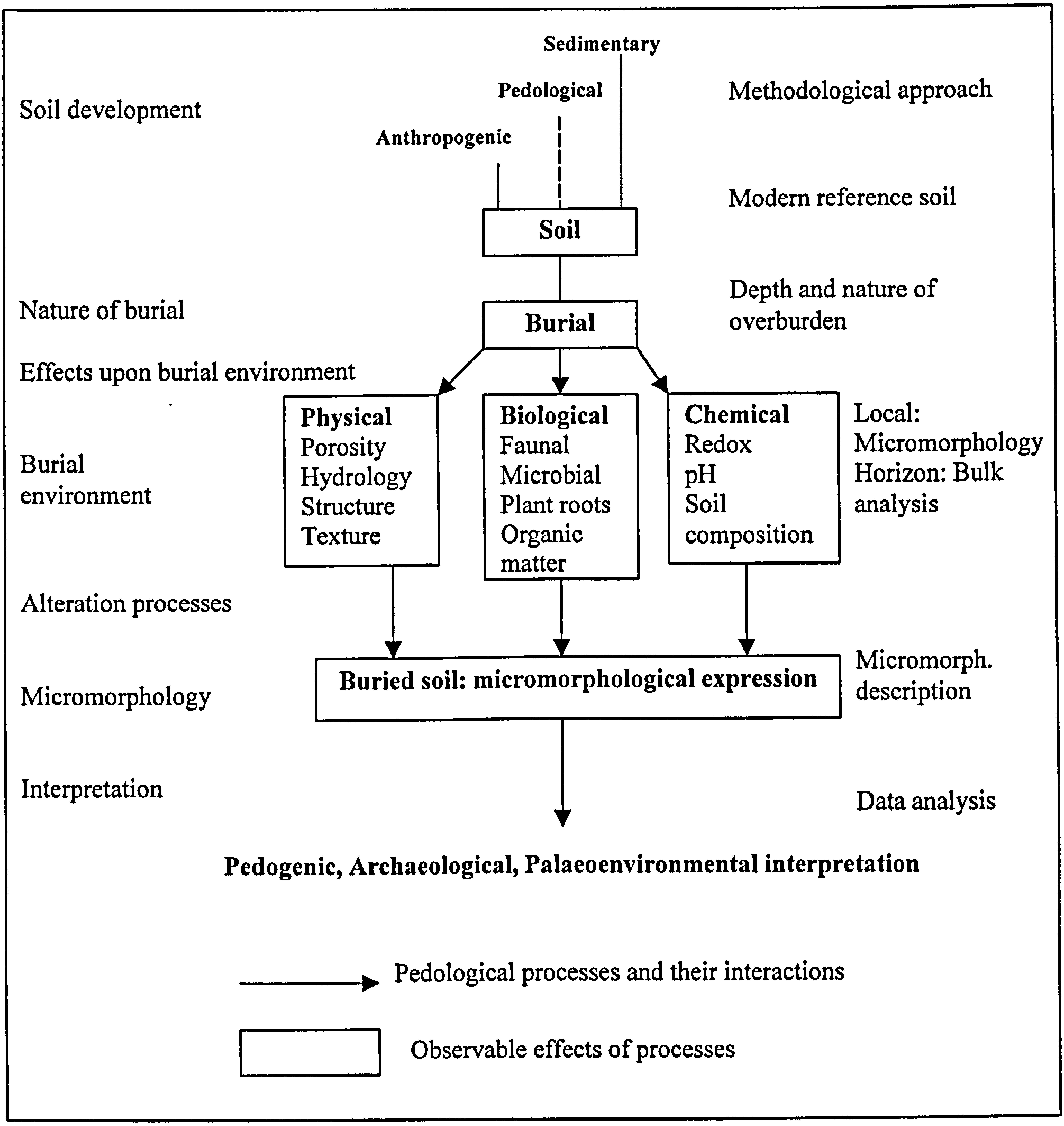
This framework is based around the simple theoretical model of change presented in section 2.1.1. In this model, change is ongoing throughout the development of the soil right up to the point of sampling. Each phase of development acts as a filter upon the quantity and quality of information that the buried soil contains from the previous development stages. The final stage in the evolution of the soil fabric, as it is seen in thin section, is that taking place within the burial environment. As has been shown in section 2.1, three elements comprise the post-burial stage, (1) the variables of burial, (2) the effect of these variables upon the properties of the burial environment, and (3) the processes that operate within this environment to produce the soil features present in thin section. All three of these elements have to be addressed if post-burial change in archaeologically buried soils is to be better understood. The first of these (burial variables) should be addressed at the sampling stage. The sampling strategy needs to be designed in such a way as to isolate the three key burial variables of parent material, time since burial and the depth of burial. Sampling sites with variation in each of these three variables would, therefore, be required. The second element of the model (properties of the burial environment) needs to be quantified through the chemical and physical analysis of the buried and burying profile. The examination of unburied soil profiles would help to discern between the properties associated with the local soil environment and those truly associated with burial. Finally, the effects of burial and post-burial change, will be addressed by the examination of soil thin sections, supplemented by field descriptions of the profile upon a macro scale, and the physical and chemical examination of the buried soil.

Figure 2.3 shows how the research framework and broad methodological approach outlined above was designed to address and unravel the complex developmental history of buried soils with the aim of elucidating the role of post-burial change in their development. This system should allow the testing of specific research hypotheses that have been briefly introduced in section 2.2.2.

2.3 Summary of Research framework

By providing a clear framework, a number of specific hypotheses are proposed together with the means for their testing. The research framework provides the necessary focus to ensure that the main research aims are met through a well planned sampling and analytical programme. The research variables chosen are those that have been hypothesised to have significant effects upon the nature of the burial environment. The research design was of study regions, sites and profiles that will provide differing physical, chemical and biological conditions within their burial environments in order to test a range of hypotheses. The analysis of bulk chemical and physical properties and the study of the buried soil micromorphology, should determine the nature of the burial environment and the processes of change operating within each soil can them be investigated. The effects of processes of post-burial change upon the buried soils micro-fabric can then be used to examine the initial research variables in order to assess the effect that parent material, time since burial and depth of burial have had upon the preservation of the buried soils. The following chapter develops the sampling methodology designed to answer the research aims and hypotheses that have been raised in this chapter.

Figure 2.3: The research framework fitted to a model of post-burial change in archaeological buried soils.



3. Sampling framework and site choice

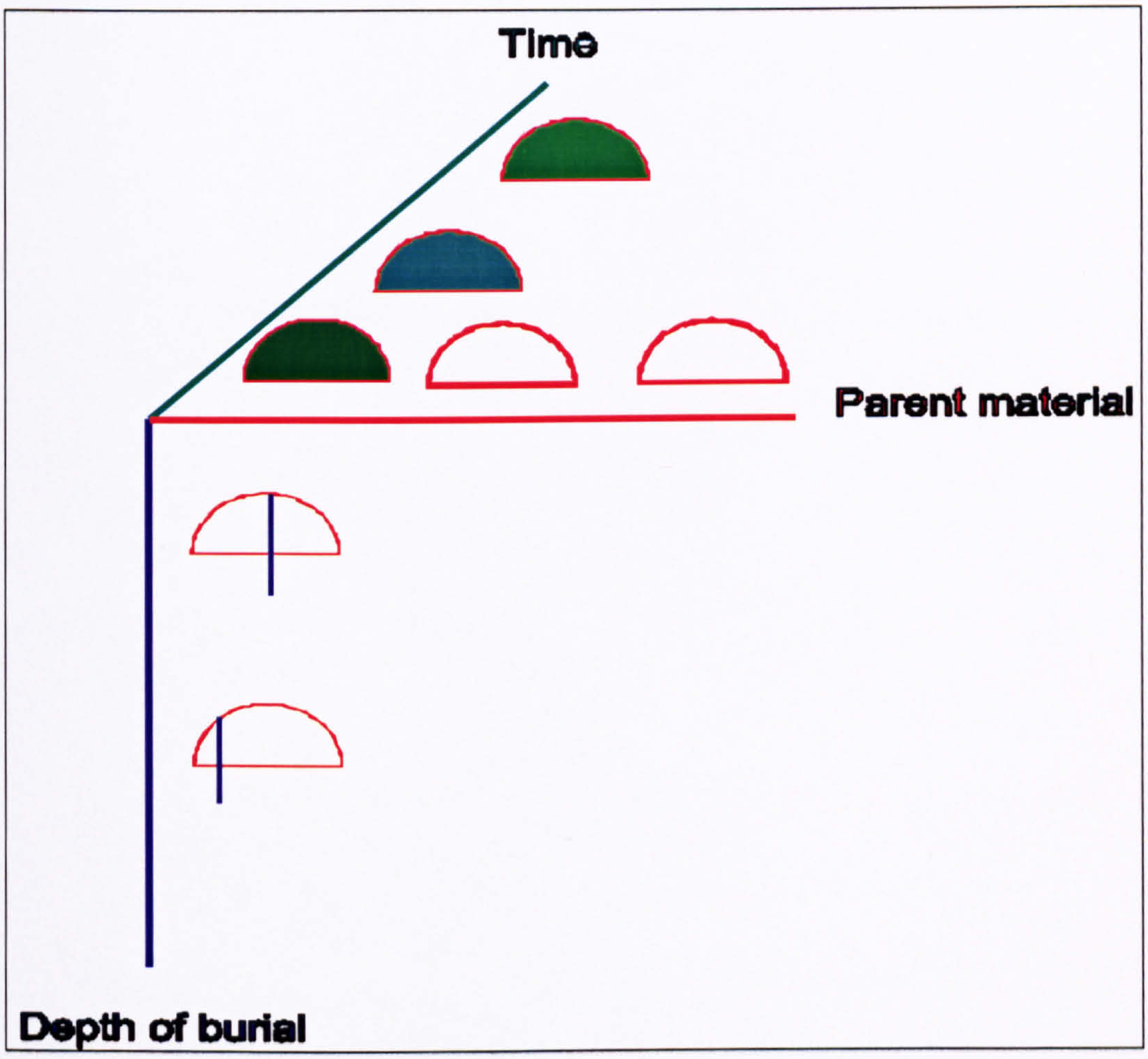
3.1. Sampling framework

The framework for the research ensures that the aims outlined in chapter 2 are fulfilled despite the limited number of samples that can be analysed. To do this requires that the key variables, processes and features involved in post-burial change be identified in order to provide a sampling framework. The variables hypothesised to be crucial in determining the nature of post-burial change have been introduced in the previous chapter.

The simplest way of addressing the three burial variables of parent material, time since burial, and depth of burial was to use a nested, factorial sampling strategy (Figure 3.1). This involves the identification of a number of sampling 'regions' with contrasting parent materials, within each region would be archaeological 'sites' of different age producing regional chronosequences of buried soils. Each site would then provide multiple sampling 'profiles' from beneath different depths of burial. Three spatial levels of sampling are included, the first a 'regional' level associated with areas identified upon the basis of their parent material. The second are sampling 'sites' identified upon the basis of their age, and the third level involves sampling 'profiles' that have been buried to different depths. This sampling framework is a hierarchical, nested scheme, with a number of 'profiles' within each 'site', and multiple 'sites' within each 'region'.

The sampling framework requires three or more study 'regions', each of which would have developed upon contrasting parent materials. Within each of these 'regions' there should be a number of 'sites' i.e. a human-made, archaeological construction with an associated buried soil profile. The relative ages of the sites within each study region must vary sufficiently to provide an archaeologically relevant time span to allow the effect of time since burial to be assessed. Finally, each 'site' should then provide sampling opportunities for at least two buried soil 'profiles' from beneath differing depths of overburden. As well as the archaeological sites, a modern, unburied reference profile under climax vegetation conditions was sought within each of the study regions in order to provide a comparison for each of the buried soils. All other environmental variables within the study regions, and between sites and profiles should be kept as constant as possible, and for this reason it was desirable to keep the study regions as spatially controlled as possible.

Figure 3.1: Schematic framework of nested study variables.



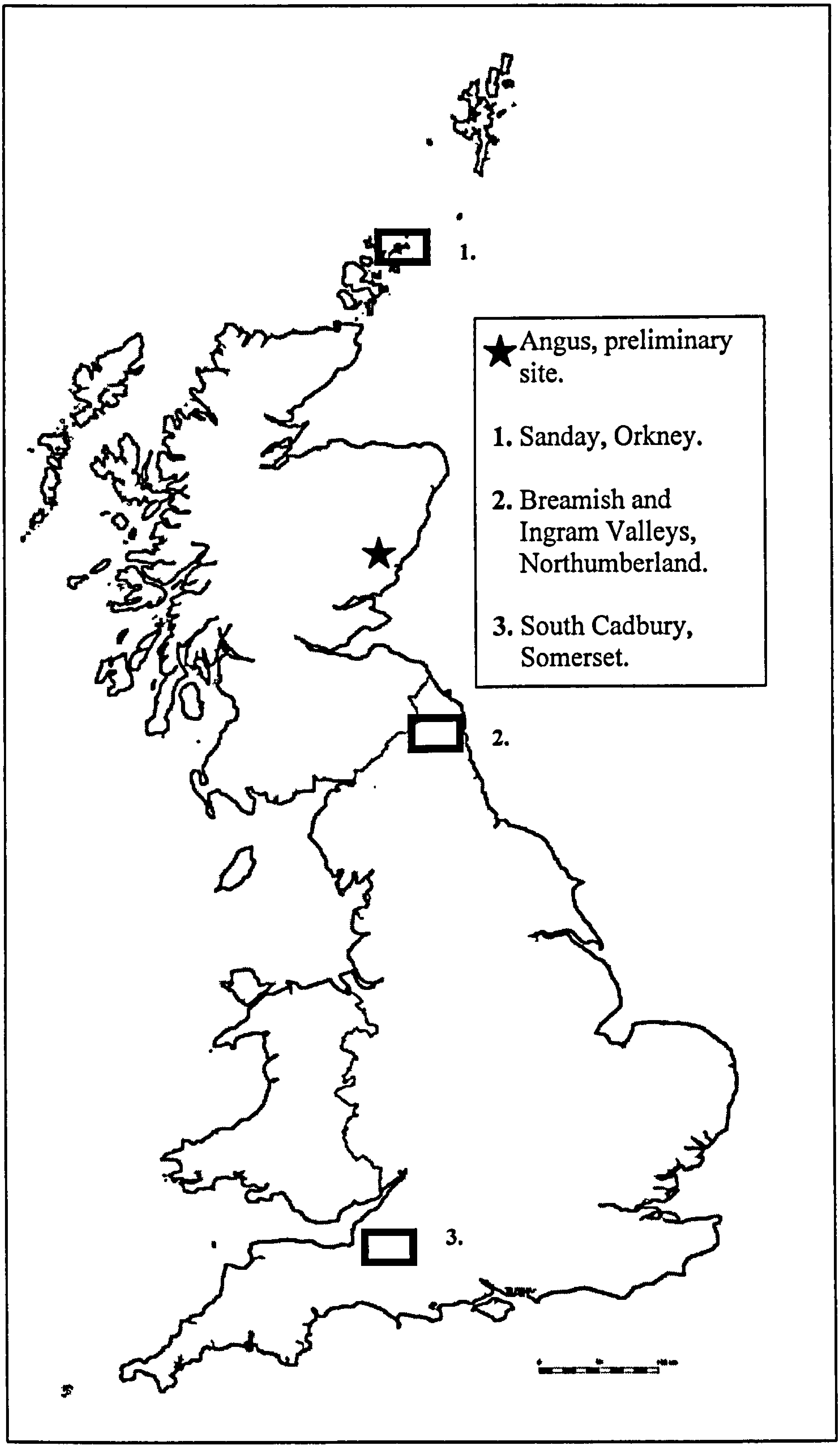
3.2 Sites sampled

The choice of study regions involved contacting field archaeologists and archaeological groups listed within the Institute of Field Archaeology's Handbook (1997) who were asked for details about sites under excavation with known buried soils, ideally of various ages. Further site possibilities were added from the research experience and knowledge within the Department. Single period archaeological sites were not at this stage excluded from the search. Once all the possibilities had been collected, the geology of each was investigated. The archaeological sites chosen were those upon a relatively homogeneous geology, which offered a firm chronosequence of sites with buried soils. Following field reconnaissance to establish parent material, site availability and access, and the presence of a suitable reference soils, final decisions were made and the study regions were decided. The choice of sites within the region and of profiles within the site have been discussed within the previous chapter, but involved the study of published literature and unpublished field reports supported by field reconnaissance visits and the advice of local archaeologists.

Three study 'regions' were chosen together with a preliminary study site. These regions are the island of Sanday in the northern Orkney islands, the Breamish and Ingram valleys within the Northumberland National Park, and the area surrounding South Cadbury, Somerset in southern England. The geology of these regions varies from the acid Old Red Sandstone of Orkney, through the intermediate Andesite of Northumberland, to the basic Lias clays, sands and Oolitic limestone of the Somerset study sites. The preliminary study site was that of Fordhouse Barrow, Angus also located upon Old Red Sandstone.

This geographical spread of study regions was necessary to achieve the contrasting geologies and hence to provide the variation in parent materials required by the research design. Ideally the regions would have been more closely sited as this would have greatly improved comparability between the different regions, however such a wide spatial spread of regions increases the general applicability of this work to British sites as a whole. Besides the geological constraints to this proposal, the choice of multi-period archaeological sites open for excavation within the main field season of summer 1997 was a second limitation. The time and costs involved with a large multi-period excavation are such that within any year only a few excavations will be ongoing, and even then it is unlikely that those features representing the full time period of the archaeological site will be opened. Add to this the need for sites with well preserved buried soils and if possible well-established chronologies, and the

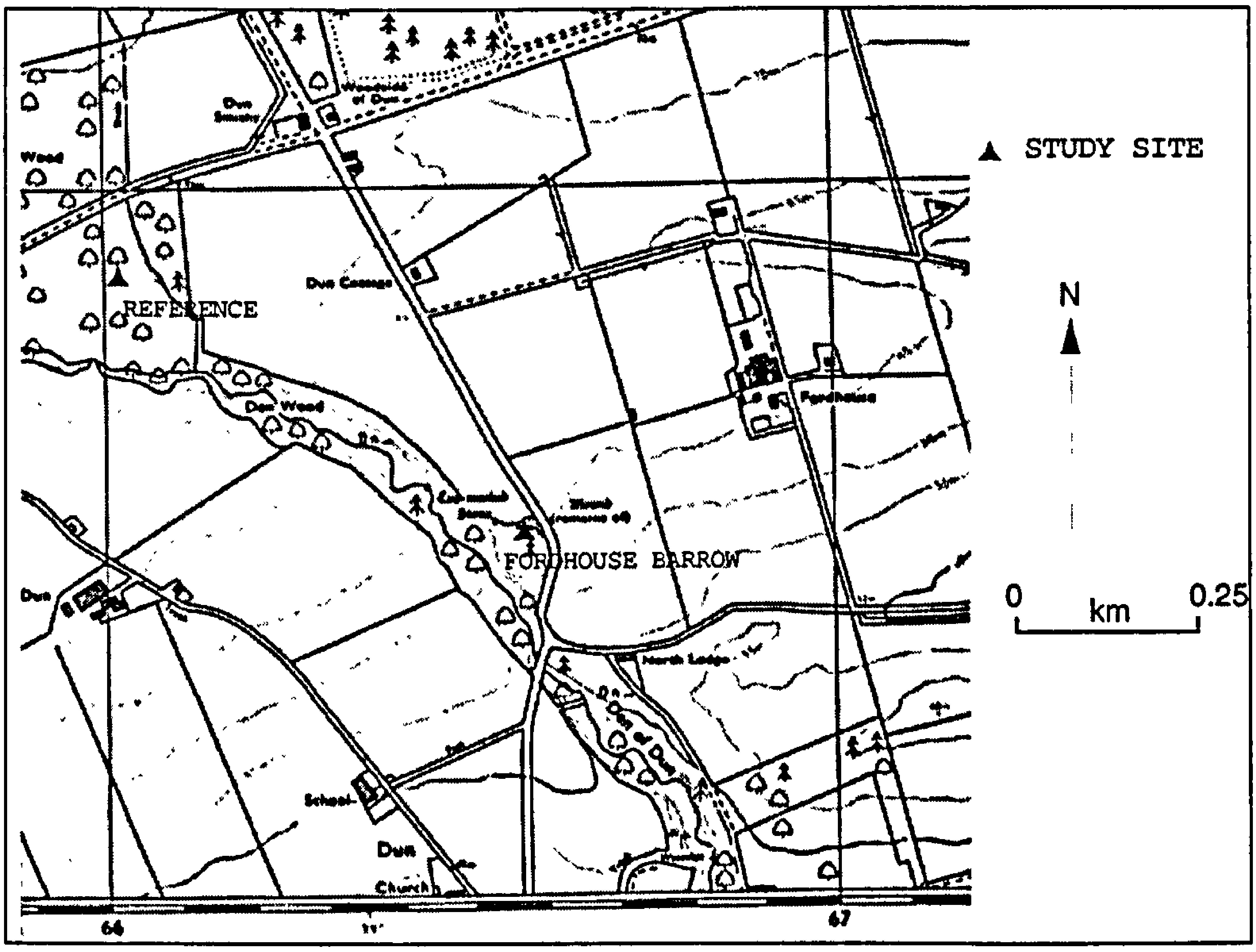
Figure 3.2: Map showing the location of study regions throughout England and Scotland.



choice becomes very limited. In fact the study regions chosen to complete this research project were the only excavations / accessible archaeology with buried soils meeting the research framework requirements that were available. The constraint of one field-sampling season was necessary because of the relatively long time periods involved in the manufacture of thin sections and their micromorphological description. The individual study regions are briefly described below, and their locations are shown on figure 3.2.

3.2.1 The preliminary study site of Fordhouse Barrow, Angus.

Figure 3.3: Map showing the location of Fordhouse Barrow burial mound and the reference profile.

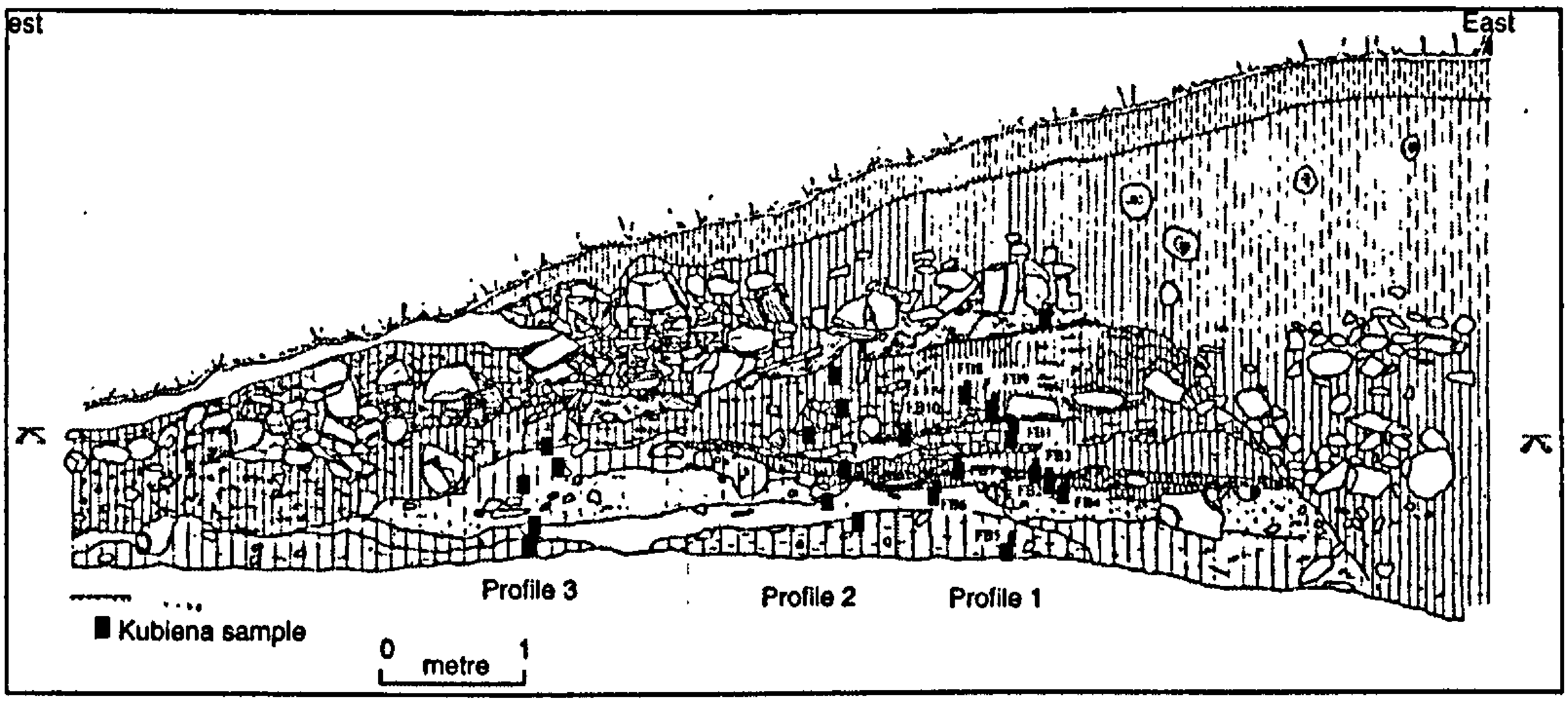


This Late Neolithic / Early Bronze Age site in Angus, Scotland (NO 6658 6053) is situated upon the edge of a 19th century sandstone quarry. Quarrying activity had removed part of the mound and the remainder was under threat from rabbit and tree root disturbance. The mound has a diameter of approximately 20m and is ca. 2.5m high. The site lies upon Old Red Sandstone derived tills, which locally support acid brown earths and iron podzols of the Balrownie association. Excavation of the site began in 1994 and revealed a burial mound dating to the Early Bronze Age with several peripheral later burials added dating through to the Medieval. In the final 1998 excavation season, a Neolithic passage grave was uncovered beneath the mound. In the course of excavation the disturbed southern face was cleaned back to reveal a discontinuous buried soil. During the 1996 excavations, thin sections were taken from the central most portion of the buried soil and the overlying mound material (Figure 3.4); these initial samples were studied by Dr. Ian Simpson, University of Stirling. The results of this study showed that the mound has been constructed of local soil materials, top-soil materials have been used in the lower 0.5 – 1 m portion, with sub-soil sands and clays used more frequently towards at the top of the mound (Simpson, 1996b). Beneath the barrow is sealed a brown forest soil with evidence of incipient podzolisation. A complicated array of amorphous iron and textural pedofeatures within both the mound material and the buried soil was noted and the possibility that at least some of these were post-burial features was raised.

This site was chosen as the preliminary study site because previous micromophological analysis had already suggested the possibility of post-burial iron and clay movements through the mound and the buried soil. Knowing that post-burial textural and amorphous iron pedofeatures were present (Simpson, 1996b), made this ideal as a preliminary site upon which to test the sampling strategy and analytical scheme. No further archaeological excavations upon the Old Red Sandstone drift deposits in the area took place through 1997 and 1998, and it was not possible to expand upon the single site study to include variation in the time since burial variable. However, as the buried soil appeared sporadically over the breadth of the exposed section from the deeply buried central portion to the shallower periphery, the effects of depth of burial were investigated. Suggestions of a two-phase construction process consisting of an initial ring cairn, later infilled to form the mound, meant that the very edge of the mound had to be avoided to ensure comparable dates between the profiles. However, three profiles from beneath contrasting depths of overburden material were sampled, the shallow, outermost of which was preserved beneath stone work (Figure 3.4). Field descriptions are given in appendix 4, pp 352-355.

An unburied, reference profile was selected in the mixed broad leaved and coniferous Den Woods 200 metres to the north of the site. A flat site neither receiving nor supplying material was chosen well away from the drainage ditches criss-crossing the woods. These are not primary woods, but they are amongst the most mature locally. The acid brown forest soil was formed upon the same sandstone drifts as underlay the barrow, profile drawings and field descriptions are given in Appendix 4, pp 351-352.

Figure 3.4: Section drawing from Fordhouse Barrow showing the three sampling profiles.

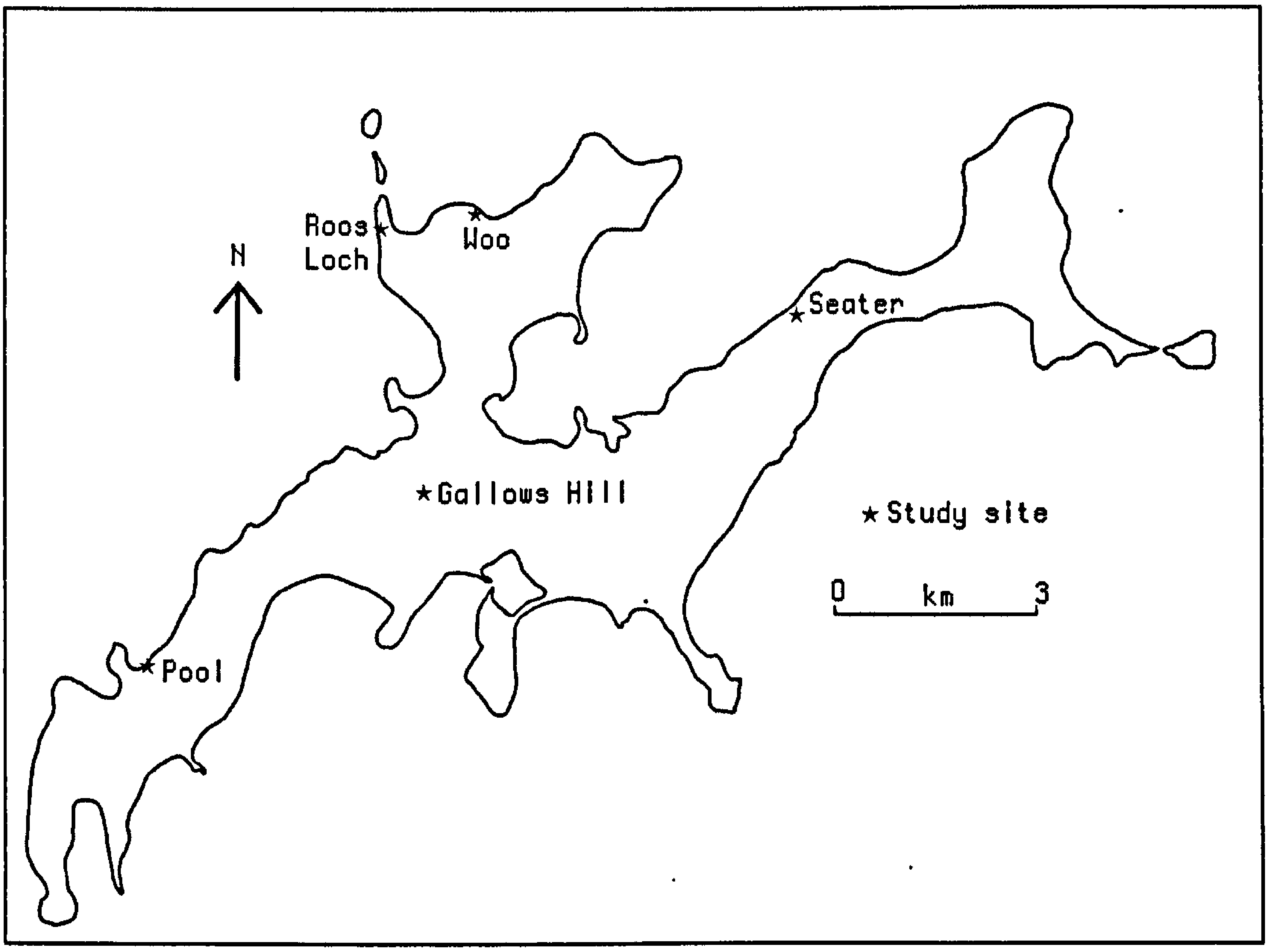


3.2.2: Study region 1. Sanday, Orkney

The island's (Figure 3.5) geology is dominated by Old Red Sandstone and Old Red Sandstone derived tills. These support soils belonging to the shallow and intermediate phase Bilbster series of freely and imperfectly drained soils which have been reclaimed from peaty podzols and are now classified as cultivated podzols (Futty and Dry, 1977). The island was chosen for study because of the high density of archaeological sites, varying in age from Neolithic through to the Medieval, upon an island ca. 40 km^2. This, together with the actively eroding coastline, presented a range of possible sampling opportunities from the exposed sea sections cutting archaeological sites. The geology here is comparable with the preliminary study site of Fordhouse Barrow, and so the Sanday study region helps to place this otherwise isolated site more firmly within the overall research framework. The sites were identified by reference to the archaeological survey of the islands of Sanday and

North Ronaldsay (Lamb, 1980) and through field reconnaissance. The sites all fell within an 8km radius and so macro-environmental differences could be expected to be low. The main inter-site differences, besides age, are expected to be attributable to differences in the levels of exposure to sea spray determined by aspect and geomorphological shelter.

Figure 3.5: Map of the location of study sites in Sanday, Orkney.



Gallows Hill (OS HY651 408)

This is a modern unburied reference profile from a shallow phase, imperfectly drained, Bilbster soil. This central island location supports the only surviving patch of uncultivated heather heath on Sanday (figure 3.6). Field descriptions are given in appendix 4, p. 355.

Figure 3.6: View of Gallows Hill site.

Roos Loch (OS HY645 454)

This site is in the far North of the island with a westerly aspect and is located at the edge of a small sandstone quarry. The shallow phase Bilbster soil is buried beneath a mound of stripped soil and solid rock upcast from the creation of a shallow extension to the quarry some 3-5 years previously. The quarry cuts the corner of the mound exposing a profile of the buried soil (figure 3.7). For sampling the mound was dug back and the buried soil profile cleaned back by up to 0.5m. The exposed profile faces seawards and is distant from the 10m high rock cliffs by some 20-30m. Although some metres clear of the splash zone, as delineated by the occurrence of the black lichen *Verrucaria* along the top of the cliff, the profile still receives significant amounts of sea spray. Field descriptions are given in appendix 4, pp. 356-357.

Figure 3.7: View of Roos Loch site.

Seater (HY 7205 4359)

Listed as nothing more than a prominent tell (Lamb, 1980); this site on the northern coastline (figure 3.8) was assumed to be Norse. C^{14} dating of bone and shell recovered from the interface of the midden and the underlying soil was undertaken. Two profiles were taken from within a test pit at the top of the mound within which there appeared to have been a shallow, shelving midden deposit, beneath which was an apparently well preserved soil. Within the deposits the presence of dressed stonework was noted. Occupation and garden cultivation at the top of the mound had occurred recently. Field descriptions are given in appendix 4, pp. 357-359.

Figure 3.8: View looking northwards from Seater.

Woo (HY 6679 4533)

Situated upon a small headland in the very north of the island with a north-facing coastline, this site is a limpet midden 0.8m thick with evidence of substantial stone work within the rapidly eroding face (figure 3.9). A second, thinner midden deposit on the opposite face of the headland revealed a series of dressed stone 'floors' within the midden deposits. Upon the mound is a house and barns, to the side is an abandoned mill originally used to drain the now reinstated marsh behind. Slump and otters had damaged the section and limited the sampling possibilities. The area is mapped as Bilbster series soils, and the modern soils to the west of the midden agree with this categorisation although they appeared to have been deepened by inputs of windblown shell sand. To the east is a sandy beach and dune system behind which the modern soils are freely drained brown calcareous soils of the Fraserbrough series. Beneath the midden deposits is an intermittent, buried land surface, consisting of a series of brown and grey thin horizon and laminae separated by layers of white shell sand of variable thickness. This laminar horizonation closely resembled the sequence seen in dune soils with primary, stabilising dune grasses. The buried soil represents a soil of the skeletal Fraserburgh series. Field descriptions are given in appendix 4, pp. 359-363.

Figure 3.9: Views of the midden at Woo.

Pool (HY 6194 3785)

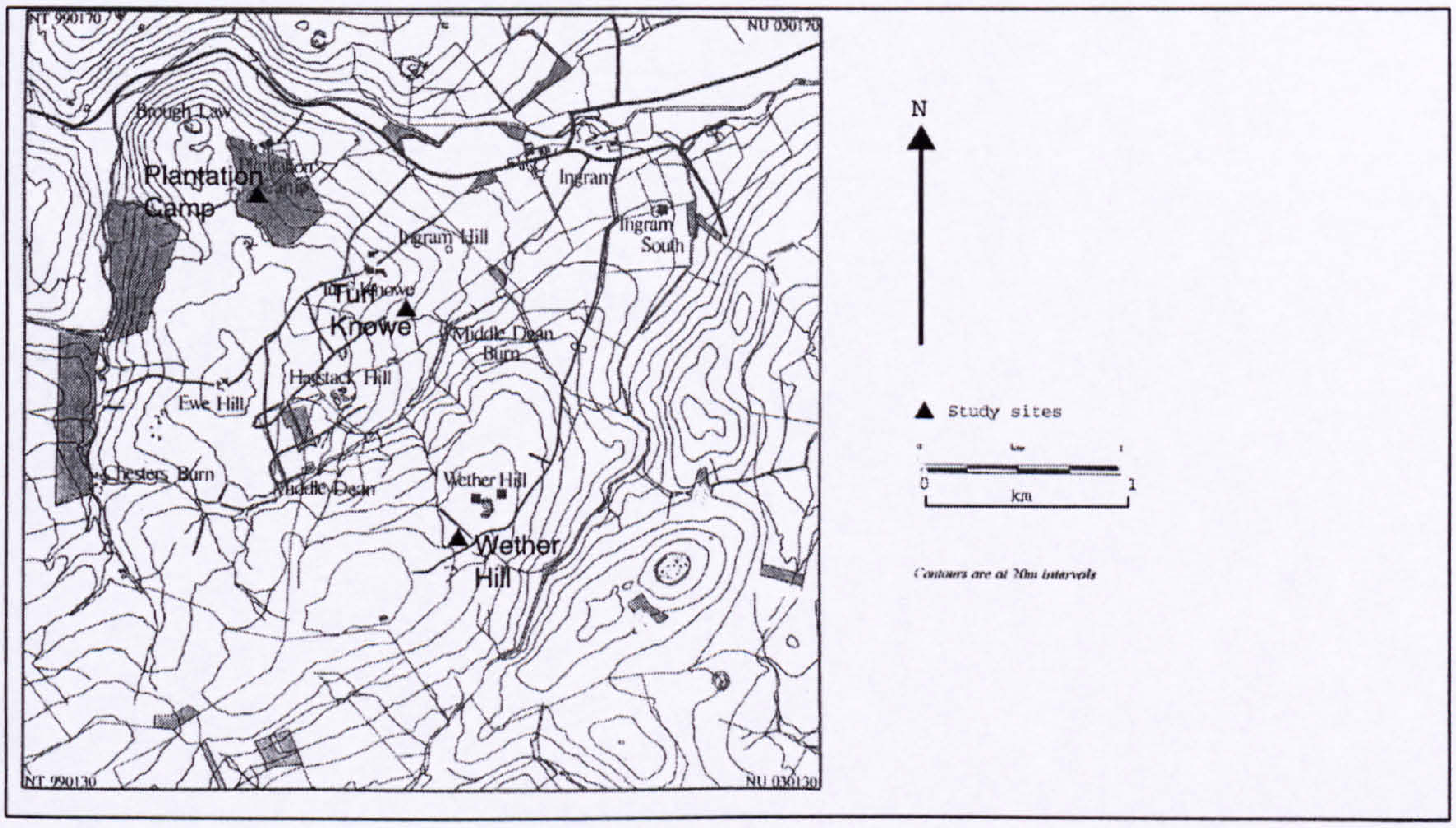
This settlement mound, exposed in a coastal section on the west coast of the islands south western peninsula, consists of midden deposits up to 2.5m thick in places (figure 3.10). Finds from this site date to the Norse, Iron Age, and Pictish periods. The site is rapidly eroding despite being situated within a sheltered bay inlet. The recording and partial excavation of this site has dated the basal deposits to the Neolithic and subsequent events to the Iron Age and Norse periods (Hunter and Dockrill, 1982; Hunter, 1988). The samples were taken from beneath the central portion of the site where the three phases of deposition could be clearly identified; the initial date of burial was, therefore, assumed to be Neolithic. The remnants of an original soil buried beneath this site were heavily truncated in both of the profiles sampled. Field descriptions are given in appendix 4, pp. 363-367.

Figure 3.10: Midden and view northwards from Pool.

3.2.3: Study region 2. The Breamish and Ingram Valleys, Northumberland

The Breamish and Ingram Valleys (figure 3.11) lie within the Northumberland National Park, upon a geology of intermediate andesites and locally derived drifts. Periglacial activity dated to the Loch Lomond stadial has formed fragipans and solifluction terraces across much of this area (Payton, 1992; 1993a; 1993b). The valley slopes and hill tops are covered by relicts of pre-historic anthropogenic occupation and agricultural activity. Bronze Age cairns, Iron Age hill forts and ring-groove houses, Romano-British scooped settlements, Medieval and post-Medieval remains suggest a long history of occupation. Agricultural remains include hillside terraces, and both cord and broad rig. Many of these agricultural remains are thought to be pre-historic in origin. The prominent agricultural terraces are thought to be deliberate single-phase constructions (Topping pers. comm.). Charcoal from beneath a terrace in the Ingram valley has been dated to the Neolithic, 5190 +/- 70 BP (Adams and Carne, 1997). Reworking of old charcoal is a possible cause of this very early date, but elsewhere terraces have been given an Early Bronze Age *terminus ante quem* and in some areas pre-date cord rig (Topping, 1989). The cord rig is thought to be the result of spade and ard cereal cultivation, and is known to date from the Early Bronze Age through to the 15th Century AD in Scotland and Northumberland (Carter *et al.*, 1997). The broad and reverse-S rig is formed by a mouldboard plough and dates to the Medieval and Post-Medieval. Alluvial sequences (Mercer and Tipping, 1994) and pollen studies (Davies and Turner, 1979; Turner, 1979) suggest phases of clearance, pasturing and landscape instability in the Early Bronze Age and Late Iron Age. The modern soils in this area are shallow acid brown earths and stagnopodzols of the Sourhope Association which support the heavily grazed, dense *Festuca-Agrostis* sward distinctive of the area (King, 1962). Two sites and a reference profile were sampled.

Figure 3.11: Map of the study region of the Breamish and Ingram Valleys, Northumberland, showing sampling positions.



Turf Knowe, Area 11 cord rig (OS NU002 157)

This section was first opened in 1996 and was then deepened and extended in 1997. It revealed cord-rig cut into an underlying fragipan and tills with an associated buried soil buried beneath a stone and earth bank and colluvium (figure 3.12). Charcoal from the buried soil has given a Neolithic date of early 4th Millennium BC (Adams and Carne, 1997); this ties in with the date from the nearby terrace, but again may be the result of reworking. The stratigraphic relationship of this cord rig with an Iron Age building abutting the section reveals that the buried soil pre-dates the structure and so can be no later than the Iron Age (Adams and Carne, 1996). Ard marks at a comparable level were also uncovered. Two profiles were taken from beneath the bank structure and their field descriptions are given in appendix 4, pp. 377-378.

Figure 3.12: View looking across Turf Knowe.

Wether Hill, Cross-ridge dyke (OS NU015 148)

The cross-ridge dyke is associated with the adjacent Iron Age hillfort. The dyke runs for a distance of 30m and consists of a ditch approximately 0.75m deep accompanied by an inner bank apparently constructed from the ditch spoil (Adams, 1995). Trenches across the ditch and bank were excavated in 1994 and 1995 and a buried soil beneath the bank was revealed. Dates from this turf line date from the Middle to Late Iron Age, 385 – 20 cal BC (Adams and Carne, 1996), but because of the difficulties in dating soil organic matter the true date may be somewhat more recent. The bank section was reopened in 1997 and three profiles from the centre to the outer edge of the bank were sampled. Field descriptions are given in appendix 4, pp. 375-376.

A reference profile was taken from level ground beneath the mature, mixed woodland besides Plantation Camp (OS NT 998 161, figure 3.13). Again, a primary woodland could not be found, but this was the most mature woodland in the area that was upon the same geology. The ground layer consisted of *Holcus*, *Festuca* and *Agrostis* grasses, together with bracken, and occasional sedges. The field descriptions are given in appendix 4, pp. 376-377.

Figure 3.13: View of Plantation Camp.

3.2.4: Region 3. South Cadbury, Somerset

The third sampling region centres upon the village of South Cadbury in Somerset (figure 3.14). This area was made famous by the 1966-1970 excavations of South Cadbury Castle undertaken by Prof. Leslie Alcock with the intention of finding archaeological evidence to link this prominent hill fort with the Camelot of Arthurian myth (Alcock, 1972). This excavation revealed a seemingly continuous settlement sequence dating from the Neolithic through to the establishment of a Saxon mint belonging to Ethelred the Unready. The fortifications date to the Iron Age and the remains of a 5th – 6th century hall were also uncovered (Alcock, 1972). More recently, excavation and survey of the lower slopes of the castle and the surrounding area has been undertaken by Glasgow and Birmingham Universities as part of the 'Cadbury environs project'. This project has centred upon the site of Milsoms Corner beneath the Iron Age fortifications and with occupational evidence dating from the Neolithic to the Iron Age, but has also included the excavation of a Bronze Age barrow and a Roman settlement 4km away at Sigwells. The geology of the surrounding area is a complicated sequence of Jurrasic Lias clays, Oolitic limestone, and sands dissected by

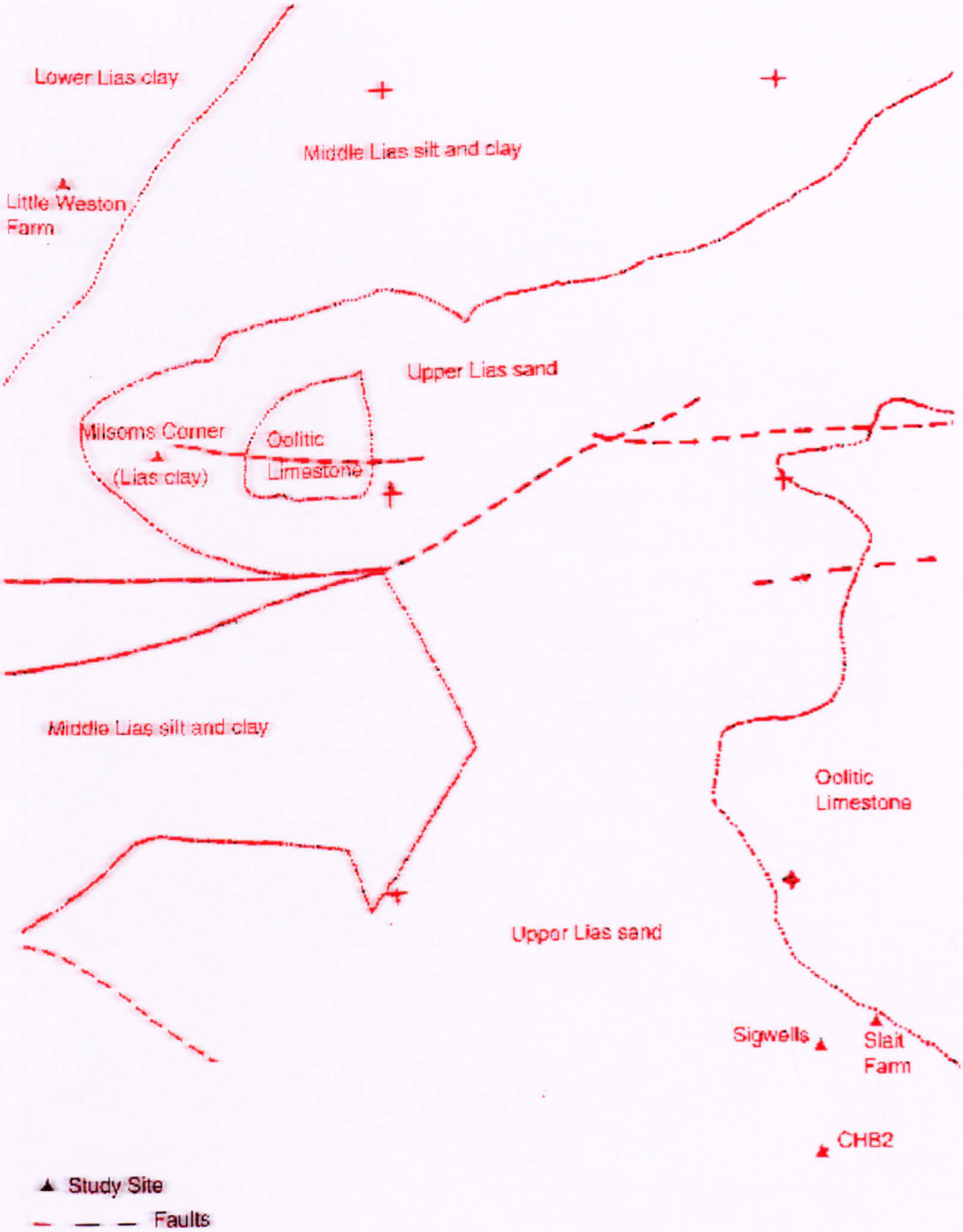

Lower Lias clay
Middle Lias silt and clay
Little Weston Farm
Upper Lias sand
Milsoms Corner
(Lias clay)
Oolitic Limestone
Middle Lias silt and clay
Oolitic Limestone
Upper Lias sand
Sigwells
Slait Farm
CHB2
Study Site
Faults

Figure 3.14: Map of the Somerset study region with overlay showing sites and simplified geology.

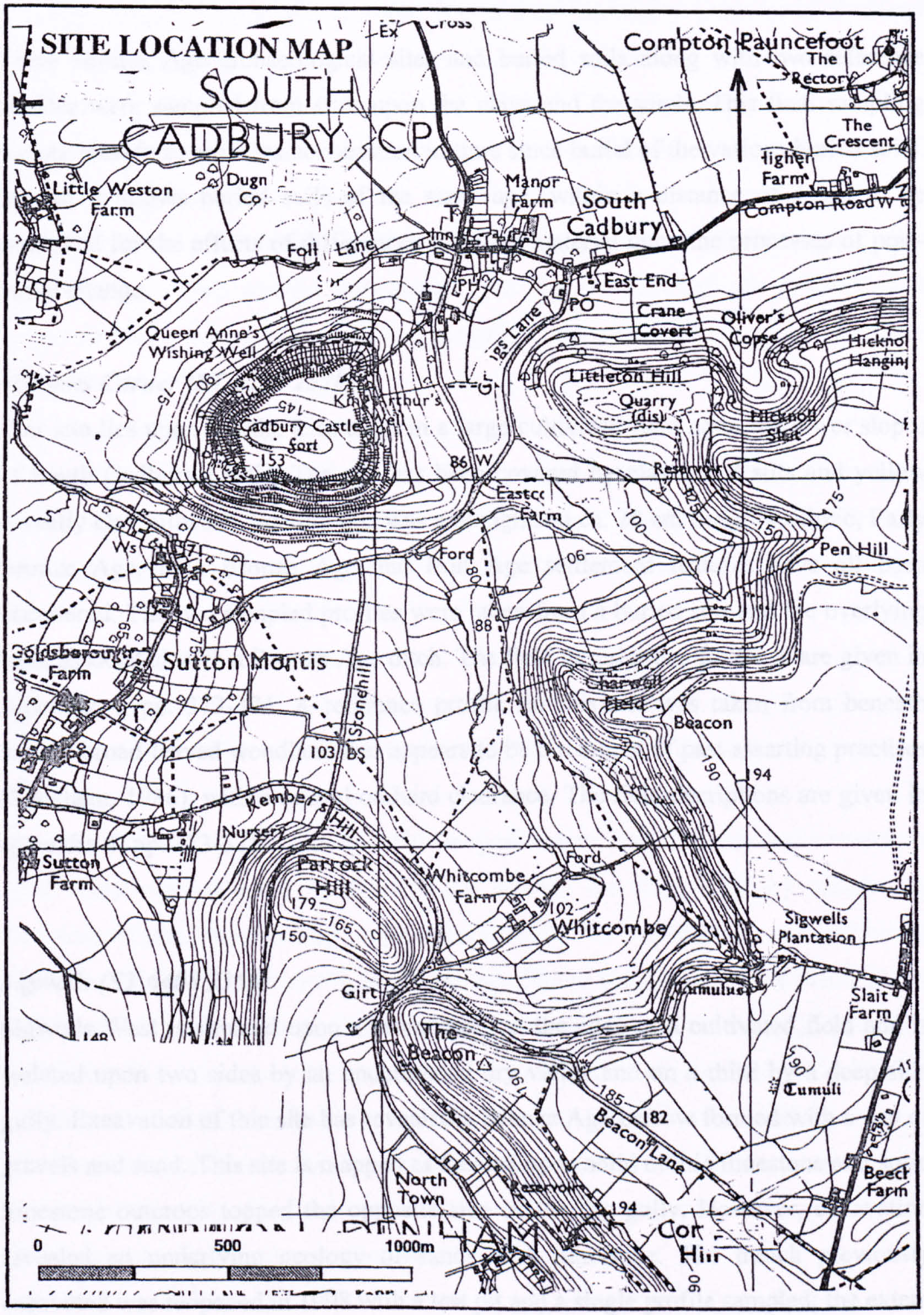
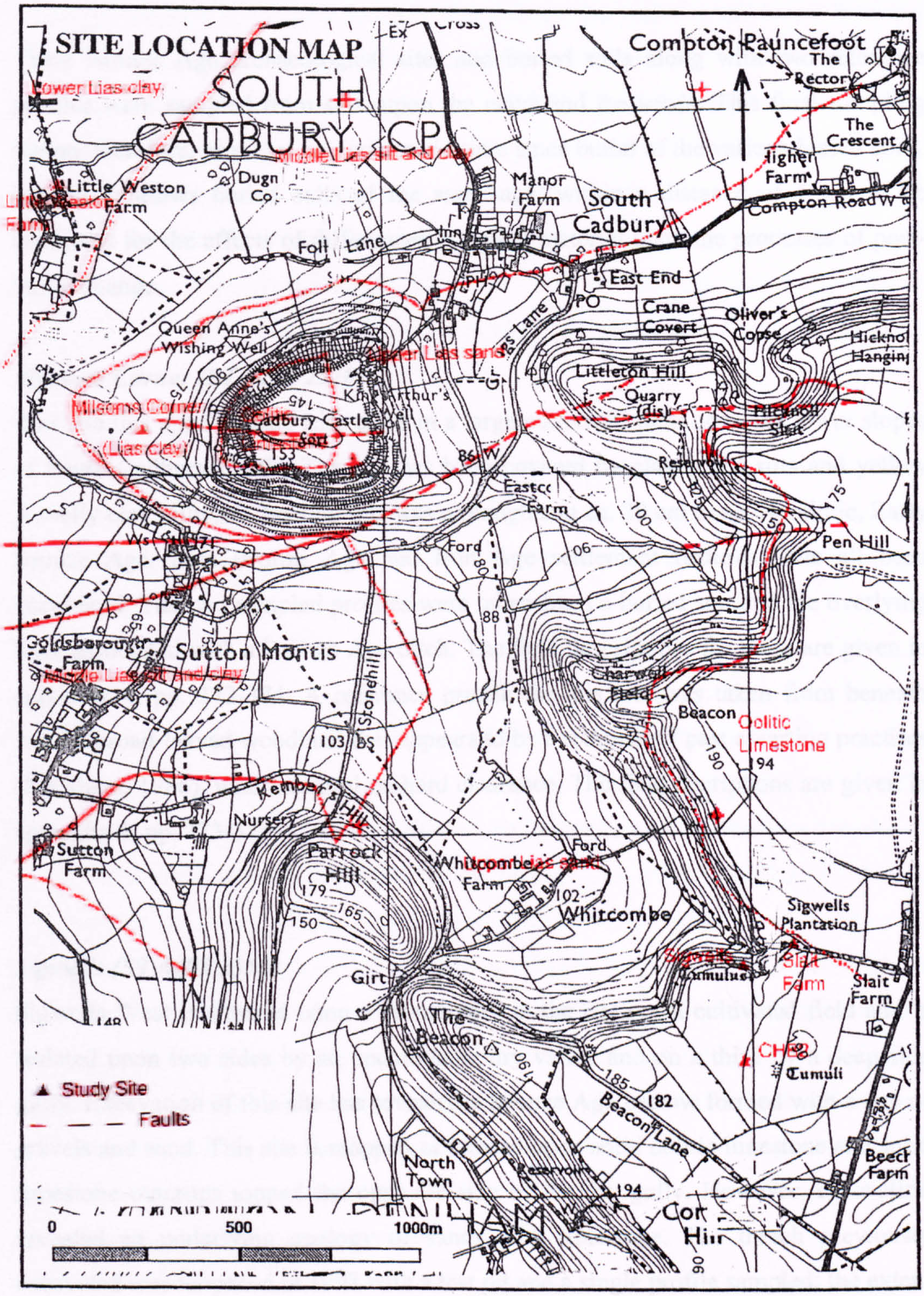


Figure 3.14: Map of the Somerset study region with overlay showing sites and simplified geology.



faulting. These support freely and imperfectly draining, brown earths and calcareous brown earths of the Martock and Atrim series.

Three Bronze Age archaeological sites and buried soils along with two reference profiles were sampled from sites upon the clays and the sands. This final sampling region, therefore, provides no variation in time since burial of the various buried soils. Instead it allows buried soils of the same age, within a distance of 4 km to be examined for the effects of differences in parent material upon the processes of post-burial change.

Milsoms Corner (ST 6230 2520)

This site lies upon Middle Lias clays in a large cultivated field upon the lower slopes of South Cadbury Castle. The site has been covered by clayey red silts and yellow gravelly clay hillwash. Sealing this was a plough soil ca. 20 cm deep. Neolithic, Early Bronze Age, Late Bronze Age and Iron Age settlement features have all been uncovered. The two sampled profiles were taken from a buried soil and the overlying bank associated with a Bronze Age ditch. The field descriptions for these are given in appendix 4, pp. 373-374. A reference profile for this site was taken from beneath mature broad-leaved woodland that appears to be a remnant of past assarting practises (Rackham, 1986), with a central orchard clearance. The field decriptions are given in appendix 4, pp. 373-375.

Sigwells (ST 6408 2356)

Sigwells West is situated upon a promontory at the edge of a cultivated field and is isolated upon two sides by an uncultivated dry valley and on a third by a deep side gully. Excavation of this site has revealed a Bronze Age barrow formed with a cap of gravels and sand. This site is mapped as located upon solid oolitic limestone and solid limestone outcrops topped the opposite side of the dry gully. However, excavation revealed an underlying geology of sands with limestone. The trench previously excavated was reopened in 1998 with a test pit and a single profile sampled; the extent of the test pit did not provide for sufficiently different depths of burial to justify further sampling. The field descriptions are given in appendix 4, pp. 368-371.

CHB2, (ST 6411 2354)

This site consists of two overlapping Bronze Age barrows which are situated 500m to the south east of the Sigwells Barrow. The barrows lie within a cultivated field and ploughing has extended the barrow outline in a north and south direction. Test pits were dug into both barrows in the autumn of 1997. The north slope of the northern Barrow and the east slope of the southern most Barrow were excavated, no buried soil was identified from the first, but one was located beneath the second. The capping material of the barrow was similar to that of Sigwells and the geology was again sands with limestone. Two profiles were taken from this site although the differences in depths of burial were minimal. Field descriptions are given in appendix 4, pp. 371-373.

A second reference profile (ST 6412 2356) for these two sandy soil sites was taken from beneath mature broad leaved trees with a closed canopy along the side of a nearby lane running from Slait Farm. Field descriptions are given in appendix 4, pp. 367-368.

3.2.5 The place of the sampling regions within the research framework

These three study regions, together with the preliminary site, form the core framework upon which this research is based. They provide the framework by which any processes of post-burial change in their buried soils can be compared and contrasted so that meaningful statements as to the nature of these changes might be made. Table 3.1 shows how these sites fit into the research framework with respect to the study variables of parent material, time since burial and depth of burial. The main contemporary climatic differences between these study regions are outlined in table 3.2. These environmental variations will have had a formative effect upon the nature of the modern soil profile while past climatic variations may account for some of the inter-regional variation observed within the buried soils.

Table 3.1: The relationship between sample sites and study variables.

Parent Material				
	Acidic	**Acidic**	**Intermediate**	**Basic**
Region	Angus	Orkney	Northumberland	Somerset
Neolithic		Pool (2)	Turf Knowe (2)	
Bronze Age	Fordhouse (3)			Sigwells (1),CHB2 (2), Milsom's Corner (2)
Iron Age		Woo (2)	Wether Hill (3)	
Norse		Seater (2)		
Modern		Roos Loch (3)		
Reference	Woodland (1)	Heath (1)	Woodland (1)	Woodland (1)

figure in brackets represents number of profiles.

Ten buried soils were sampled and these had developed over a range of parent materials resulting in soils which were expected to differ with respects to their base status and textural characteristics. These properties should in turn have resulted in differences between the soils in respect of their structural and physical, biological, and chemical characteristics. The respective ages of the buried soils stretch from the Neolithic through to a modern buried soil only five years old. Not all of the study regions however encompass this range of dates, and indeed the sites in Somerset are all dated to the Bronze Age. It is the sites on Sanday, Orkney, which provide the most complete temporal framework. The depth of burial variable was often the hardest to satisfy because of the limitations of test pitting as a means of opening the site, problems with access to parts of the exposed sections, and the discontinuous nature of the buried soils exposed at others. Nonetheless at all but one site, two or more profiles were described and sampled with contemporary depths of burial falling in a range between 50 cm and 3.5 m.

Table 3.2: Regional climate data

	Altitude ASL metres	Mean Annual Temp C Min/ Max	Mean July Temp C	Mean Dec. Temp C	Mean Annual Precip. mm.	Monthly Precip. Max. mm.	Monthly Precip. Min. mm.	Average Annual Sunshine Hours
Somerset	75-175m	12.9 5.7	20.6 12.5	5.9 0.0	781	Dec. 92	Jul. 38	1670
Northumberland	250-300m	10.9 3.1	18.2 8.5	4.5 -1.0	1276	Dec. 138	Apr. 74	1385
Angus	55m	11.9 4.6	18.5 8.5	6.0 0.2	701	Jan. 69	Apr. 45	1481
Orkney	5-15m	10.2 5.0	15.1 9.5	5.8 1.5	1009	Nov 123	May 50	1119

Climatic data taken from Wheeler and Mayes (1997) and covers period 1961-1990

4. Field and laboratory methodologies.

4.1 Field methodology

The aim of any sampling exercise is to obtain a representative sub-sample of the population being studied in order that meaningful statements and predictions about the properties of that population can be made. The ideal situation is to achieve a balance between the number of samples and the quality and reliability of the information about the underlying population that this sub-sample contains. For a sampling scheme to be successful, therefore, it is necessary that close attention is paid to the research hypotheses, and that the sampling strategy is devised so that they can be tested. The result should be that the maximum amount of relevant and statistically valid information is retrieved from a minimum of samples. This section addresses the theoretical questions involved in field sampling, the scheme adopted for this research, and how this scheme was designed to tackle the research questions.

The process of field sampling involved five distinct stages, (1) the choice of sites within each region, (2) the opening of the site and exposure of the buried soil, (3) the description and recording of the exposed sections, (4) sampling for thin sections, and (5) sampling for bulk physical and chemical analysis.

4.1.1 Site choice.

The choice of sites to be sampled within each region was perhaps the most the most crucial decision and ultimately this was made in the field. Although the sampling possibilities would already have been assessed through site reports, published literature and consultation with the relevant archaeological bodies, it was not until a site visit that the whole range of possible environmental variables and controls could be properly assessed. For example, the presence of an actual buried soil could be more satisfactorily verified, and factors such as site elevation and slope, possible site disturbance, and other local environmental variables could be assessed. The choice of individual sites within each of the regions has largely been addressed within chapter 3, but was unfortunately all too often determined by availability.

4.1.2 Exposure of the buried soil and profile description.

The excavation of the site trench and exposure of the section was the next stage. At some sites, including Fordhouse Barrow, Turf Knowe and Milsom's Corner, the trenches had already been dug. The period of time elapsed between exposure of the section and sampling is a crucial factor with respect to many of the processes that could be occurring within the archaeological site and its buried soil following burial. In particular the opening of the site may very quickly alter the redox conditions, which in turn may result in the onset of aerobic processes in parts of the profile that previously have been anaerobic. Where possible, therefore, the samples were taken as soon as possible after the opening of the section. Although many sites were freshly opened a few had been open for longer; in the case of Fordhouse Barrow the section sampled had been cut nearly three years earlier, whilst the sea sections of Sanday had been open for an unknown length of time. Fortunately, for many of the processes being investigated this is not an insurmountable problem as the features associated with clay illuviation and iron redistribution are relatively stable (Yaalon, 1971) and so should survive as relicts of pre-excavation burial conditions.

The ideal excavation trench is one that traverses the centre of the burial mound, bank etc. exposing the full overburden / buried soil profile, allowing maximum sampling opportunities and giving access to the full range of burial depths. Such an approach would create massive damage to the archaeological monument and so where such a section was not already in place, this approach was avoided. In such cases where a section trench had not been provided either through natural sea erosion or as part of the larger site excavations, a small (1m x 2m) test pit had to be excavated. The siting of such trenches is crucial as the trench has to locate a preserved buried soil and, if possible, provide the opportunity to sample beneath different depths of overburden. The trenches were, therefore, sited on the slope of the upstanding sites, close to the summit. This approach gives the maximum depth gradient over the short distance of exposed section face, whilst the centralised position maximises the probability of finding a preserved buried soil and reduces potential problems of erosion and deposition confusing the original site boundaries. The profiles from previously opened sections were thoroughly trowelled back to reveal a fresh surface.

The profiles were drawn and described according to the standard procedures described in the Soil Survey Field Handbook (Hodgson, 1976). Soil colour was determined according to the Munsell (1956) scheme in field and moist states; the colour, size, abundance and contrast of any mottling present was also recorded. Soil texture was described by hand and the nature of the horizon boundaries detailed. Soil structure and ped strength were noted. Inclusions, field evidence of iron staining or weathered stone rims, roots, anthropogenic artefacts, and charcoal also had to be recorded.

4.1.3 Field sampling

The sampling strategy required the collection of three types of soil samples from all sites. The samples consisted of undisturbed blocks for thin sectioning, bulk soil samples for chemical analysis, and bulk soil samples of known volume for the determination of physical properties. Each of these sample types involved different priorities and techniques for their collection and post-excavation treatment. The retrieval of adequate and apt samples for all these analyses within a single site visit was important because in the course of archaeological excavation each site is effectively destroyed, thereby precluding repeat sampling visits. For this reason an effective sampling strategy had to be devised before the field visit was made.

4.1.3.1 Kubiena samples

Undisturbed blocks of soil were collected using Kubiena tins (8 x 6 x 5cm). These tins were carefully cut around and pressed into the exposed section. They were then marked with sample number and orientation relative to the soil surface, before being cut out of the face, sealed and bound. The tins were placed into polythene bags and if processing could not start soon after they were kept refrigerated to reduce biological activity. The biggest investment of time and resources in soil micromorphology is the manufacture and subsequent analysis of the sections. It was important, therefore, that the initial sampling scheme was designed to collect as efficiently as possible samples to address the research questions. Murphy (1986) lists the points that have to be established before sampling as:

- What is the purpose of the sampling?
- What orientation of the eventual samples is needed?
- What size of sample is needed, and what replication is required to characterise the components or volume of material being investigated?

Two main sampling methods have been described by Courty *et al.* (1989), selective and systematic. Selective involves sampling to answer specific questions about context or composition of a particular stratigraphic unit, for example, Exaltus and Miedema (1994). Systematic sampling involves sampling the entire vertical profile in order to look at profile dynamics.

The aim of this research was to evaluate the prevalence of particular pedogenic and post-burial processes that had been hypothesised to operate within the archaeological profiles. The emphasis upon 'processes' in this work necessitated the adoption of the latter, systematic sampling scheme with the tins placed vertically into the soil face to obtain a continuous, vertical profile as the preferred approach. The sampled profile needed to include both the buried soil and the overburden so that the interaction of the two units could be studied. However, systematic sampling was not always possible because of stones or masonry within the substrates sampled. In cases where a continuous, vertical profile could not be obtained, samples were taken with the aim of obtaining as full a profile as possible. To do so tins were staggered around obstructions with the horizontal displacement from the vertical sample profile kept as small as possible. The result of this lateral displacement is to interrupt the profile continuity, because of the heterogeneous quality of many soil properties the comparisons possible within a vertical profile are no longer as valid. At other sites the section height from the top of the overburden down through the buried soil was too great to allow a complete profile to be sampled because of the time and cost issues involved with thin section work. In these cases, careful selectivity in the sampling scheme was very important.

Where selectivity is necessary, there are two approaches to siting samples that can be used. For classification purposes it is recommended that samples are taken from a central position within each of the soil horizons to give a representative sample of each horizon (Miedema, pers. comm.). The second approach is to sample across the horizon boundaries so that each thin section covers the boundary zone and at least two adjacent soil horizons. The detailed characterisation of individual soil and sedimentary horizons was of secondary importance to this study, which concentrates on soil processes. This may benefit from the study of horizon boundaries where contrasting horizon properties are highlighted. For this reason, the sampling of soil blocks for thin sectioning concentrated upon the horizon boundaries and in particular upon the interface between the buried soil and the overburden. This method has the added advantage of reducing the total number of slides required.

The number of samples taken should ideally account for the majority of the variance in a particular soil characteristic. This has previously been addressed using a nested sampling approach upon three levels, namely Kubiena tins, thin sections, and microscopic frames (Ringrose-Voase and Humphreys, 1994), in which multiple thin sections are manufactured from each tin, and multiple frames examined within each section. The variability of any soil characteristic cannot reliably be known prior to sampling, but is likely to be both site and soil specific. Puentes *et al.* (1992) found that the precision in the study of porosity in Vertisols was increased significantly in two Kubiena tins over one with five sections per tin and five microscopic frames per section. Murphy (1983) found that although porosity could be effectively measured from four slides, the estimation of illuvial clay (a highly heterogeneous property, and one central to this study) could not be relied upon. In general, Murphy (1986) suggests that six samples per sub-surface horizon should be sufficient with one section taken from each.

Because of the number of sites sampled, the total number of slides was necessarily going to be high, and prevented the taking of replicate tins. The lateral sampling of numerous profiles for 'depth of burial' however, did mean that up to three tins were taken from single horizons and these should indirectly address the lateral variability of the soil. Only one finished section was taken from each tin, but the quantitative element of slide analysis did involve the examination of numerous microscopic frames per slide.

The same sampling principles were applied to the reference profiles as to the archaeological sites. A few samples were too stony and / or compacted to allow sampling with Kubiena tins. Where the materials were cohesive, enough these were hand cut from the face and wrapped carefully in stiff aluminium foil for support, otherwise these were treated with the same standard procedures. In total 140 Kubiena samples were taken from the field and returned to the thin section laboratory at the University of Stirling.

4.1.3.2 Bulk chemical and physical samples

Bulk soil samples were taken to provide more detailed chemical and physical information to support the properties described and catalogued from the thin sections. The aim of bulk sampling was to establish both the nature of the physico-chemical burial environment and to characterise the overburden and the buried soil properties that may have affected their response to burial and the ensuing burial conditions. The sampling scheme evolved in response to the following questions.

- Which materials should be sampled in order to address the research questions?
- Where should the samples be taken from?
- Which analyses were to be carried out upon the materials and how would these affect the their collection and treatment?
- What volume of material should be taken and with what lateral and vertical extension?

To assess the movement of materials between the buried soil and the overburden, it was necessary to sample both materials and in order to address the overall dynamics a systematic, continuous profile was again the best sampling option. As this data was to support and relate to the thin sections, it was desirable that any samples were taken from close-by and at the same time as the Kubiena tins. This was achieved by taking the bulk samples from directly behind, or to the side of the Kubiena tins. Bulk samples, therefore, were concentrated around the overburden / buried soil interface. To characterise the upper horizons, occasional context samples from the top of the section were also taken.

The samples were used in the determination of soil bulk density, particle size distribution, moisture content, loss-on-ignition, soil pH, and iron concentration. The samples for the determination of bulk density, moisture and loss-on-ignition were taken collectively as one sub-sample and the soil for the remaining analyses jointly within a second sample. The determination of bulk density requires the collection of a known volume of soil and this was achieved by taking a second set of soil blocks in Kubiena tins, which were then emptied into a labelled, sealed, polythene bag. This sample, being sealed was also used for the determination of soil moisture and was the most convenient source of material for the loss-on-ignition analyses. The second sample for pH, iron concentration, and particle size analyses consisted of loose soil collected within a labelled polythene bag, stored upright and left unsealed to prevent the build up of organic acids before their return to the laboratory.

The lateral and vertical extent of the samples is an important question as this relates to the question of soil variability and the representation of this within the samples. The size and extent of the bulk density samples was predetermined by the size of the Kubiena tin (8 x 6 x 4 cm) with a volume of 192 cm^3. The vertical extent of the second set of chemical samples was kept as small as possible as a high resolution was desirable in the study of profile dynamics. Samples were, therefore, taken continuously down profile in 3cm deep spits. This depth was the smallest size that could be accurately removed from the section face. It was also found to be a flexible size interval and minimised the overlapping of adjacent horizons; where overlap occurred the sampling was adjusted to prevent this. The horizontal extension of the sample allowed the bulking of highly heterogeneous soil properties and helped to reduce the possibility of bias in the sample. This advantage was balanced against the need to tie these samples together with the thin samples, and to limit the sampling within the profiles designated to meet the depth of burial variable. These samples therefore were laterally extended up to 10 x 10 cm, centred upon the depth of burial profile and the position of the thin section samples. In total therefore ca. 300 cm^3 of soil went into a bulk sample.

4.1.4 Summary of field sampling

Table 4.1: Summary table of Kubiena and bulk soil samples collected and analysed.

Site name	Thin section Kubiena samples	Kubiena samples for physical analysis	Loose soil for chemical analysis
Fordhouse Barrow	22	16	49
Fordhouse Reference	5	5	18
GallowsHill	3	3	12
Roos Loch	9	9	27
Seater	6	10	13
Woo	14	24	24
Pool	9	8	17
Plantation Camp	4	3	15
Turf Knowe	13	11	28
Wether Hill	10	14	21
Slait Farm	4	7	14
Sigwells	8	8	25
CHB2	7	13	17
Little Weston Farm	3	3	9
Milsom's Corner	6	3	18
Total	123	127	287

The field sampling was designed with the aim of collecting sufficient, representative materials from suitable locations to investigate the research hypotheses. The key components of this sampling strategy involved:

- Sampling of regions with contrasting parent materials, each of which contained sites of contrasting age, and in turn offered profiles with buried soils beneath different depths of overburden.
- Sampling of a modern, unburied, reference profile within each sampling region
- Detailed field description and recording of each sampled profile.
- Adoption of a continuous, systematic sampling scheme concentrated especially upon the buried soil and the interface between the buried soil and its overburden.

- Collection of three types of samples, undisturbed Kubiena samples for thin sectioning, Kubiena samples for bulk density and a bulk sample for other chemical and physical analyses.

The field element of this research successfully fulfilled these key requirements and amassed the samples outlined in table 4.1. The micromorphological, chemical and physical analyses for which these samples were collected are outlined below in sections 4.2 and 4.3.

4.2 Micromorphological analysis.

4.2.1 The theory of micromorphological analysis of soil thin sections.

Micromorphology concerns the qualitative, quantitative and semi-quantitative description of undisturbed blocks of soil at the microscopic level. This allows soil to be viewed with the spatial characteristics and relationships of different soil constituents preserved. A wealth of previous research allows the identification of the features present within the soil and the same experience guides interpretation of these features. The discipline revolves around the qualitative description of features in terms of their colour, size, shape, smoothness, optical characteristics, frequency, and distribution, at a range of magnifications and illuminations. These properties characterise the micro-fabric of the soil, sediment or other material.

The basic tool of a micromorphologist is a petrological polarising microscope. This allows the observation of thin sections not only in plane polarised light (PPL) but also under crossed polars (XPL). In cross polarisation the light transmitted by the polariser is fully absorbed by the 'analyser' (a polarising filter turned at 90$^{o)}$ unless it has first been refracted by any anisotropic material through which it has passed. This allows detailed observation of the optical characteristics of the materials in thin section and is especially used in the identification of mineralogy. Another technique is the use of reflected or oblique incident light (OIL}.

Problems with the technique revolve around the quantification of slide characteristics, and the relationship between the two-dimensional thin section and the three dimensional, dynamic, soil unit that it is assumed to represent. Whilst the first two problems can with care be accounted for, the latter is inherent and leads to a number of effects difficult to amend. Taking a two dimensional slice through a three-dimensional object can result in a two dimensional area which bears little logical relationship, both in shape and size, to the original 3D volume (Ringrose-Voase and Humphreys, 1994). As size and shape are two of the fundamental measures in micromorphology the consequences of this effect are deep rooted. The Holmes effect is another problem that leads to the overestimation of opaque and dark bodies in thin section, whilst wedging effects can lead to the underestimation of transparent particles such as quartz and void space (Bullock *et al.*, 1985).

Despite these problems, micromorphology is a powerful tool allowing *in-situ* examination of soil particles and the relationships between the different soil elements, from which functional dynamics can be extrapolated. For example, whilst field examination of a soil profile may reveal horizons richer in clays, the process of clay illuviation can only be positively confirmed in thin section where the presence of clay void coatings indicates down profile movement. Alternatively, the spatial relationship between iron impregnation and void space provides evidence of redox and drainage conditions (Arocena, 1998). Spatial patterns may also elucidate the temporal sequence of pedological processes, where a feature is overlain or cut by another then the first must logically pre-date the latter.

The application of micromorphology to the question of post-burial change in archaeological buried soils has a number of possibilities. Firstly, micromorphology allows the identification of the pedogenic and post-burial processes that have formed the microfabric of the buried soil, and importantly it offers the possibility of establishing a relative chronology for these processes. This ultimately should reveal an evolutionary sequence covering the pre-burial pedological development of the soil, including any anthropogenic disturbance, through the burial process and the response of the soil to the conditions of burial over time. The micromorphological process involves four key steps, (1) sampling (outlined in section 4.1), (2) manufacture of the soil thin sections, (3) description and measurement of the soil microfabric at any one of a number of possible levels of observation and (4) interpretation of these microfabrics.

4.2.2 The manufacture of soil thin sections.

All thin sections in this investigation were manufactured in the thin section laboratory at the University of Stirling according to the standard methods advocated by Murphy (1986); the methodology is given in appendix 3. Kubiena tins returned to the laboratory from the field were stored at 5°C when immediate processing was not possible. All blocks were treated identically with the exception of organic samples that were dried in acetone vapour, and the Fordhouse Barrow slides, which were stained using keystone oil blue. Slides took on average 3-4 months to produce.

4.2.3 Protocols adopted for micromorphological description.

As a descriptive and largely qualitative discipline, it was important that a systematic approach was adopted to deal with the thin sections and the data they generated. The system devised, therefore, had to operate throughout the initial visual description, the microscopic examination, and the description and quantification of the soil properties and features present. The mass of information that is generated by a full description as proposed in Bullock *et al.* (1985), where every soil property is described in detail is vast, selectivity was, therefore, required after the initial characterisation of the soil environment. Each slide was described in a two tier system, whilst a few were also described at a third level. This approach was developed prior to thin section description whilst the first slides were being manufactured; the recording system was then refined during the analysis of thin sections from the preliminary study site of Fordhouse Barrow.

The first level of description collected the information necessary to characterise each of the soil / archaeological materials, to outline the processes operating therein and to highlight features of interest within the slide for the second and third levels of description. The second level involved detailed description of particular pedofeatures and soil properties, which were selected as representative of the key processes of post-burial change. The third level of description involved more detailed characterisation of these features through measurement and quantification.

4.2.3.1 First level of description.

The first level of description was applied to all of the slides. Slides were described according to standard procedures (Murphy, 1986), firstly by eye and low magnification (x5 - x10) upon a light box, and then using an Olympus BX-50 petrological microscope at magnifications from x20 to x400 in plane polarised light, cross polarised light and oblique incident light. On a light box the slide was divided into zones upon the basis of colour, texture or structure and the nature of each zone was recorded. Any zones identified were treated as separate units and described individually. Microscopic descriptions were made according to the scheme of Bullock *et al.* (1985) supported by the key to this system published by Stoops (1998) and with reference to Fitzpatrick (1984; 1993). Descriptions were presented in standard summary tables using a dot system to represent the estimated abundances (e.g. Simpson, 1996b); these level 1 tables are presented in Appendix 5. Abundances were based upon the class system given in the International Handbook, however, the pedofeatures were frequently present in very low numbers within the soil and so a new system was devised in order to differentiate between these low abundances. The resultant size classes used were <1%, 1-2%, 3-5%, 6-10%, 11-20%, >20% slide area. The summary table contains information about the mineralogy, porosity and void type, microstructure, fine material, limpidity, organics, pedofeatures, coarse: fine ratios and coarse: fine related distributions. Besides the information presented in the table, further details of size, shape and distribution were made in a written description to support the tables where necessary. The identification of certain features in thin section does present problems, most notably in the distinction between humified organics, charcoals, and charred organics. The 'rules' used for the identification of these and some other features are given in appendix 3; it must be stressed that these did not ensure the accurate distinction between features in all cases, but provided a standard means of description. The size distinction between the coarse and fine material was taken at 10 µm for all slides to allow for later comparisons between sites. This initial stage of description took approximately 2-3 hours per slide.

4.2.3.2 Second level of description.

The second stage of micromorphological description concentrated upon specific features. The description and quantification was again based upon the International System of Bullock *et al.* (1985). The features and soil properties investigated were textural pedofeatures, amorphous iron pedofeatures, depletion pedofeatures, excremental pedofeatures, and the weathering of the more widespread and easily weathered soil minerals. The aim was to give more detailed information concerning the abundance, distribution and form of soil features deemed to be of most importance in answering the questions raised by post-burial change in buried soils. All slides were examined, as the absence of a feature was thought as potentially important as their presence.

The textural pedofeatures were investigated to test the hypothesis that after burial, silts and clays may in some cases move down profile and into the buried soil to be deposited as clay rich void coatings and silt cappings. Similarly the post-burial formation of iron pan and amorphous iron nodules was also hypothesised in the research framework. Both of these features are also of interest to help to elucidate the processes of pre-burial pedological development. Depletion features in the soil matrix, void walls, and stone rims were recorded to help identify source areas of the silts, clays and iron. For each of these features a summary table was devised which allowed the abundance of different size classes, and for the textural features different colour and textural classes to be recorded along with the degree of impregnation, shape, and contrast with the matrix of nodules and depletions. Size classes were kept constant, and were decided during the study of slides from the preliminary site. Textural and colour classes for the textural pedofeatures were devised on a site by site basis to cope with inter-site variability. The distribution of features in relation to others in thin section and other more general comments about these features were also recorded and it was these observations that helped to untangle the relative chronology of the features and the processes that formed them.

At sites where complex textural features were present, the orientation of the thickest part of the cutans relative to the soil surface was recorded to help differentiate between those formed *in-situ* and those inherited from constructional materials that were used in the building of the sites. This was recorded after the method of Dalrymple and Theocharopoulos (1989) who categorised cutans as u, n, c, or dependant upon the orientation of the thickening. The number within each category was counted within five fields of view at x50 magnification and presented as a percentage of the total within each thin section zone. The theory is that if clay and silt deposition is at least in part due to suspension retention (Sullivan, 1994), gravity will affect cutan formation causing them to be thickest at their base. However, the plane through which the section has been taken, also affects the orientation of the thickest part of the cutan as seen in thin section. If a cutan has been cut tangentially, then even if it is typic (even) in form, in thin section it will appear uneven; the nature of the relative thickening will be dependent upon the actual plane of the cut. Where the void system that the cutans are associated with is itself randomly oriented, then this effect would theoretically even itself out between all of the classes. If, however, the void system exhibited a preferential orientation, this could exert a heavy bias upon the results. The meso-sized channels, vughs and packing voids in which these cutans form appeared to show no preferential orientation, but care must still be taken with the interpretation of this data which should be seen as yet one more strand of evidence in the overall picture.

Excremental pedofeatures relate to the level of activity of the soil meso-fauna. Within a buried soil the level of biological activity is expected to decline very sharply after burial. However, the results from the Overton Down experimental earthworks suggest that here at least there has been massive biological reworking of the buried soil over a 32 year period (Crowther *et al.*, 1996). The identification of excremental features to genus is complicated as size, colour and texture of the excrements are affected by the age / size, and food of the organism. Basic distinctions can be made upon the basis of shape (Bullock *et al.*, 1985; Fitzpatrick, 1993), sectioning problems again being borne in mind. The abundance of excremental shape classes, defined following Tipping *et* *al.* (1994), were recorded, as was their position and level of coalescence / disintegration, as defined in the International Handbook (Bullock *et al.*, 1985).

The weathering patterns of biotite and muscovite micas, plagioclase and alkali-feldspars were also investigated. Within each slide section, estimation was made by of the weathering severity of each of these minerals following the four-stage system of the International System (Bullock *et al.* 1985). The weathering class given in brackets represented rare particles weathered at either extreme of that typical for the slide. A slide section in which most of the plagioclase feldspar grains were altered or pitted across 25-75% of their surface but where one or two specimens showed alteration of only 2.5-25% surface area the zone would be given a code of (1)2-3. This was then converted to a numerical code by averaging the classes present, and representing the extremes as half figures. In the cases illustrated above this would be shown as (1.5+2+3)/3 = 2.17.

4.2.3.3 Third level of description

The final level of description involved quantifying amorphous iron and textural pedofeatures relative to the void characteristics in thin section. Quantification of features within soil thin sections is a difficult but important issue. Even when a means to reliably measure a feature is found the interpretation of this data in the light of inherent variability and sectioning effects is often complex. Quantification is usually concerned with measuring the abundance of a particular soil feature or constituent within a thin section, in part because this is the simplest attribute to measure under the microscope. Limited quantification has already been made of the soil slides through visual estimation. For statistical analysis, however, continuous quantitative data is preferable. Two main quantification methods exist, point counting and image analysis. Point counting involves overlaying a grid upon the thin section and recording the features occurring at each grid intersection. Image analysis involves the capture and mathematical analysis of images from the thin sections. McKeague *et al.*, (1980) has investigated the effectiveness of different methods. Using a 'round robin' approach of different slides and micromorphologists, high levels of agreement between the three approaches were found. The differences between the methods arise when the less abundant more heterogeneous features are being examined, and in the flexibility of the method. Visual estimation as discussed tends to provide categorical data of less use statistically, and at lower abundances there are also difficulties of adequate categorisation. Point counting and grid counting techniques applied to heterogeneous features such as clay void coatings appear to suffer from problems of subjectivity and results vary widely between researchers (McKeague *et al.*, 1980). The reliability of these techniques has also been questioned by Finke *et al.* (1991) because of an apparent dependence upon neighbouring counts. Image analysis removes some of the subjectivity from the process, and provided a suitable level of magnification is chosen, is not affected by low abundance. Acott *et al.* (1997) have also found that a high degree of correlation exists between the results from point counting and image analysis techniques. This mathematical system also allows a far greater number of measurements to be made including area, shape, orientation, and perimeter measures.

Image analysis was chosen for this the third level of micromorphological analysis. Because of time and data volume considerations, only one site was chosen for this level of quantification, Fordhouse Barrow, Angus. This site provided the clearest evidence of post-burial movement of clays, silts and iron, and the features were often easily distinguishable upon the basis of their colour.

4.2.4 The theory and applications of image analysis

Image analysis techniques are well established - though rapidly evolving - having been applied to remote sensing, metallurgy and medical science. No standard method of image analysis exists but, the basic principles and assumptions remain constant. The technique involves the digital capture of an image as an array of pixels, each pixel recording the measurement of some variable at its corresponding 'scene' (Horgan, 1998). The source of these images in thin section analysis may include the digital capture of a microscopic frame illuminated by PPL, XPL, OIL, combinations of these in a multi-layer image (Terrible and Fitzpatrick, 1992; 1995), or from sub-microscopic SEM and X-ray analyses (Tovey *et al.*, 1992). Features are resolved by the application of threshold values to produce a binarized image upon the basis of the grey value, HSI or RGB value of each pixel. Thresholding, therefore, is the key stage in image analysis, and determines the success of the application. Thresholding values used within this study are given in appendix 3. Features thus resolved are then classified upon the basis of their size, morphology, or orientation, and quantitative measurements of each particle, classification or frame area are made. Measurements may include particle counts, particle areas, orientations, diameters, hole counts, morphology (sphericity and shape) and perimeter measures, whilst more complicated measurements, for example examination of void structures may involve the application of fractal mathematics (McBratney and Moran, 1994).

The problems of 3D modelling from a 2D slice still exist (Ringrose-Voase, 1994), and scale, number of samples, and standardisation are also important issues (Thompson *et al.* 1992). However the flexibility and relative speed of the system over traditional point counting make this a powerful and attractive tool for the micromorphologist. The possibilities of this technique are vast, however, this study employed the technique only in its most basic form using colour images with features thresholded upon the basis of their RGB (red, green, blue) and HSI (hue, saturation, intensity) spectra.

4.2.4.1 Protocols adopted for image analysis.

The results of image analysis are heavily influenced by the thresholds drawn in the grey values to delimit particular features of interest. It was very important, therefore, that a systematic approach was developed at the outset and then applied as a standard method to all of the image frames analysed. The equipment used was based within the Department of Environmental Science and consists of an Olympus BX-50 petrological polarising microscope linked to a Hitachi HCV-10, 3-chip colour camera, in turn linked to a PC. The image analysis software used is the SIS AnalySIS 3.0 system. This is complemented by the Marschuaser mechanical stage, which allows the automatic spatial mapping and recording of features.

All slides from the Fordhouse barrow site and its unburied reference profile were analysed. Each slide was divided into 2 cm spits along its length. Within each of these

2 cm divisions, five microscopic frames were captured using a W type sampling pattern. Images were captured at x 40 magnification. By trial and error this magnification was found to optimise the recording of the spatially heterogeneous pedofeatures whilst individual features still included a viable number of pixels to allow them to be accurately delimited and measured.

The features being studied were the void characteristics, the various types of clay void coating present at this site, and the amorphous iron features. The aim was to compare the relative distributions of each of the pedofeatures through the profiles to aid identification of the processes responsible. In order to recognise each feature threshold values had to be determined. The threshold values used for the determination of each feature were arrived at by trial and error over a range of slides until the narrowest range of HSI values possible to distinguish between each feature were found, differences in thickness across and between slides did pose a problem. Thresholding protocols and HSI values are given in Appendix 3.

4.3 Chemical and physical soil and sediment analysis.

This section aims to justify the choice of analytical methods used, and to argue their rationale within the research framework. Detailed notes upon individual methods and chemical composition are given in appendix 2. Analyses were chosen which would best test the hypotheses raised, and precise methodologies were chosen for ease, reliability, appropriateness to the research questions, and for the comparability of results with those of earlier works.

4.3.1 Choice and methodology of analyses.

4.3.1.1 Determination of bulk density and percentage moisture content.

Soil bulk density (mass per unit of volume) is dependent on particle density and soil porosity. Particle density is inherited from the parent material whilst porosity reflects the soils evolution. Porosity is a key soil property that may rapidly respond to the compressive forces and structural degradation that might be associated with burial; this in turn will affect the drainage properties of the burial environment. The determination of bulk density was therefore undertaken in order to assess the effect of burial upon the old soil's structural characteristics. Many methods of bulk density determination have been used (e.g. Smith and Thomasson, 1974); one of the main problems is in overcoming problems of compression during collection. For this study the very simplest method was employed for reasons of time and efficiency, namely taking a known volume of soil using a Kubiena tin in exactly the same manner as for thin section sampling. Compression problems at the edge of the tins were checked for in thin section and generally appeared to be minimal, the determination of porosity in thin section also acts as a check for this technique. Problems of stoniness were also overcome by determining the bulk density of the <2 mm size fraction. Details of these methods are given in appendix 2.2. Soil moisture is a dynamic property, but one that is key to many soil processes including the translocation and redistribution processes of interest to this study. Soil moisture was determined gravimetrically by the difference between the soil block in its field state and when oven dried to a constant mass.

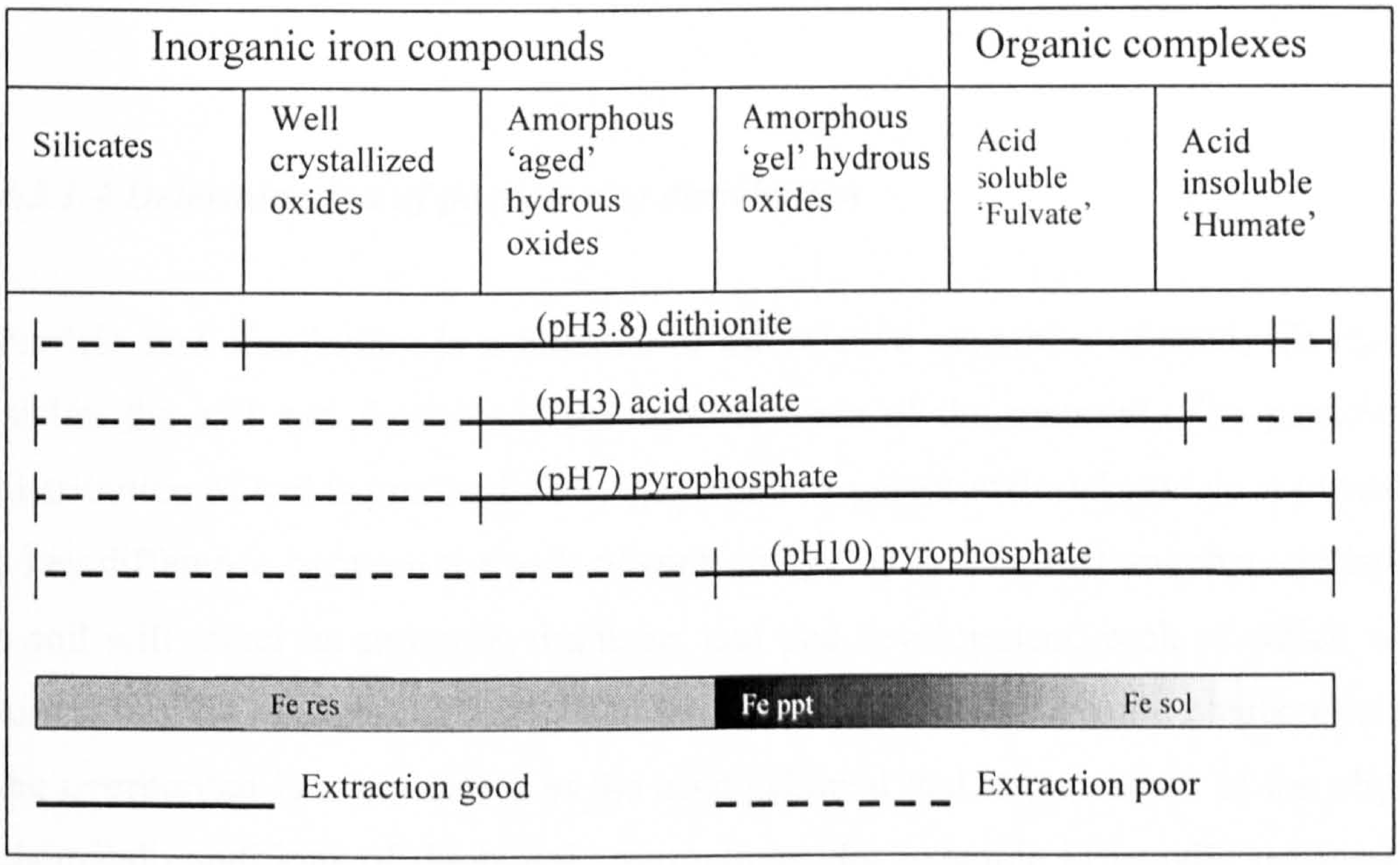
4.3.1.2 The determination of iron concentration

The determination of iron concentration was carried out in order to assess both the pre-burial pedogenic development of the soils, and post-burial alteration of the buried soil profiles. At a number of study sites podzolisation is a known factor in the development of the modern soil profile and podzolisation of soils in the past is also a possibility. The possible effect of secondary podzolisation upon a buried soil also should be considered (Runia and Buurman, 1987; Runia, 1988). Other post-burial effects may involve the movement of iron through the establishment of localised reducing conditions (Limbrey, 1975; Breunig- Madsen and Holst, 1996; 1998) and the alteration of the iron compounds present in the soil after burial (Dormaar and Lutwick, 1983). There have been numerous methods and extractants used in the determination of iron from soil materials, each of which extracts a slightly different fraction. Iron may occur in many different forms within a soil, each of which forms through different pedogenic and diagenetic processes. The choice of extractant and methodology, and an understanding of which soil iron fractions are being removed was, therefore, crucial. The down profile movement of iron in soil profiles is a well documented phenomenon; however, questions still remain as to the relative importance of mobilisation in organic complexes or within iron and aluminium sols (Bascomb, 1968; Farmer *et al.*, 1980; Farmer and Fraser, 1982) and which extractants best quantify these different fractions (Farmer *et al.*, 1983; Loveland and Digby, 1984). These questions are more complicated within buried soils where organic complexes may be degraded over time (Dormaar and Lutwick, 1983) and localised redox related mobilisations may be involved post-burial (Breunig-Madsen and Holst, 1996; 1998).

The methods followed, and reagents used are those set out by the Soil Survey for England and Wales (Bascomb, 1974). Extractions were carried out to determine pyrophosphate extractable iron and citrate dithionite extractable iron. The dithionite extraction was then also carried out upon the residue retained from the pyrophosphate experiment. Pyrophosphate is generally accepted to remove both the organically complexed iron, and 'newly' deposited amorphous iron gels, whilst citrate dithionite is thought to remove the more aged crystalline and amorphous hydrous oxide iron forms as illustrated in figure 4.1 (Bascomb, 1968). The citrate dithionite extraction upon the pyrophosphate residue material was undertaken to address the problem of overlap between the two the fractions removed by these two extractions. The advantage of these methods was that they have been the most widely used, and in particular these are the extractants used in previous studies of iron movements in archaeological sites.

Bascomb (cf. Loveland and Digby, 1984) established that variability of iron levels from a pyrophosphate extraction were reduced if the <500 µm dry earth fraction was used rather than the standard method using the <2 mm fraction (also used by the soil survey for England and Wales). For the primary site of Fordhouse Barrow, therefore, the <500 µm size fraction was used. However, in thin section it was noted that a number of iron nodules were greater than 500 µm in diameter. The optimum particle size fraction for use in these experiments was determined after a simple experiment to establish absolute levels of iron extracted, and the relative variability, when <2 mm and <500 µm particle size fractions were used (results in appendix 2, p342). Upon the basis of this experiment the <500 µm air-dried, particle size fraction was used in all following determinations. A further question mark is held over the variability associated with these extractions, Loveland and Digby (1984) found high levels of variability in extractable iron concentrations when these methods were applied to the same samples. For this reason approximately one in twelve samples were reanalysed to quantify this problem. Table 4.2 however shows that the mean and standard deviation between the two determinations was tolerably low for each extraction.

Figure 4.1 Iron forms in soils and extraction efficiencies of different methods.



Taken from Bascomb (1968, p. 262)

Table 4.2: Mean variability in percentage iron between extractions on the same sample.

Extraction	0.1M Na Pyrophosphate	Citrate Dithionite	Residue
Mean % variation	0.18	8.11	4.92

4.3.1.3 The determination of Loss on Ignition.

Loss on ignition of oven-dried, fine earth is a simple method of assessing the soil organic matter content (Ball, 1964). Note must be made that there is no direct relationship between this measurement of organic matter and soil organic carbon levels although often a relationship is assumed (Ball, 1964). Organic matter levels are of interest as they affect aggregate stability and soil biology. Inaccuracies in the technique are usually attributed to the decomposition of calcareous materials and the loss of structural waters from clay lattices at high temperatures. To alleviate these problems Ball (1964) suggested a long, slow burn at 375°C for 16 hours. This method was applied to all the samples to ensure comparability.

4.3.1.4 Determination of particle size distribution

Particle size distribution is a measure of the relative quantities of sand, silt and clay within the soil and determines the textural class of the material. The particle size distribution of soil is predominantly governed by parent material, and so is potentially a key difference between the soils of each study region. The textural characteristics of a soil will affect its structure, drainage, and ped development, each of which will in turn affect the response of that soil to burial conditions. The textural characteristics of the overburden is a key factor in the establishment and maintenance of the physico-chemical conditions of the burial environment, for example in heavily textured clay soils the formation of an anoxic zone may occur at lesser depths than in a lighter sandy material (Abdul-Kareem and McRae, 1984). One of the research hypotheses involved the proposition that clays and silts may be released within the overburden and transported down profile to be deposited within the lower portions of the profile. The determination of particle size distribution within samples from sites that exhibited evidence of clay illuviation in thin section, also offered the possibility of verifying and quantifying these movements.

Two levels of analysis were used; the first involved hand determination of texture in the field to assess the relative proportions of sand, silt and clay and to assign each profile horizon / context to a textural class. This level of analysis allows the basic discrimination of soil texture between sites within the different study regions, and so helps to illustrate the effect of parent material upon the regional development of the soils. The second level of analysis involves the laboratory determination of grain size using sieve and laser grain-size determination. The bulk samples from each study site were sieved down to 500 μm. Profiles from those sites thought to have been subjected to post-burial clay translocation on the basis of their micromorphology went on to laser grain size determination of the < 500 μm fraction using an LS230 Coulter Counter. This equipment studies the diffraction patterns formed upon passing a laser beam through a particulate suspension. Upon the basis of this, the Coulter Counter is able to model the particle grain size distribution down to 0.004 μm. The theory, methodology and problems encountered using this equipment are outlined in appendix 2.5.

Consistent and broadly comparable results were obtained down to a grain size of 0.4μm. Although concentrations of illuvial clay are not always evident when hand sizing, sieving and pipette methods of grain sizing are used (Buurman *et al.*, 1997), it was hoped that the finer resolution offered by Coulter Counter determinations would be more sensitive. Beuselinck *et al.* (1998), however, found that clay fractions were underestimated by laser determination relative to pipette analysis. A limited number of grain size determinations from the clay rich site of North Cadbury, Somerset were carried out using the standard pipette method (Bascomb, 1974) in order to support the problematical Coulter Counter characterisation of clay rich soils.

4.3.1.5 Determination of pH

Soil pH is a measure of the concentration of hydrogen ions and is affected by the soil base status as derived from the parent material, and the soil drainage and bio-chemical status. The aim of the pH measure was to assess the influence of the parent materials within each of the study regions upon the pH of the soils developed thereupon, and to investigate the effects of burial upon this soil property. Soil pH is an important factor influencing soil biological activity and the mobility of certain cations. It influences the pedogenic pathways along which soils may evolve and could affect the response of the soil to burial. The determination of pH was carried out in the laboratory following the standard methods of Avery and Bascomb (1982). The pH of each sample was also determined in the presence of calcium chloride which acts as a buffer causing the displacement of hydrogen ions from exchange sites at the surface of organics and clay micelles within the soil. This allows the measurement of the 'reserved' soil pH as compared to the pH determination in water, which reflects the pH of the soil solution. The addition of $CaCl_2$ to the soil slurry usually depresses the pH as adsorbed hydrogen ions are released into solution; this has the advantage of stabilising the pH measurement and of equalising the salt content between samples. The difference between these two measures is known as the salt effect.

4.3.2 Summary of bulk chemical and physical analyses.

A number of analyses were undertaken to determine both chemical and physical soil properties. The choice of analyses was by no means exhaustive and many physico-chemical characteristics of these soils remain unknown. Those analyses which were used to establish the broad characteristics of these soils, were those highlighted in the theoretical discussion of post-burial change (Chapter 1.3) as important in both conditioning the response of the soil to burial and those which themselves were most characteristic of a burial environment.

The chemical and bulk analyses undertaken upon the bulk samples yielded a large quantity of data pertaining to the chemical and physical characteristics of the soils, the overburden materials and the various burial environments.

4.4 Data Manipulation

4.4.1 Data interpretation and manipulation.

The analysis and interpretation of data is that stage which Murphy *et al.* (1985) identified as that most likely to be affected by the subjectivity of the micromorphologist. The interpretation of the data generated here was made with reference to the wealth of literary experience of archaeological (including Courty *et al.*, 1989; Gerbhardt, 1992; 1995; Macphail *et al.*, 1990a; 1990b; and Davidson *et al.*, 1992), palaeopedological (Kemp, 1985; McCarthy, *et al.* 1998; 1999) and agricultural (Jongerius, 1983) investigations. This level of analysis determined the nature of the soil environment prior to burial and identified the features that had formed since burial; chapter 5 presents this level of information. Interpretation relied heavily upon the comparative analysis of microfabrics, between different soil and sediment contexts, buried soil and overburden, buried soils and non-buried reference profiles, depth position within profiles, depth positions between profiles, buried soils of different ages, and buried soils upon different parent materials. This level of interpretation allowed the effects of parent material, time since burial and depth of burial upon the alteration of soil fabric after burial to be investigated.

All data from chemical and physical soil analysis and thin section image analysis were stored and processed using Microsoft Excel '97 spreadsheets. In this medium data characteristics of mean, standard deviation, variance etc. were calculated. The data was then imported into SPSS for Windows version 8.0. Each data set was examined for normality using the Kolmogorov-Smirnov statistic and where this assumption was not met attempts to normalise the data were made using logarithmic and square root transformations. The data from each analysis were plotted against depth for each of the sampled profiles, and within each profile scatter graphs were plotted and the correlation was determined between the results of each analysis. Student's 2-tailed t-tests were also calculated for equivalent sets of data from the two or three profiles from individual sites. These techniques gave information at the profile and site level.

The qualitative and semi-quantitative data generated by the traditional micromorphological descriptions of the level 1 thin section analysis were gathered in Excel spreadsheets and coded to enable statistical analysis, these coded tables are given in appendix 5. The codes relate to abundance classes for individual features and also to qualitative descriptions of microstructure, distribution, related distribution, limpidity and fine material composition, the coding of these is designed to reflect the relative stage of pedological development of the soil fabrics.

4.4.2 The statistical analysis of quantitative and qualitative data.

In order to assess the wider site and regional influences the quantitative physical and chemical data was assessed using general linear model for repeated measures of two-way ANOVAs. This allowed assessment of the between subject effects of the independent factor (region) and the within subject effects of factors and co-variates (age and depth of burial) upon the multiple observations made at sequential depths of the continuous variable (for example bulk density). The assumption of sphericity made in this model was not met by the large datasets and in such cases the results were adjusted using the Huynh-Feldt epsilon value (Kinnear and Gray, 1999).

The discrete coded data derived from the micromorphological descriptions was analysed first using chi-square contingency tables. The chi-square test is only valid if greater than 20% of the calculated expected values are greater than five (Kinnear and Gray, 1999); where this was not so variable classes were recoded into fewer classes sequentially until expected values had been raised sufficiently. This continued until a 2x2 presence / absence table was achieved; if expected values were still low Fisher's exact test was used, which although less powerful was able to cope with these lower values. This technique identified correlations between the presence of different soil features and between soil features and the determinant study factors, but was unable to cope with the nested nature of these three factors. Significant correlations were further analysed using the general log-linear model. This employs both the chi-square statistic and the log-linear likelihood ratio (L^2) to test whether the model for the logarithms of the cell probabilities is a linear function of the marginal possibilities (Kennedy, 1992; Knoke and Burke, 1980). The model is sequentially constructed and the effect of adding each new parameter upon the L^2 value is noted. To fit the model the calculated cell values should not deviate significantly from those observed. Low L^2 values for degrees of freedom, and high p values are, therefore, required to accept a model. The saturated model which includes all possible study parameters and their interactions will always perfectly explain the observed values, however, the aim is to identify the most pertinent factors and interactions. Knoke and Burke (1980) suggest model acceptance should occur at p-values between .10 and .35, at higher levels the model may be too good a fit and include unnecessary parameters.

Finally a cluster analysis was applied to the data sets in order to identify clusters of similar cases. Hierarchical cluster analysis was used in preference to the k-means technique, as no initial judgement as to the number of clusters is required, and a layer of subjectivity is removed from the analysis. The final number of clusters was identified after analysis, by taking the point at which the greatest difference between successive co-efficients of similarity was identified.

4.5 Summary of field and laboratory methods.

Soil and sediment samples were collected from field sites to help explain the effects of parent material, time since burial and depth of burial upon the processes of post-burial change in archaeologically buried soils. These soil materials were suitable for thin section analysis and for the physical and chemical analyses. The sampling strategy, therefore, fulfilled its main aim and allowed the collection of quantities of data suitable for addressing the research aims and testing their hypotheses. Quantitative and qualitative data was collected, collated and interpreted with the aid of statistical analysis; ANOVAs, Hierarchical clusters, Chi-square contingency tables and many more. These analyses allowed the testing of the specific research hypotheses. However, before this detailed analysis could be done the more general soil and burial environment for each of the sampling regions and sites had to be established this was achieved principally using thin section micromorphology, the results and interpretations of which are detailed in the following fifth chapter.

5. Regional site results: buried soil environments and their interpretation.

To investigate the nature and effects of the processes of post-burial change that are of primary interest to this thesis, the features that result from these processes have to be teased out from amongst the soil microfabric. However, problems arise when the features formed during the sedimentological, pedological, and anthropogenic soil history, are similar in nature to those formed within the burial environment. The textural and amorphous iron pedofeatures of interest here may all form under specific conditions associated with any of these four potential developmental phases. This chapter presents the most pertinent field, micromorphology, and bulk physico-chemical results from the sites within each of the four study regions studied. An interpretation of the nature of the sedimentary, pedogenic, archaeological and burial environments is made for each of the study sites. Full details of the field, micromorphology, and bulk analytical results are provided in appendices 4, 5, and 6 respectively. For each study site the development of the buried soil prior to, and following, burial is investigated. Specific reference to the study variables (depth of burial, time since burial, and parent material) is not made here, but is the focus of attention in chapters 6, 7, and 8.

5.1 Fordhouse barrow, Angus, Scotland.

The site of Fordhouse barrow in Angus, together with its reference profile, was used as a preliminary study. The aim was to gain experience in the field, and to provide analytical practice and early results to guide the efficient analysis of later sites. This site was chosen because previous work has suggested that processes of post-burial change has played a significant role in the formation of the contemporary buried soil fabric (Simpson, 1996a,b).

5.1.1 Results from Fordhouse Barrow

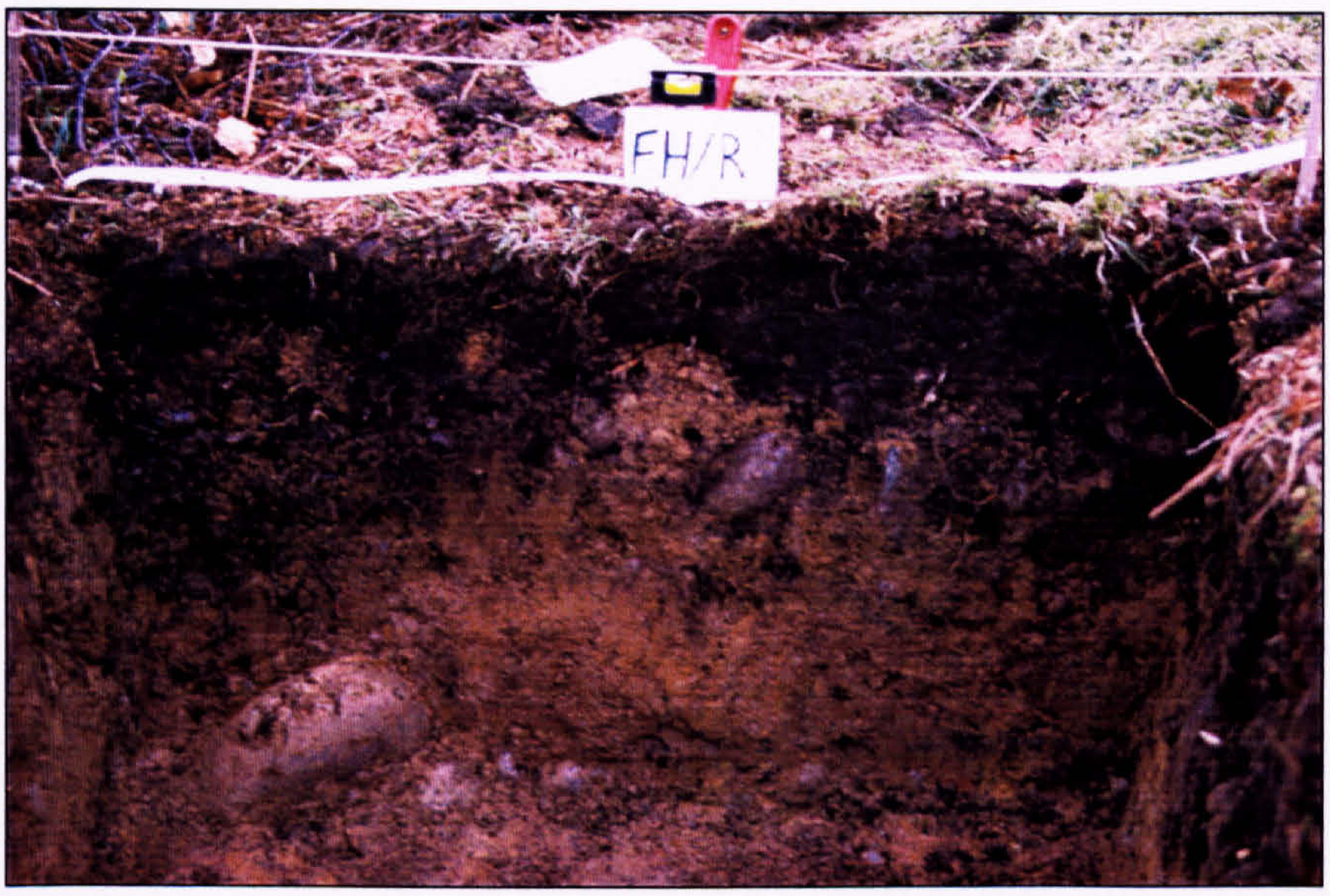
Besides the field, standard micromorphology, and bulk physical and chemical results that are presented in this section, the thin sections from this site were also analysed using image analysis techniques. This analysis was undertaken to further quantify the distribution of textural and amorphous iron pedofeatures. These results are not presented here but are discussed in chapter 8 within the discussion of the effects of depth of burial.

5.1.1.1 Field results from Fordhouse Barrow

The profiles were taken from a south-facing cross-section through the burial mound (figure 5.1). This section had been cut at the start of excavation some 3 years previously in order to clean back the mound where it had been damaged by quarrying and rabbit activity. Since 1994, excavation of the site had progressively reduced the height of the mound, by 1997 when sampling took place over 1m of material had been removed from the top of the section. Figure 5.1 shows the entire section as it was first described in 1994 and identifies the three profiles sampled for this project in 1997. Full context descriptions and section drawings are given in Appendix 4 (pp. 362-366). The section consists of soil and sub-soil type materials with sandy loam and sandy clay loam textures with frequent gravel clasts and water-worn cobbles. The soil structure is massive with occasional weakly developed, fine sub-angular blocky peds. The reddish brown buried soil has similar textural and structural properties to the mound material and runs discontinuously across the section, at a level slightly above that of the modern ground surface. This overlies the local parent material of sandstone derived till with a clay loam texture and massive structure. No visible differences were discerned in the nature of the overburden and buried soil between the three profiles sampled. However profile three, from the outermost and shallowest profile includes a layer of constructional stone some 25cm thick, which lies directly on top of the surviving buried soil. The reference profile (figure 5.2) was taken from a soil pit freshly dug in the nearby mixed woods to the north. The sandstone derived till parent material is similar to that beneath the mound. The soil consists of an imperfectly draining, brown forest soil formed directly upon sandstone derived till deposits.

Figure 5.1: The archaeological section at Fordhouse Barrow.

Figure 5.2: The soil pit of the Fordhouse reference profile.



5.1.1.2 Micromorphology results from Fordhouse Barrow

Eleven slides were manufactured from the first profile, six from the second, and five from the third, a further five slides were taken from the reference soil; summary tables of the micromorphological descriptions are given in appendix 5 (pp. 391-395). Level 1 and 2 micromorphological analysis of the sections revealed a complex set of textural clay and amorphous iron pedofeatures, the analysis and interpretation of which form the central theme of the study at this site. A typology of the textural and amorphous iron pedofeatures identified at Fordhouse barrow is given in tables 5.1 and 5.2 and examples of the different pedofeatures are given in figures 5.3 – 5.7. This typology identifies six textural pedofeature types. The silty brown and orange type 1 cutans are distinct and discrete categories. The boundaries between orange type 2, orange / red, and orange / brown cutan types, however, are less distinct, and in some cases a distinction was drawn between cutans which appeared to be part of a continuum. Amorphous iron features are present in three forms, pans, diffuse nodules, and distinct, rounded nodules. As has been suggested by Simpson (1996a,b) their nature and relative distributions suggest that at least some of these pedofeatures have formed in response to processes of post-burial change.

The micromorphology of the reference and buried soils has been used to identify and interpret the microfabric types from within the mound itself. The reference soil consists of Ah and A horizons of organic and organo-mineral material with occasional sand sized quartz particles, and an inter-grain microaggregate and channel microstructure. Biological activity is high in these upper horizons with both the mammilate and bacillo-cylindrical excrements typical of earthworms and enchytraeids respectively present. Beneath this, the mineral and organo-mineral horizon of the mottled B(g) horizon consists of medium sized quartz sand with a dense channel microstructure. A few strongly impregnated iron nodules, up to1500µm in diameter, have been formed *in-situ*. The width of the very few iron depleted stone rims decreases with depth. A very few brown, silty void cutans are found coating channels and vughs towards the top of the horizon. Beneath this the mineral glacial tills forming the parent materials of this and the buried soils are relatively homogeneous. The tills are formed of mica rich sandstones, and metamorphic mica schists in a clay and silt fine matrix with common medium sand. They show evidence of periglacial modification in the form of silt cappings, type 1 orange silty clay void cutans.

Table 5.1: Typology of main textural pedofeature types from Fordhouse Barrow.

Textural Pedofeature	Description	Distribution
Brown clay cutans	Dusty, mid-brown with frequent black organic punctuations, up to 25μm thick, similar to bA type microfabric, v. diffuse or masked extinction, low birefringence, orange / brown in Oblique Incident Light. Coating voids up to 250μm diameter. Commonly fractured, particularly within the barrow. Tend to account for <2% slide area.	Always associated with A and AB type microfabrics. Found at depths of 20-40 cm within the reference soil profile, and throughout the lower overburden and buried soil.
Orange clay cutans: type 1	Limpid to silty, pale / mid orange, extinction clear, form thick (up to 300μm thick) silty compound coatings, occasionally haphazardly oriented clay domains form coatings, rare orange/brown, orange/grey and orange/green coatings. In channels and vughs up to 1000μm diameter. Channels often relict and coatings occasionally fractured. Within the parent material may account for up to 2% slide area.	As coatings and infillings in till parent material type microfabrics both within the reference soil, buried soil and towards the top of the barrow.
Orange clay cutans: type 2	Limpid and dusty, Mid / dark orange, rare silty laminations, extinctions clear to diffuse, up to 300μm thick. These are not intermediates between the brown clay cutans and either of the orange clay types, as they lack organic punctuations. Orange in OIL. Coatings and infillings occurring with all microfabric types. In vughs and channels up to 1000μm thick. Very rarely fractured. Can be common within the overburden and buried soils, accounting for up to 5% slide area.	Occurred coating charcoal, Fe nodules, iron pan at base of monument, charcoal, and in rare instances brown clay cutans. Are found in association with all micro-fabric types in barrow and buried soils, absent from reference soil and stone sealed buried soil of profile 3.
Orange / brown clay cutans	Limpid to dusty, Mid orange / brown, punctuations absent, mod. Birefringence, few laminated, yellow brown in OIL, up to 150μm thick. Coatings and infillings, in channels and vughs up to 1000μm diameter. Very rarely fractured. Locally within the barrow may account for up to 2% slide area.	Possibly overlying brown clay cutans in places, predominantly associated with A and AB microfabrics, rare occurrence within till type materials in monument.
Orange / red clay cutans	Limpid and dusty, mid to v. dark orange / red, up to 300μm thick, extinctions clear or masked, orange pink in OIL. Coating and infilling vughs and channels up to 1000μm diameter. Very rarely fractured. Locally within barrow may account for up to 2% slide area.	Pred. Associated with A and AB microfabrics and occasionally with till in upper portion of barrow. Often found with orange type 2 clay around iron pans.
Silty cutans	Predominantly silt, mid-grey and orange / grey, up to 500μm thick within relict voids. Very rarely fractured. Tend to be rare and only account for less than 1% slide area where present.	Single and compound coatings and infillings, associated with till type microfabrics, in barrow reference soil and buried soils.

(Tables 5.5 and 5.6, show relative distribution and frequency of different coatings, Figs 5.3 – 5.7 illustrate the different coating types.)

Figure 5.3: Type 1, orange clay coatings associated with till microfabrics in Fordhouse Barrow and reference profile.

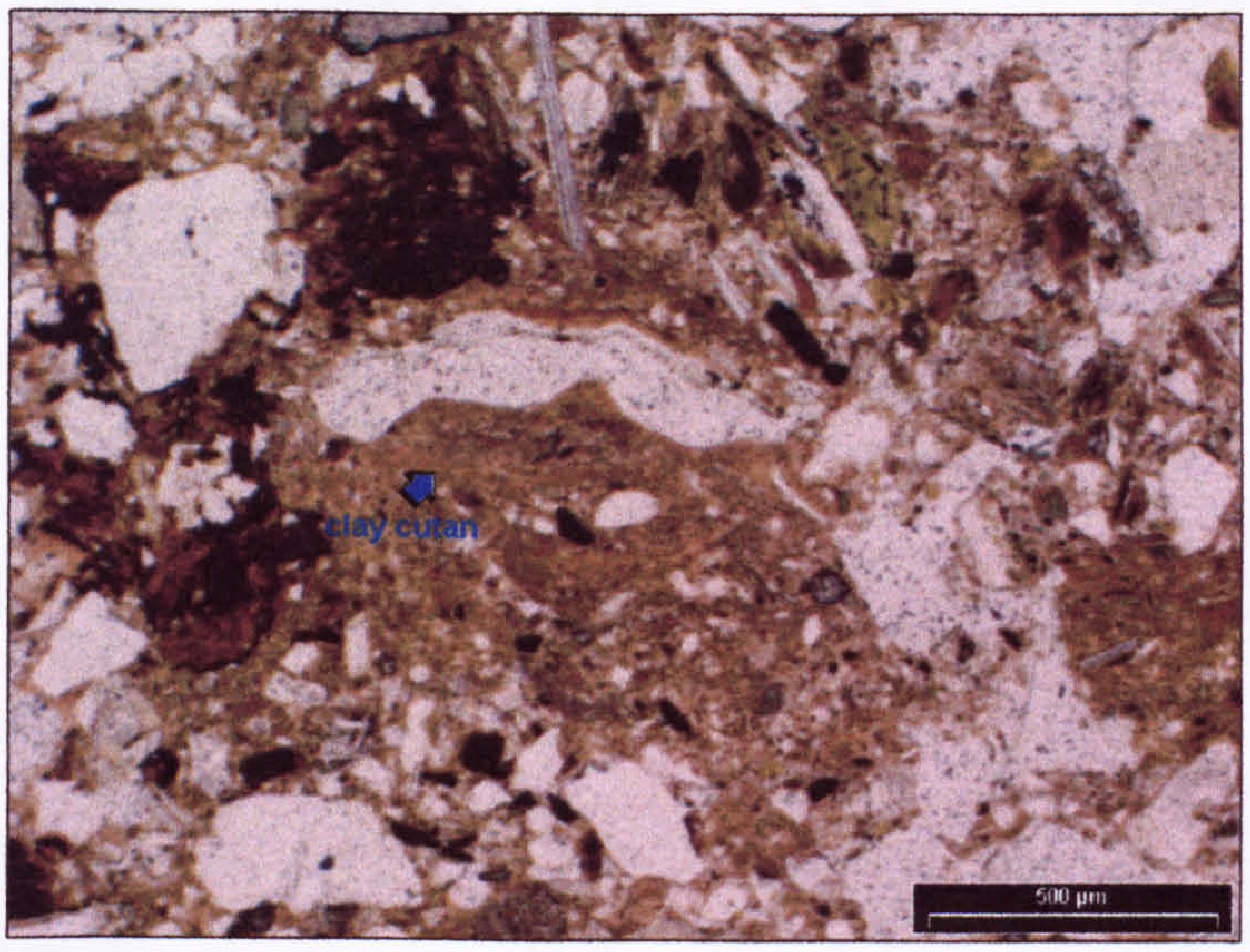


Fig. 5.3a: Till parent material from reference profile showing type 1 orange clay coatings.

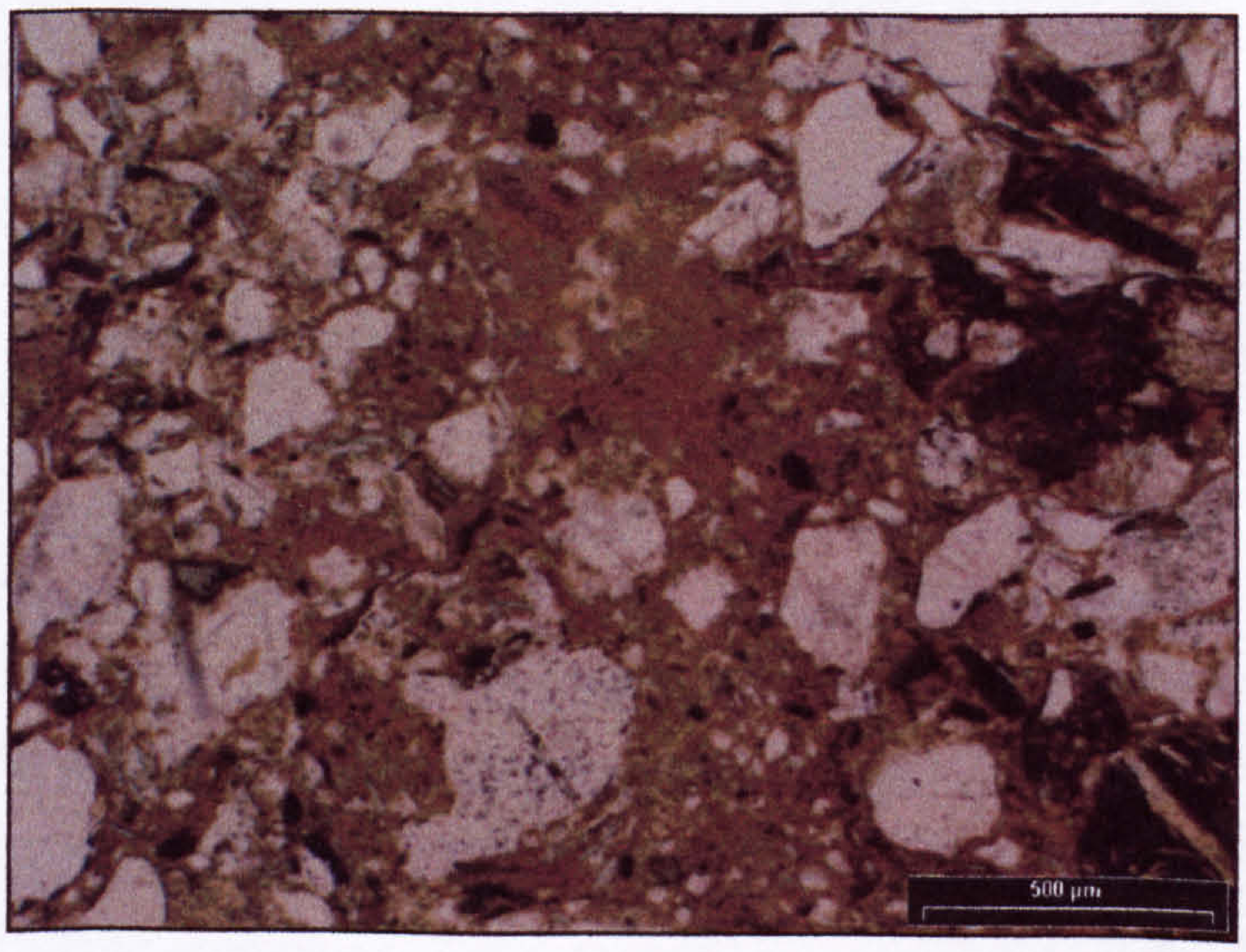


Fig. 5.3b: Type 1 orange clay within Till in overburden of Fordhouse Barrow.

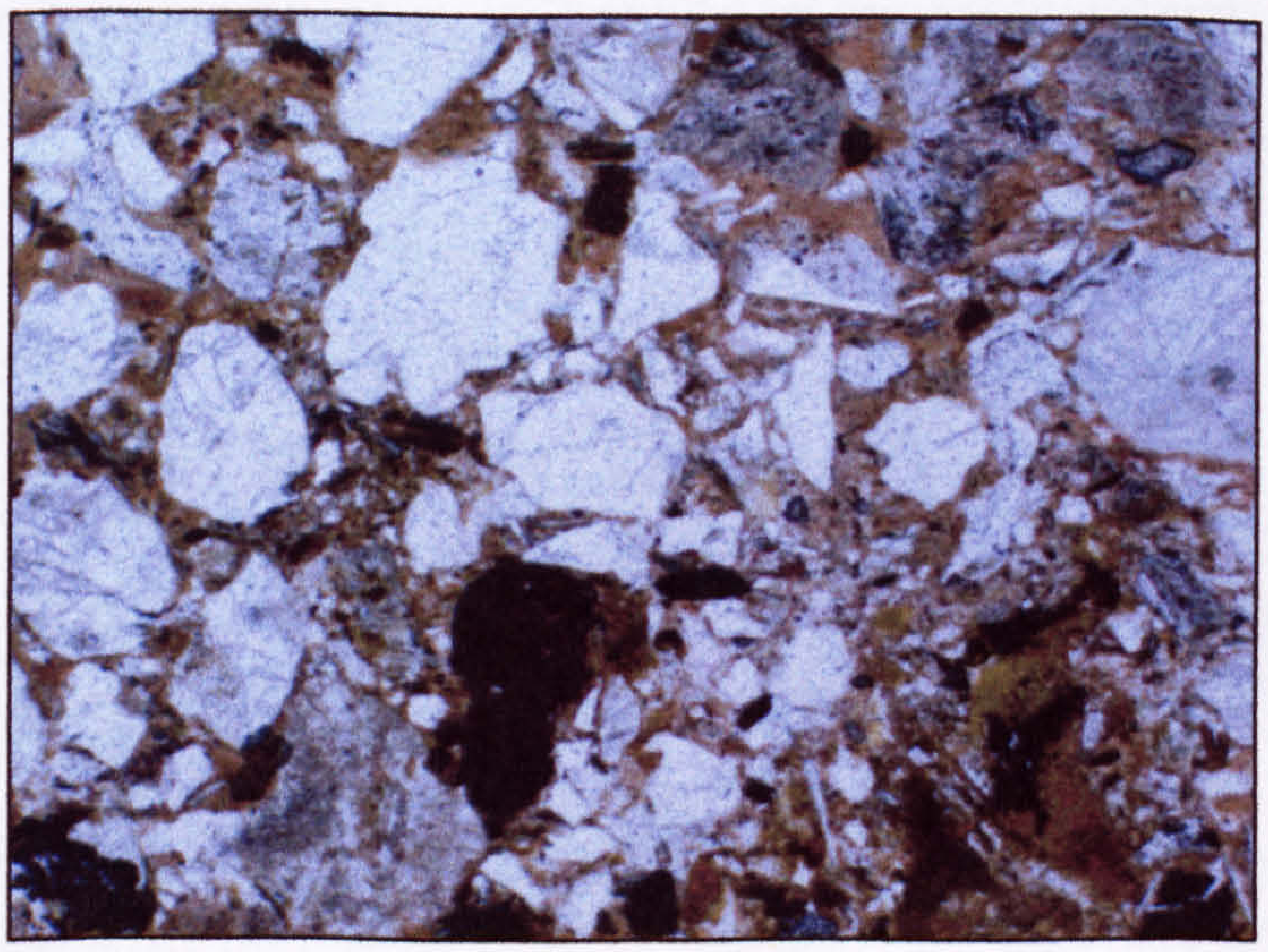


Fig. 5.3c: Till parent material from reference profile.

Figure 5.4: Type 2, post-burial orange clay coatings in Fordhouse Barrow.

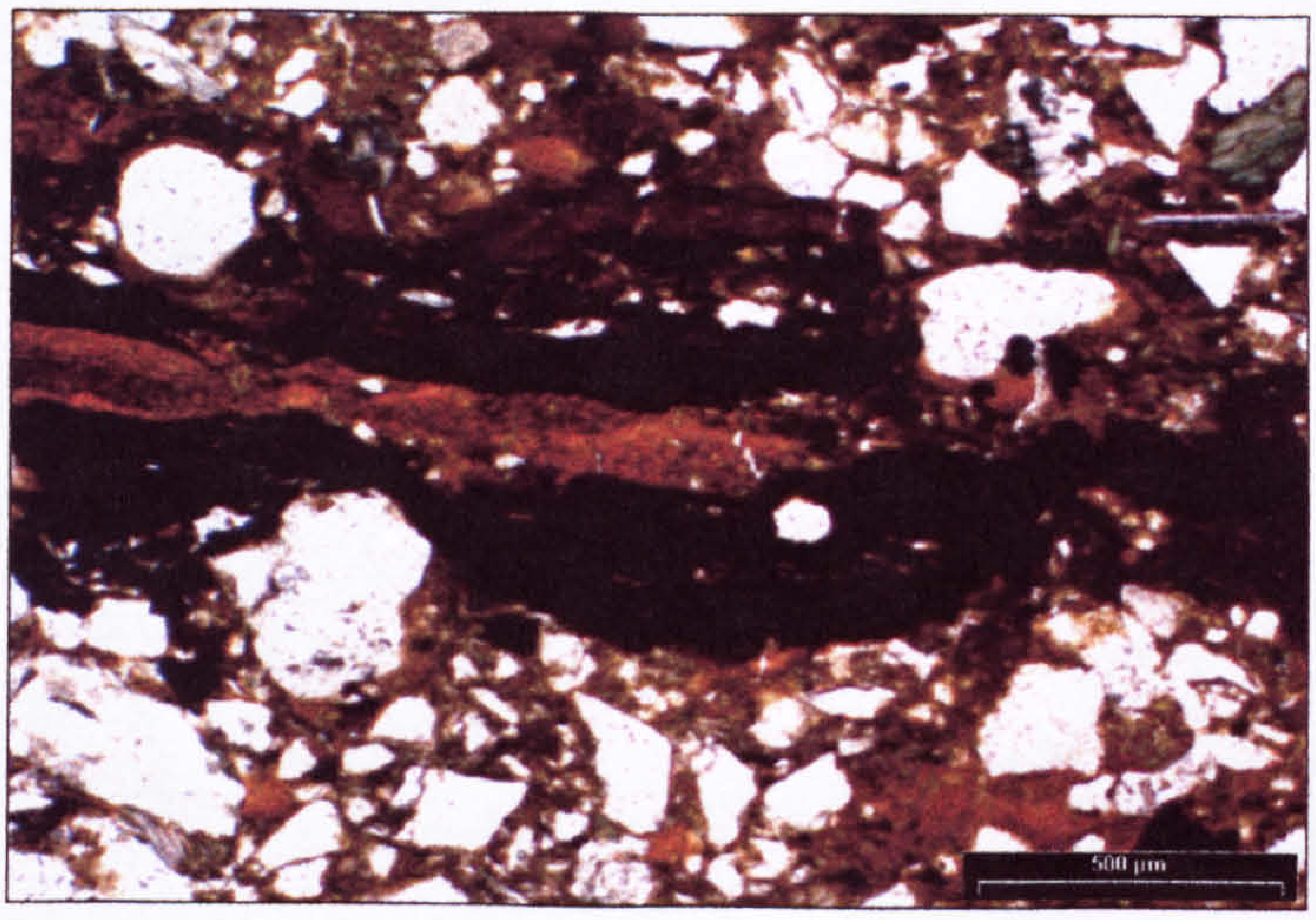


Figure 5.4a: Iron pan coated by type 2 orange clay coatings.

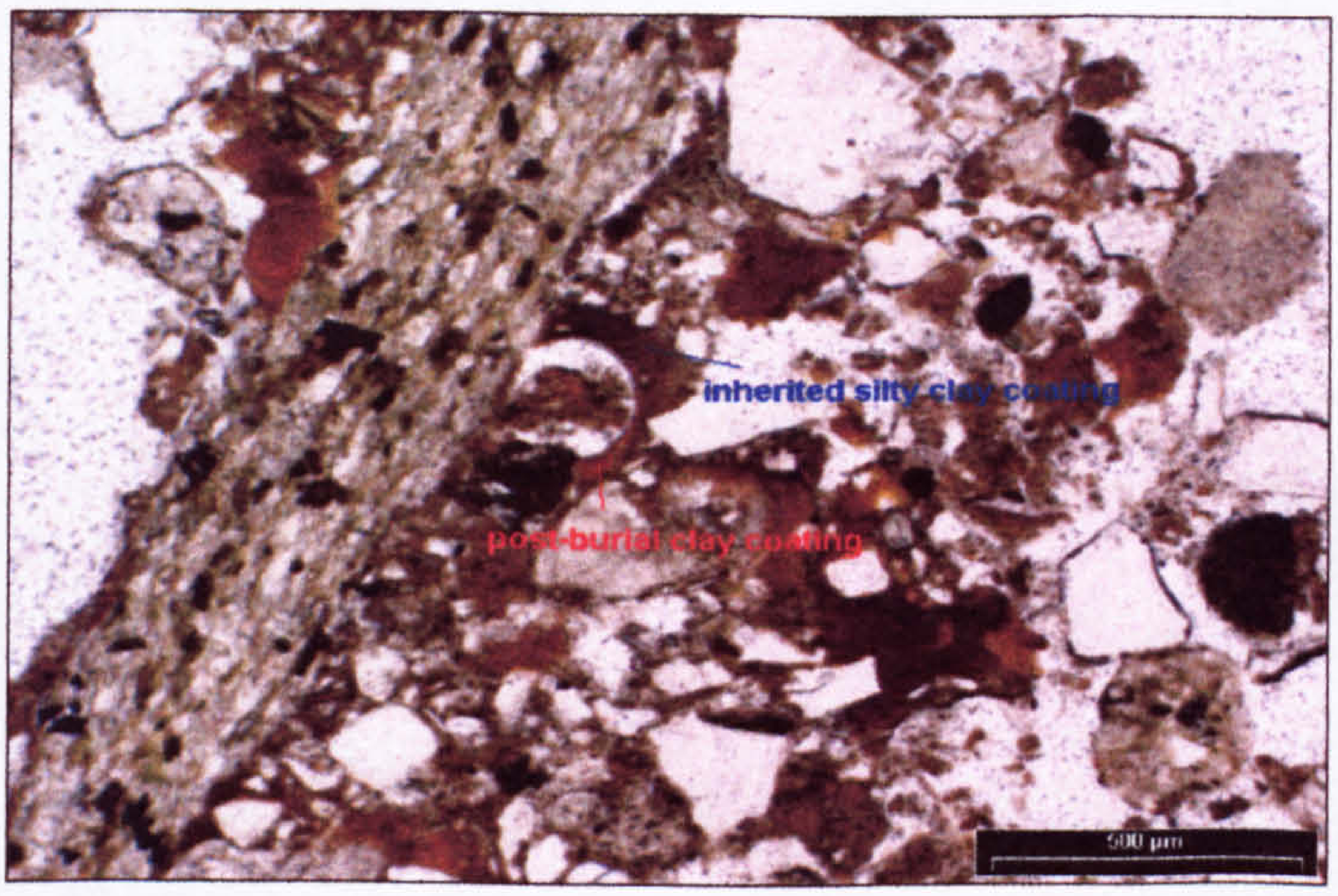


Fig. 5.4b: Silty orange clay coating (type 1) in till derived constructional material, overlain by type 2 orange, post-burial clay coatings.

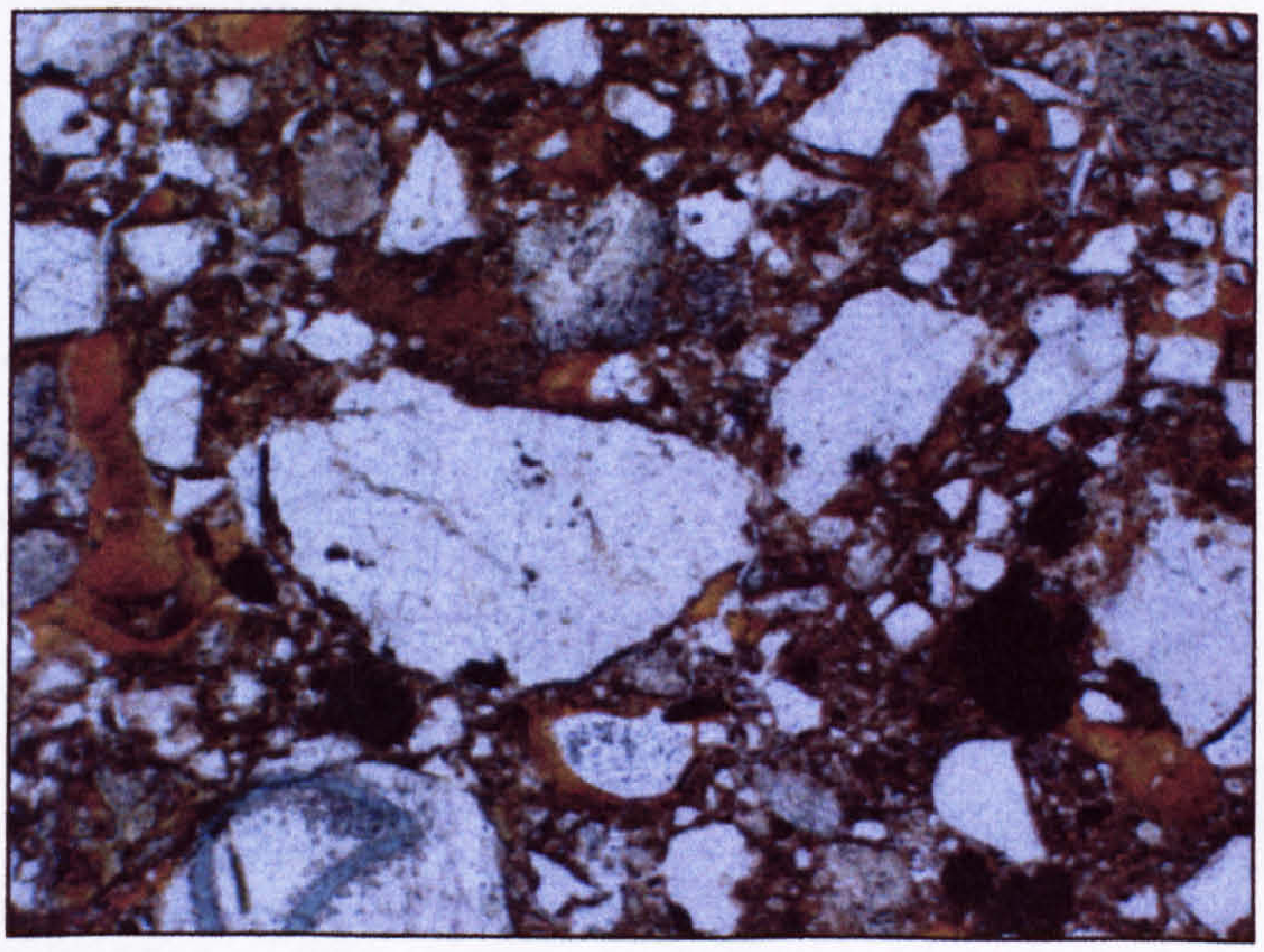


Figure 5.4c: Type 2 post-burial orange clay coatings.

Figure 5.5: Post-burial orange/red type clay coatings in Fordhouse Barrow.

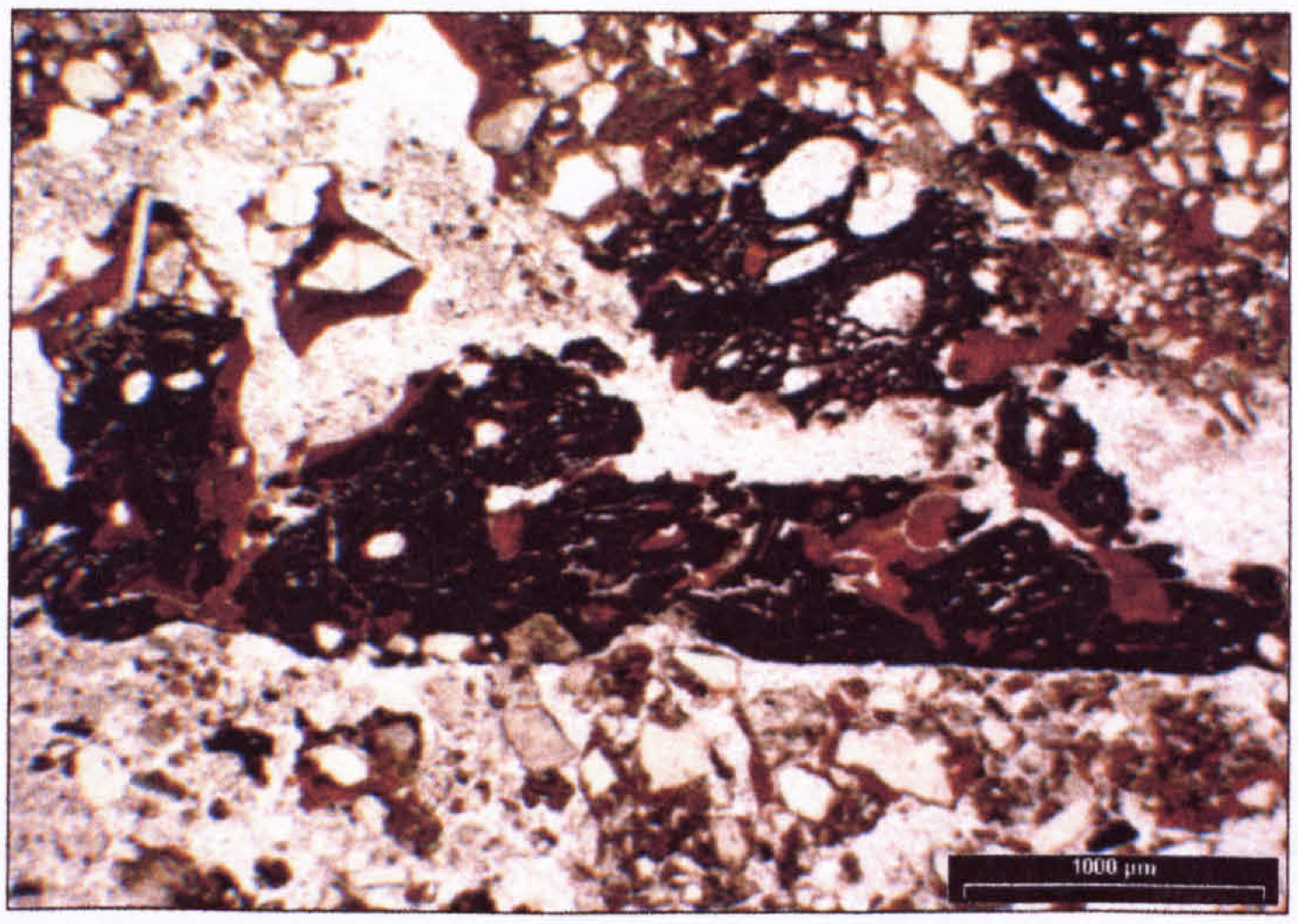
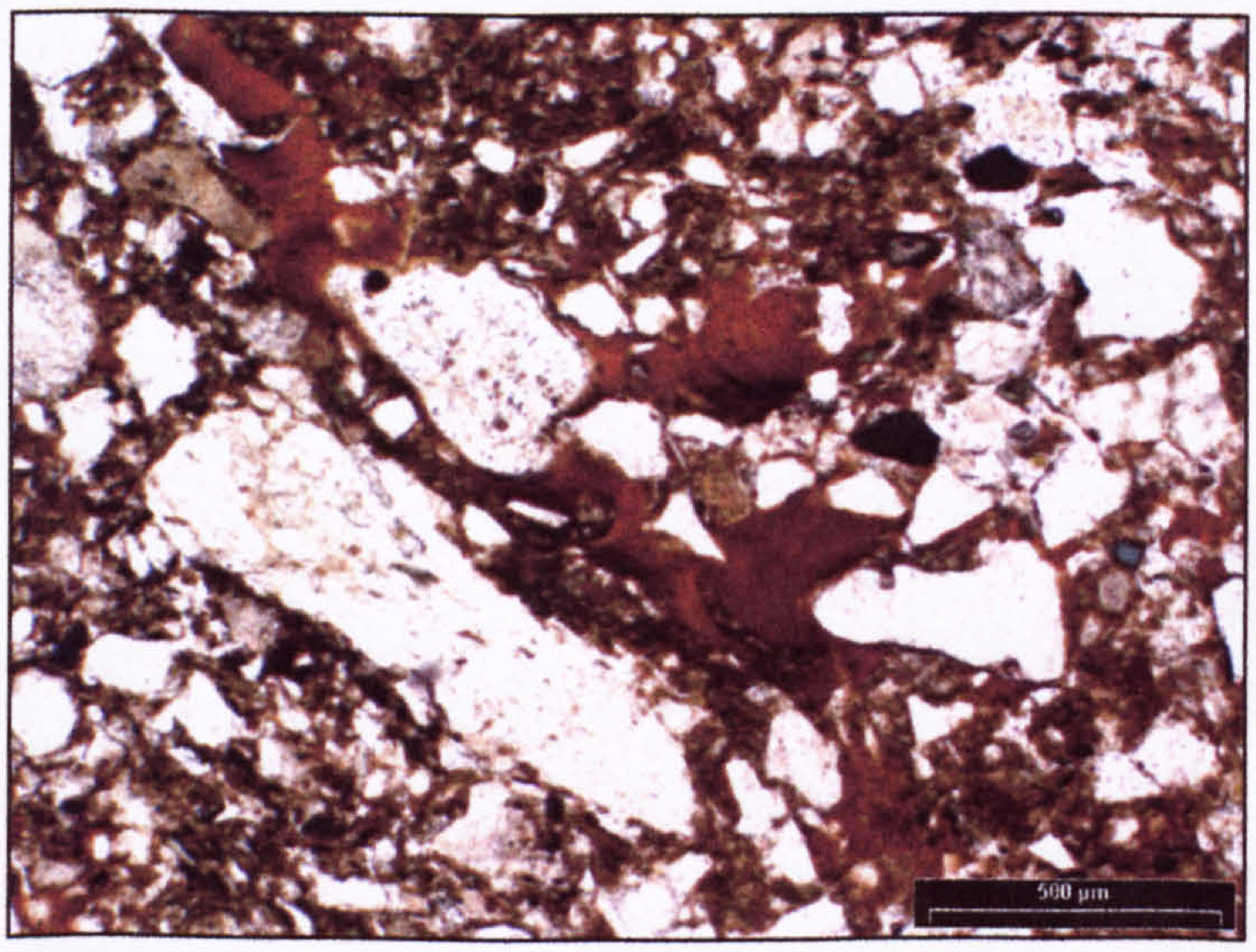


Figure 5.5a: Charcoal in Fordhouse Barrow profile 1 coated by orange/red post-burial clay.



5.5b: Post-burial orange/red clay coatings.

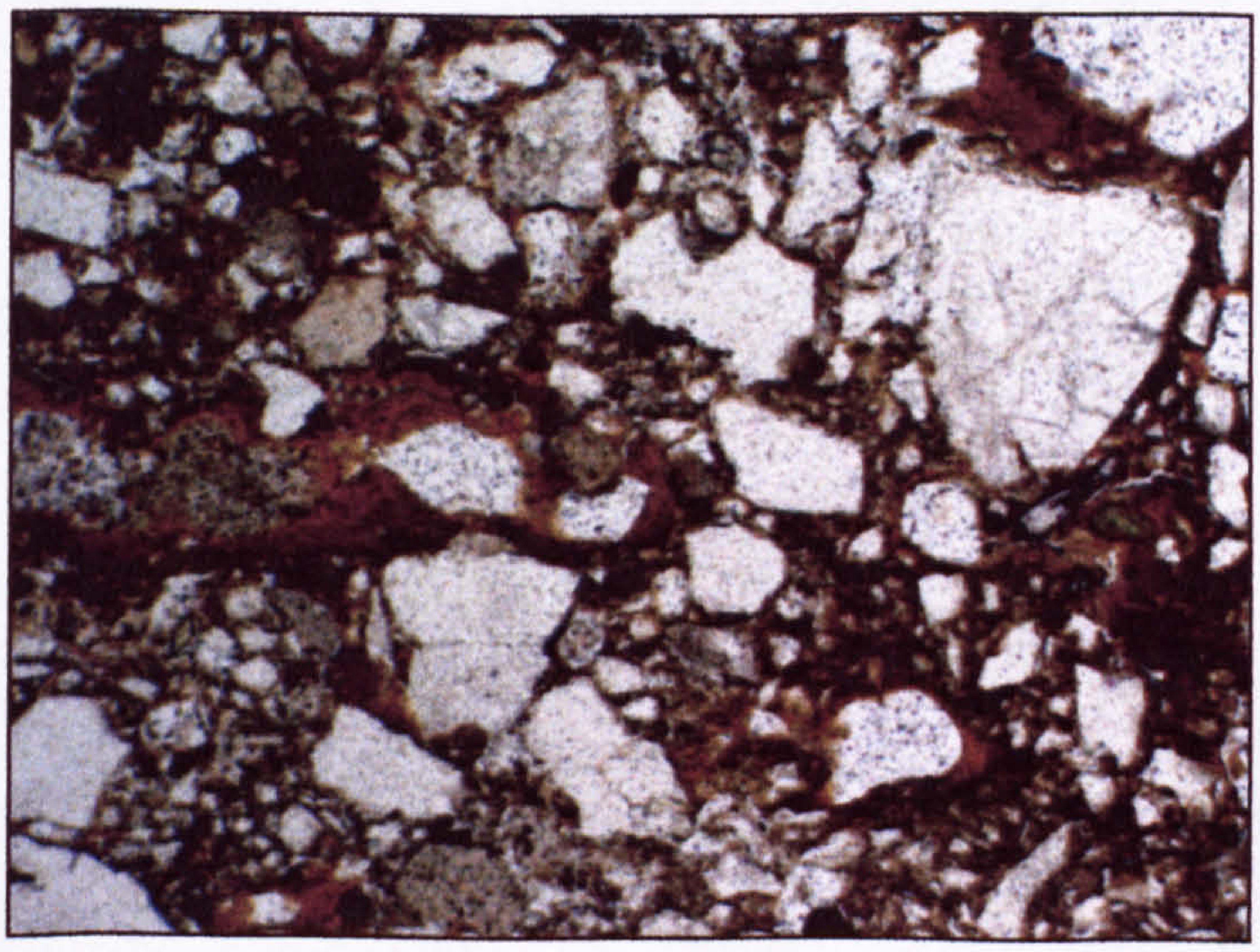


Fig. 5.5c: orange/red clay coatings in Fordhouse Barrow overburden.

Figure 5.6: Orange/brown type clay coatings from Fordhouse Barrow.

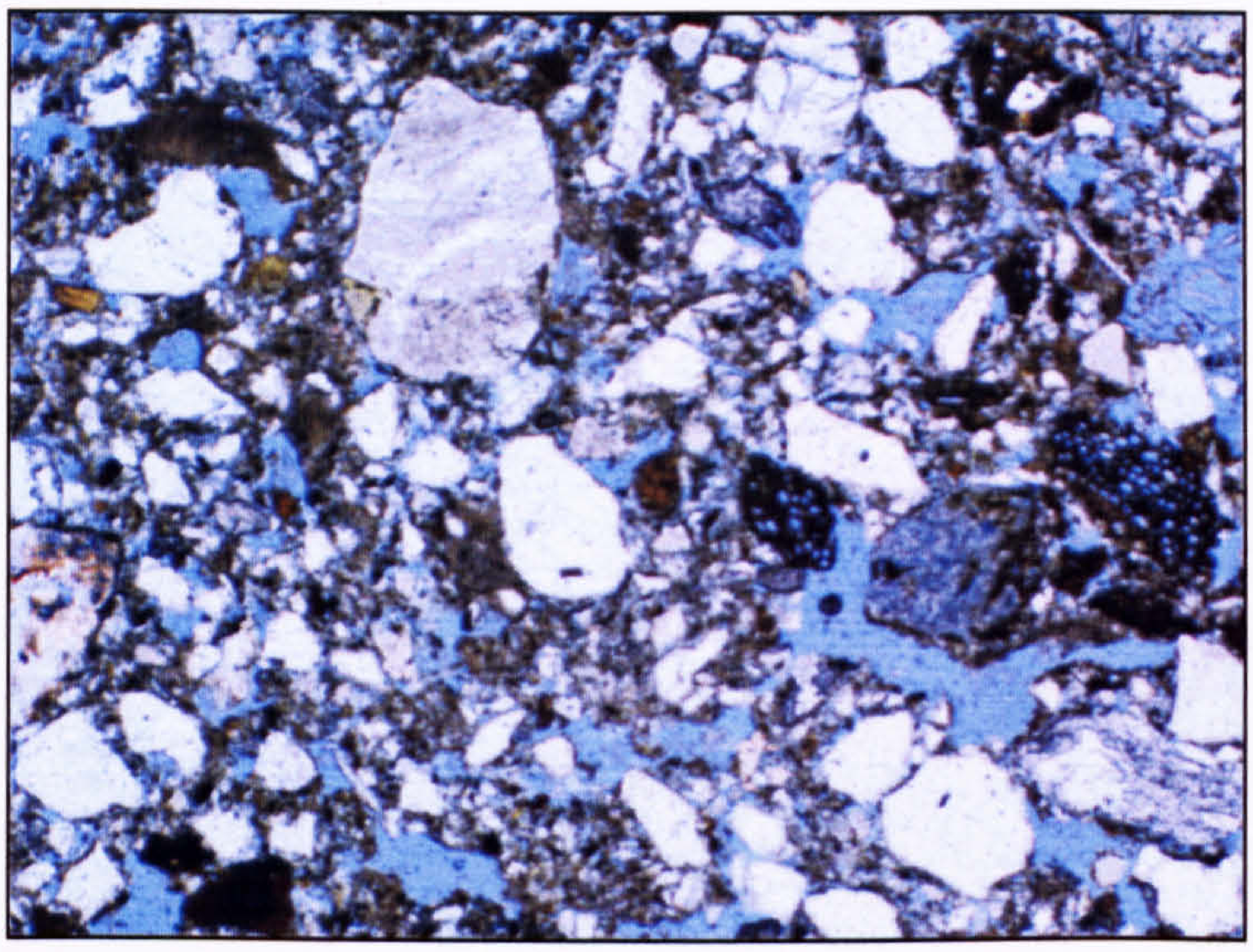


Fig 5.6a: Orange/brown type clay coatings within Fordhouse Barrow overburden.

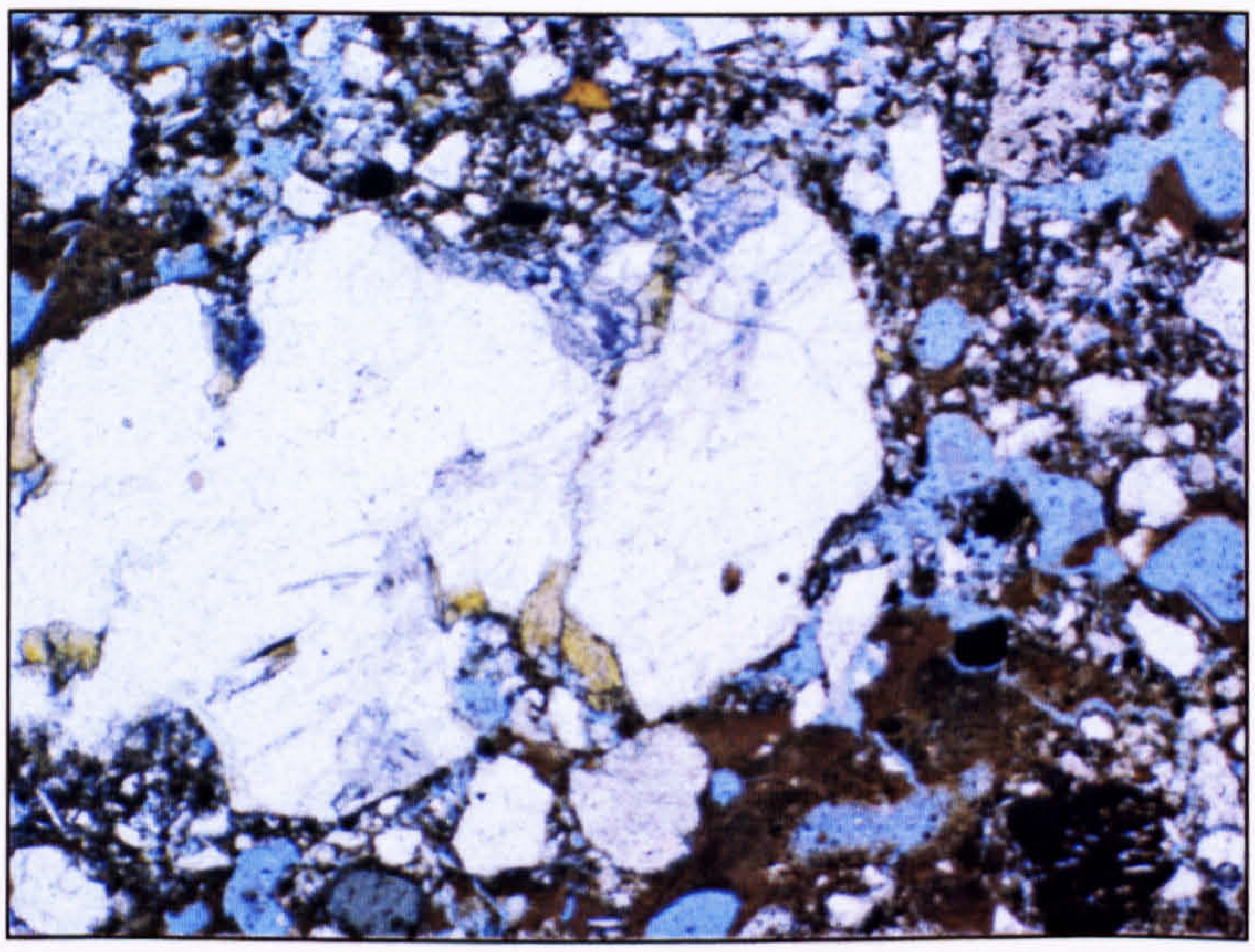


Fig 5.6b: Orange/brown clay coatings in profile 3, Fordhouse Barrow

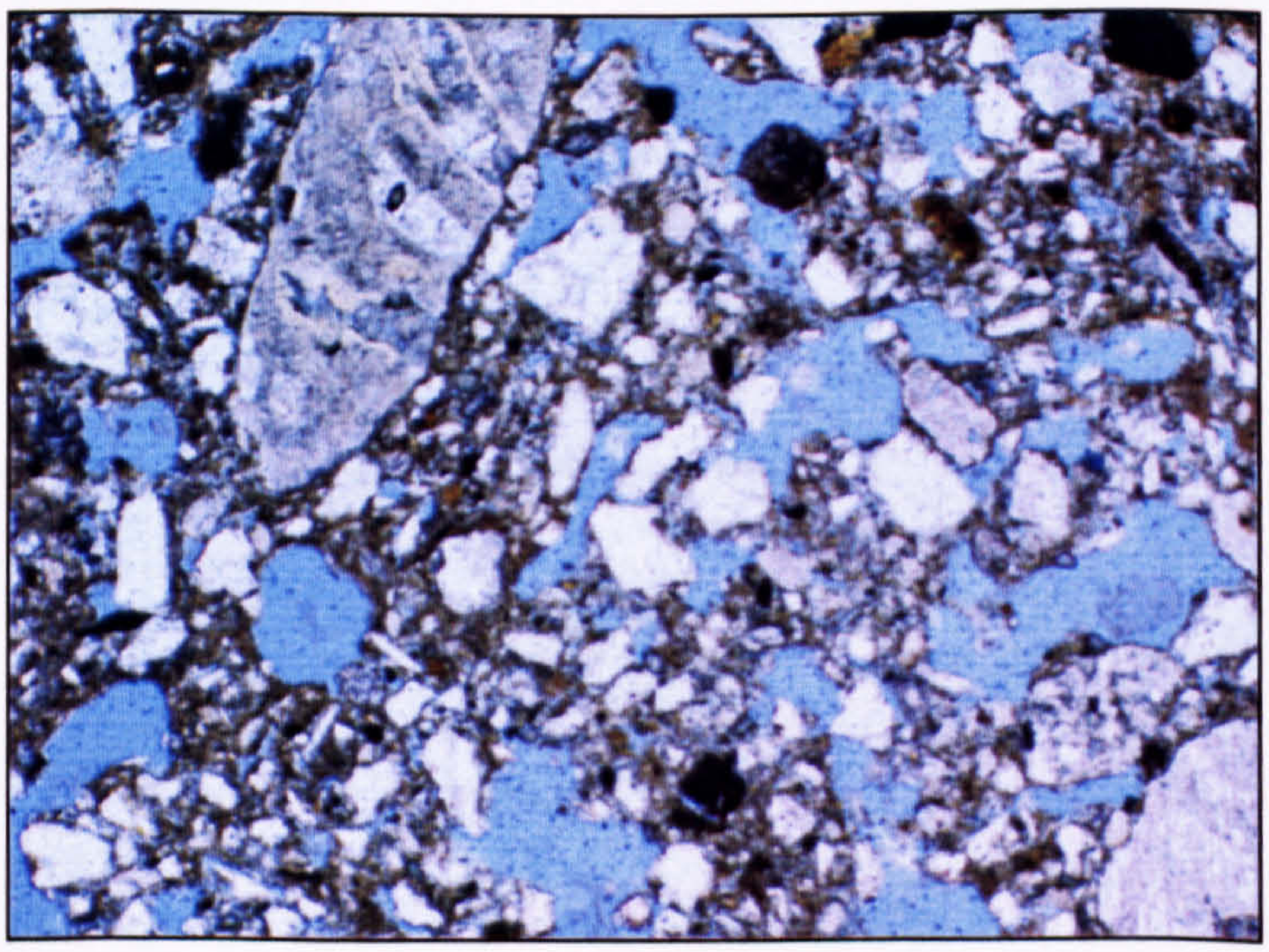


Fig 5.6c: Orange/brown clay coatings in overburden at Fordhouse Barrow.

Figure 5.7: Brown silty clay coatings types from Fordhouse Barrow and reference profile.

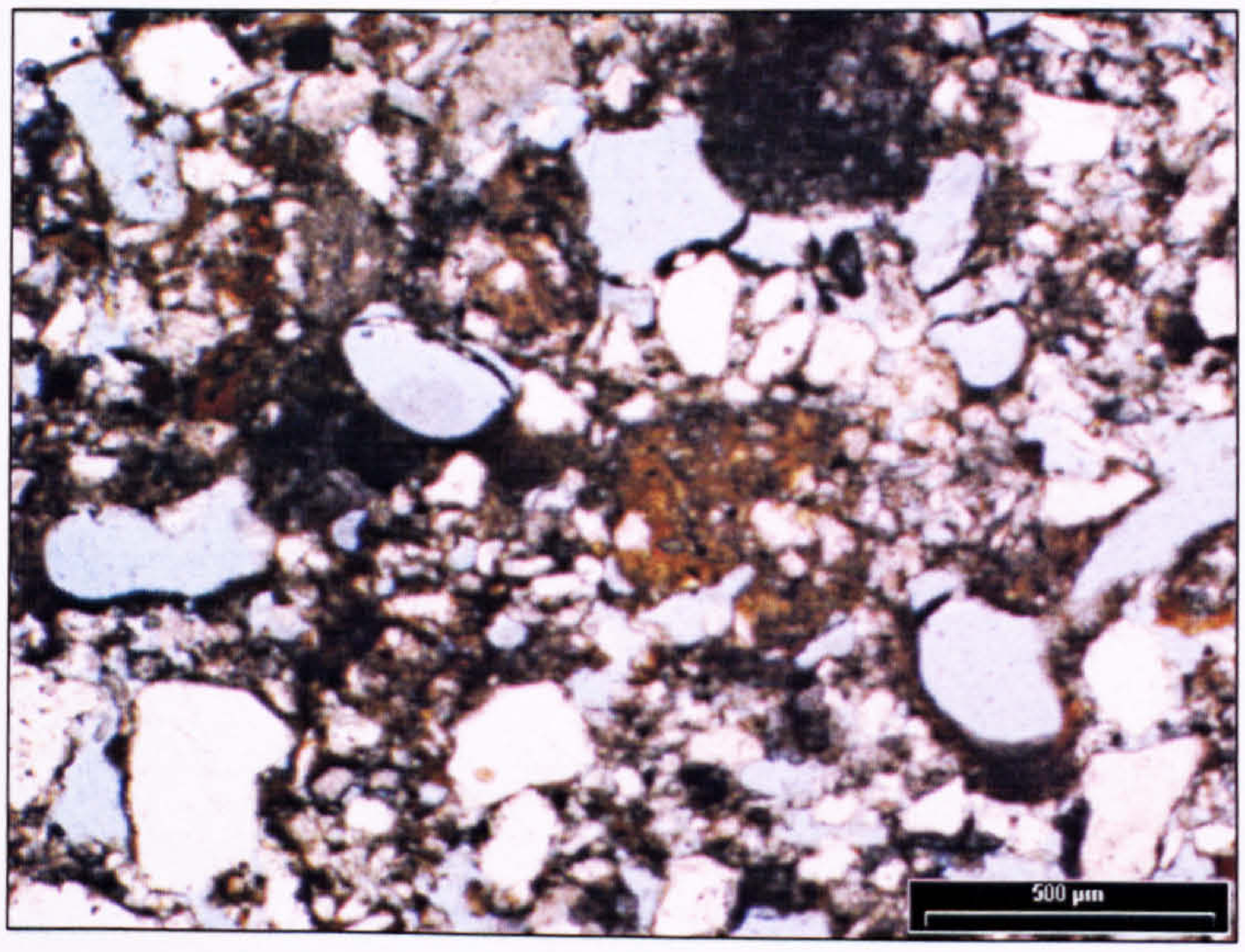


Fig. 5.7a: Silty brown clay coatings within the overburden at Fordhouse Barrow.

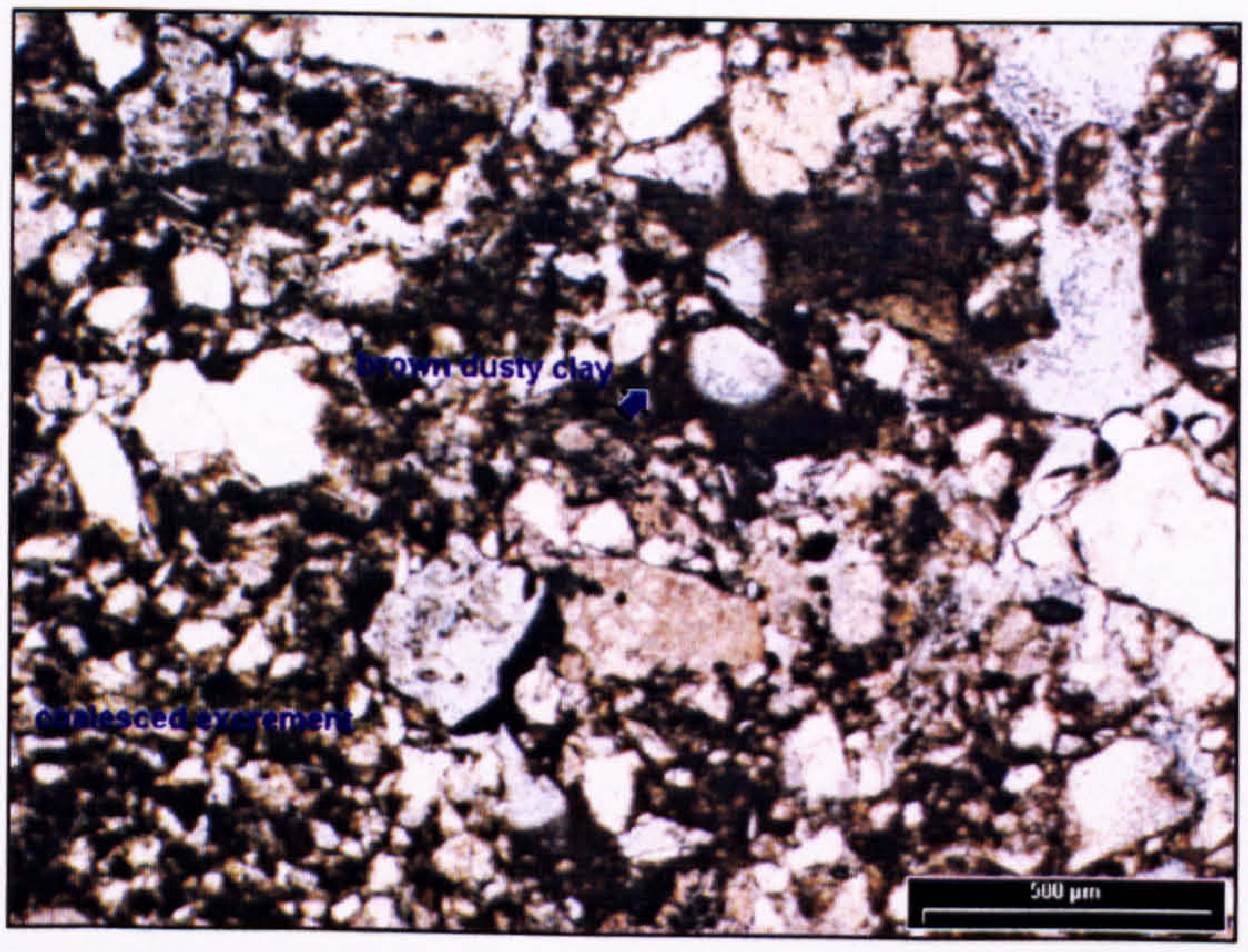


Fig. 5.7b: Brown silty clay coatings within buried soil.

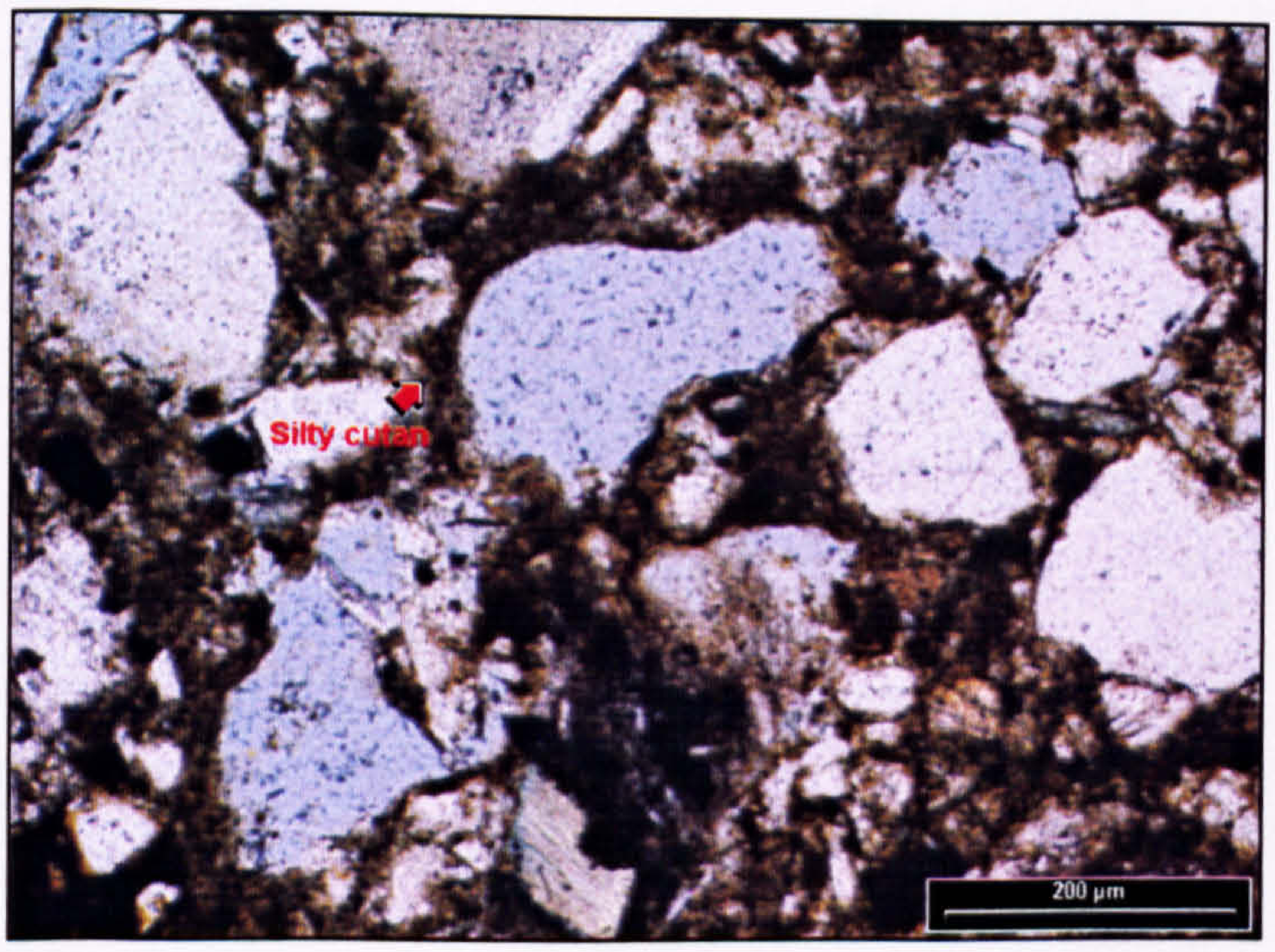


Figure 5.7c: Brown silty clay coatings within reference soil.

Table 5.2: Typology of main amorphous iron pedofeatures from Fordhouse Barrow.

Feature	Description	Distribution
Iron pans	Thin iron pan up to 250μm thick. Most strongly cemented at top of pan. In places pan double with amorphous red isotropic material between. Coated with type 2 orange and orange / red clay cutans, and cut through by channel voids containing plant phytoliths and enchytraeid excrement. Black and red/brown at x200 magnification.	Within A and AB type microfabrics at the interface of the buried soil and overburden, and within the overburden itself associated with turves. Discontinuous over site section, but rarely fractured and has a horizontal orientation.
Iron nodules type 1	Strongly impregnated, up to 5000μm diameter, with rounded, sharp edges distinct from surrounding soil matrix. Often include quartz clasts and occasionally coated by orange type 2 cutans. Black and red/brown at x200 magnification.	Throughout the overburden, buried soil and parent material. In profiles 2 and 3 tend to be more frequent in the buried soil and towards the top of the barrow.
Iron nodules type 2	Moderately to weakly impregnating soil matrix and occasional void cutans, particularly orange type 2, with diffuse edges. Red/brown and orange brown at x200 magnification	Within the lower overburden and buried soil.

The buried soil materials of the first and second profiles differ from the shallowly buried third. The difference is due to the differential occurrence of textural and amorphous iron pedofeatures. The nature of the underlying soil fabric is a mid-brown to orange organo-mineral material with an inter-grain microaggregate and vughy microstructure. Both thick (up to 250μm thick) dusty orange type 2, and thinner (up to 70μm thick) silty brown void cutans are present in this layer. The orange cutans, however, are absent from the third, stone sealed, buried soil profile.

The mound material consists of two distinct fabric types. The first tends to occur towards the top of the mound. This includes microfabrics similar to that of the lower reference soil and till materials. Pedofeatures within this material include type 1 orange void cutans similar to those found in the buried soil and till parent material. The second fabric type tends towards the base and edge of the mound. This microfabric is similar to the A, and A/B type microfabrics of the buried soil and the reference profile, although poorer in organic material. Brown, orange type II, orange/brown and orange/red clay cutans are frequent in the vughs and channels of this microfabric. Iron nodules and iron pans, are also present particularly at the base of the mound.

5.1.1.3 Bulk chemical and physical analyses from Fordhouse Barrow

Bulk chemical analysis reveals the reference profile as an acid profile (pH 4 and 5), with levels of pyrophosphate extractable iron decreasing steadily with depth (table 5.3). This profile suggests that although the profile has acidified, processes of podzolisation are not advanced. Clay and silt levels peak within the B horizon, whilst sand forms a greater proportion of the till material. Soil moisture decreases down profile and bulk density increases three-fold.

These properties contrast markedly with those of the barrow and buried soil. The barrow can be split into two main sections corresponding with the main microfabric types, the buried soil and till parent material can be dealt with separately. A summary of the chemical and physical properties of these material classes is given in table 5.4. Within the barrow, pH is on average one point higher than in the reference profile and decreases with depth from the surface. Moisture and loss-on-ignition values are also lower and do not follow the same depth relationships. Levels of pyrophosphate extractable iron are comparable between the barrow and the reference soil and decrease down profile. Soil texture shows no down profile trends though the till parent material is more clay rich than the overlying soils and sediments.

Table 5.3: Bulk chemical and physical properties of the Fordhouse reference profile.

Horizon	pH	Moisture %	% LOI	Bulk density g/cm^3	%Fe (pyr ext.)	%Fe (dith ext.)	%Fe (res)	%sand	%silt	%clay
Ah	4.2	47.8	47.8	0.51	0.3	0.6	0.3	66.7	31.9	1.5
A	4.4	41.5	41.5	0.53	0.3	0.7	0.4	50.6	47.1	2.2
B(g)	4.7	15.3	9.9	1.03	0.1	0.9	0.8	53.5	42.1	4.3
C	4.9	6.0	2.1	1.53	0.03	0.8	0.7	70.5	25.4	4.1

Table 5.4: Bulk chemical and physical properties of the soils and sediments from Fordhouse Barrow.

Context / depth (cm)	pH	% Moist	% LOI	Bulk density g/cm3	% Fe (pyr. ext.)	% Fe (dith. ext.)	% Fe (res.)	% Sand	% Silt	% Clay
Barrow (0-25)	5.6	15.6	1.28	1.15	0.32	1.08	0.91	61.2	32.3	6.5
Barrow (25-50)	5.5	17.2	1.71	1.05	0.17	1.04	0.81	64.4	29.7	6.0
Barrow (50-75)	5.5	11.5	1.80	1.23	0.13	1.04	0.99	62.6	31.2	6.2
bA	5.5	15.2	0.74	1.01	0.08	1.13	1.04	61.7	31.9	6.4
Till	5.4	13.2	0.52	1.10	0.03	1.12	1.09	54.0	37.8	8.2

5.1.2 Interpretation of results from Fordhouse Barrow

Interpretation of the soils and sediments from Fordhouse Barrow focuses on the identification of microfabric types and understanding the spatial and temporal hierarchy of pedofeatures. The microfabrics and pedofeatures, supported by the field data and bulk analyses, reveal a complex developmental history for the buried soil. Images of selected pedofeatures are provided in figures 5.3 to 5.7.

5.1.2.1 Pedological and anthropogenic soil development

The pre-burial soil environment involved a number of distinct phases. The first of these was the sedimentological environment of clay rich, Devensian till material derived from Old Red Sandstone and mica schist geologies. These glacial till materials have been subjected to periglacial processes of freeze-thaw resulting in the formation of silt cappings and poorly oriented silty clay void infillings and cutans (figure 5.3); features commonly found in association with periglacial deposits (Van-

Vliet *et al.*, 1985). The nature of this parent material is a key factor in the subsequent development of the soil environment, determining the soil mineralogy and chemical status, and the soil textural and drainage characteristics.

The nature of the buried soil is similar to that of the reference profile suggesting that the soil developed beneath woodland as a brown forest soil. The dusty and silty brown cutans present in the buried soils, the overburden, and the reference profile are interpreted as pre-burial in origin, probably resulting from anthropogenic disturbance. Table 5.5 shows the distribution of these brown and other cutans in relation to the microfabric type that they are present within and table 5.6 illustrates their distribution in the reference profile. Where brown cutan features are present within the barrow they are associated with A and AB horizon type microfabrics suggesting they are inherited from soil materials used in the construction. Dusty clay void coatings have been associated with anthropogenic clearance and cultivation activities. The brown cutans at Fordhouse Barrow were rare and relatively thin (figure 5.7). Anthropogenic artefacts within the soil included charcoal and heated stone consistent with clearance of the site by fire. Clearance activities were, therefore, important in the development of the buried soil, but there is little supporting evidence for cultivation activity prior to the building of the barrow. Incipient podzolisation of the buried and reference soils is suggested by the presence of iron depletion rims around sandstone clasts. Romans and Robertson (1975b) found that within soils of the Ettrick association, depletion rims are related to eluviation of iron and aluminium. The width of these rims at Fordhouse Barrow (only a few mm), however, indicates that full podzolisation has not occurred. Processes of podzolisation may be initiated by the exposure of the soil surface, and so this phase may also relate to anthropogenic clearance of the site. Chemical data also suggests that the buried soil had not developed into a full podzol, although perhaps the surface soil formed upon the barrow after construction has been podzolised indicated by the elevated pyrophosphate extractable levels at the top of the surviving profile.

Table 5.5: The distribution of textural pedofeature types within Fordhouse Barrow with depth from buried soil /overburden interface (0cm).

Slide	Micro-fabric type	Depth (cm)	Brown silty	Orange type 1	Orange type 2	Orange / red	Orange / brown
1/8	Sands	81		t	**	**	
1/9	Till	71		**	*		
1/10 I	Till	60		*	*	**	
1/10 II	A, AB	57	t		**		
1/10 III	Till	55		*	*		*
1/ 1	A, AB	50			*	*	
1/ 7	AB	35	*		***	t	**
1/ 2	A, AB	19	t		*	***	
1/ 2	AB	15	*		**	*	
1/ 6	AB	14	*	t	*		
1/ 3 I	A	9	**		**		
1/ 3 II	A, B	4	*		**	*	
1/ 3 III	A	2	t		*	**	
1/ 4	Buried soil	-6	*		**		
1/ 5	Buried soil	-32	*		***		
1/ 5	Till	-35		**	t		

Table 5.6: Distribution of textural pedofeature types in the Fordhouse Barrow reference profile with depth from surface.

Slide (depth)	Microfabric type	Depth (cm)	Brown silty	Orange type 1
A	A	1		
B	Ah	7		
B	A	11		
F	B	28		
C	B	31	*	
D	Till	48		**

t	trace (isolated occurences)
*	>1% slide area
**	1-2% slide area
***	2-5% slide area

5.1.2.2 The effects of site construction and post-burial change

Construction of the archaeological site was a multi-phase operation commencing in the late Neolithic with the construction of a passage grave and culminating in the Early Bronze Age with the erection of the barrow. The mound itself has a history of later disturbance with sporadic burials continuing through to the Medieval and further damage to its south side from quarrying and rabbit activity. Comparison of the distribution of the pre-burial silty, brown void cutans within the reference profile and buried profiles, together with the shallow nature of the buried soil is suggestive of truncation of the soil profile prior to the construction of the mound. Perhaps the stripped turves were used along with soil materials from the surrounding area to construct the mound itself. Top-soil type microfabrics are found towards the base of the mound, and pseudomorphs that appear to be of monocotelydon plant material are preserved within the iron pans. The presence of orange type II, clay cutans throughout the first and second buried soil profiles and their absence from the third 'stone sealed' buried soil and reference profile, strongly suggests a phase of post-burial clay translocation. The presence of these orange, orange / brown, and orange / red void coatings within the overburden and even above the unaffected sealed buried soil suggests a source for these materials within the upper mound and its redeposition down profile within the mound and the buried soil. These cutan features, unlike the brown void cutans, occur irrespective of the microfabric type adding credence to the theory that they are of post-burial origin relating to a phase of illuviation after the construction of the barrow monument. The coating of the iron pans by clay suggests that this post-burial phase of clay illuviation itself post-dates the formation of the iron pans. Charcoal within the mound is also found coated by *in-situ* orange, orange / red and orange / brown cutans further supporting the hypothesis of post-burial formation. Type 1, orange clay coatings are found in the till parent materials and within the barrow material but only in association with the sub-soil type microfabrics found towards the top of the mound. This distribution suggests they are inherited from the sub-soil materials used in construction. These clay rich sub-soils may have provided a source of fine material for the post-burial phase of illuviation with the inclusion of amounts of iron and organics from adjacent top-soil materials to produce the orange / brown and orange / red coatings. The iron pans pre-date the type 2, orange clay coatings, however, they are also interpreted as a result of post-burial processes.

Similar thin iron pans from beneath the Strathallan mound were described as having formed within an acid humus accumulation at the soil surface prior to burial and were interpreted as evidence of sheep grazing (Romans, 1983). However, at Fordhouse Barrow this does not appear to be the case. The lack of an iron pan in the reference profile, and the discontinuity of the pan beneath the mound (restricted to the deepest parts of the section, profile 1) suggests this is a post-burial feature. Following both the post-burial formation of the iron pans and orange type 2, orange / red and orange / brown void cutans, biological activity has been ongoing. Iron pans and cutans are partially disturbed by channel voids that cut through them and often contain enchytraeid excrement and the remains of plant roots.

5.1.3 Summary of results from Fordhouse Barrow

Fordhouse Barrow is a complex site. The development of the buried soil continued through and beyond the construction of the Bronze Age barrow. The post-burial processes resulted in major readjustment of the buried soil microfabric and the overlying archaeological sediments, in response to the altered bio-physico-chemical conditions of the burial environment. The evolutionary sequence for the buried soil at Fordhouse Barrow is shown below in Figure 5.8.

The processes of post-burial change recognised at this site include redistribution of iron particularly at the base of the mound and its interface with the buried soil profile. The release and down profile movement of silts and clays within the mound and buried soils has also been shown. Biological activity within the buried soil is clearly post-burial in date whilst some structural alteration of the soil fabric has also been suggested. The overall effect of these processes within the buried soil is that of obscuration, the deposition of clays and iron oxides in some areas effectively hide the nature of the soil fabric beneath. However, despite the marked post-burial alteration of the buried soil fabric, evidence from some of the earliest development phases still survives within the soil fabric providing evidence of its sedimentological, pedological and anthropogenic history.

Figure 5.8: The inferred developmental sequence of buried soils at Fordhouse Barrow.

Phase 1	Deposition of sandstone derived till material. Periglacial activity forming silty clay cutans, and cappings.
Phase 2	The development of a brown forest soil upon till parent material, and under a mature woodland canopy.
Phase 3	Anthropogenic activity, including woodland clearance and the construction of a Neolithic passage grave. Disturbance led to formation of dusty brown void cutans, and some iron mobilisation resulting in incipient podzolisation.
Phase 4	Monument construction using local soil and sub-soil materials.
Phase 5	The formation of iron pans at the base of the mound where turf material present.
Phase 6	Translocation of orange clay, iron and organics, to form orange type 2, orange / brown and orange / red void cutans within the barrow and the buried soils.

Ongoing biological activity

5.2 Results from the island of Sanday, Orkney.

The island of Sanday has a dominant acid geology of Old Red Sandstone similar to that of Fordhouse Barrow. The archaeological sites studied on this island are not constructed of local soil and sub-soil type materials as sites in the other study regions, but are midden deposits composed of organic-rich waste deposits.

5.2.1 The modern sites of Roos Loch and Gallows Hill

These sites represent contemporary soil profiles; one buried by quarry waste 3-5 years previously (Roos Loch) and the other unburied developed beneath heather heath. Both have formed upon Old Red Sandstone derived drift deposits 10-30cm thick.

5.2.1.1 Field results from Roos Loch and Gallows Hill

Gallows Hill

This reference profile (figure 5.9) represents a podzolic soil of the Bilbster series formed under *Calluna* heath. The silty clay loam soil with moderately strong blocky structure has developed to a depth of 30 cm above the drift parent material. The common sandstone clasts exhibit iron depletion rims and together with discontinuous iron panning at the boundary with till material are indicative of iron eluviation. Under the heath root penetration is heavy down to the level of the iron pan. (Appendix 4, p.366)

Roos Loch

This site consists of a one metre high mound of quarry waste overlying a soil of the intermediate Bilbster series (figure 5.10). The overburden includes slabs of sandstone, gravel, soil and subsoil materials forming a coarse and open mound. The texture fines towards the base and centre of the mound where more clay and silt rich soil and sub-

Figure 5.9: The Gallows hill reference soil profile, Sanday.

Figure 5.10: Roos Loch buried soil profile, Sanday.

soil materials are present. The buried soil profile represents a podzolic soil of silt loam and silty clay loam, humic at the surface but the organic content rapidly declines down profile (Appendix 4, pp. 367-368). Immediately below the mound the buried A horizon is a silty clay loam with little structure and few roots. Beneath this a bleached Ea horizon is present. The Bs horizon beneath is reddish brown with intense mottling along its top and bottom. The drift deposits below show signs of periglacial activity (ice wedging) and recent gleying. The boundary between the overburden and the buried soil is abrupt and distinct, and the upper A/Ah horizon is significantly thinner beneath the mound compared to the adjacent non-buried soils. This loss of depth could be due to compression as suggested by the apparent loss of soil structure and the relatively high density of the upper buried soil horizons.

5.2.1.2 Micromorphology results from Roos Loch and Gallows Hill

Roos Loch

Summary tables of results are given in appendix 5 (pp. 397-400). The stony nature of the overburden prevented the taking of kubiena samples. The slides taken from the upper soil horizons reveal an organic rich, excremental micro-fabric. Excremental pedofeatures include both mammilate and small beaded excrements characteristic of earthworms and enchytraeids. Excremental features are concentrated within the upper 5 cm of the horizon, although the enchytraeid excrement is present throughout the profile within channels containing organic remains. The mammilated excrements are found fused to, and lining the channel walls, suggesting ageing of these features in their buried contexts. The organic component includes yellow, red and blackened amorphous organics, lignified and parenchymatic tissue remains. In the non-buried soils live and fresh root sections are frequent, however, in the buried horizons no live roots are present and organic remains consist of parenchymatic cell residues lining the channels giving the impression of having decomposed *in-situ*. Amorphous iron pedofeatures are present throughout. At the surface they tend to consist of rare, impregnated stone clasts. In the lower sections of the soil and sub-soil mottling accounts for up to 10% of the slide area and coincides with grey, iron depleted matrix areas suggesting groundwater gleying of the subsoil. Gleying appears to be a feature of pre-burial soil development as these mottled features of redoximorphic iron redistribution are present within both buried and non-buried soils. Yellow and orange, limpid clay void coatings are present in this soil but are confined to the deepest sub-soil horizons of the buried and non-buried profiles; these, therefore, are pre-burial, pedogenic features. Limpid cutans are commonly associated with the illuviation of clay under stable, wooded, conditions (Fisher, 1982).

Gallows Hill

Summary tables of results are given in appendix 5 (pp. 396). The micro-fabrics typical of this soil consist of a mid-brown, organic rich material in the surface A horizon, and mid to pale brown, organo-mineral and mineral fabrics in the B horizon. Channel microstructures dominate the upper horizons. Many of the channels contain excremental evidence of earthworm, mite and enchytraeid activity which is concentrated in the top 10cm. Excremental features towards the base of the profile tend to be more heavily fused than at the surface giving an impression of greater age. Towards the base of the profile there is evidence of gleying with iron mottling the soil matrix. Iron concentrations are noted to coincide with the presence of red amorphous organic material and suggest down profile movement of iron as well as a localised redistribution by gleyic, redoximorphic processes. Quartz and feldspar dominate the sand-sized mineral fraction.

5.2.1.3 Bulk analytical results from Roos Loch and Gallows Hill

Gallows Hill

Bulk chemical and physical results from the Gallows Hill reference profile (table 5.7) are typical of a shallow phase podzolic soil of the Bilbster series (Futty and Dry, 1977). The profile acidifies towards the surface where the level of organic material is high. The pyrophosphate extractable iron concentration peaks in the Bs horizon as a result of podzolisation.

Table 5.7: Bulk physical and chemical properties of the Gallows Hill reference soil.

Horizon	pH	% LOI	% Moisture	Bulk density g/cm^3	% Fe (pyr ext.)	% Fe (dith ext.)	% Fe (res.)
A	4.9	16.3	32.1	0.69	0.30	1.05	0.85
B	5.4	13.8	31.3	0.78	0.36	1.19	0.86
C	5.7	11.0	25.2	0.81	0.08	1.16	1.04

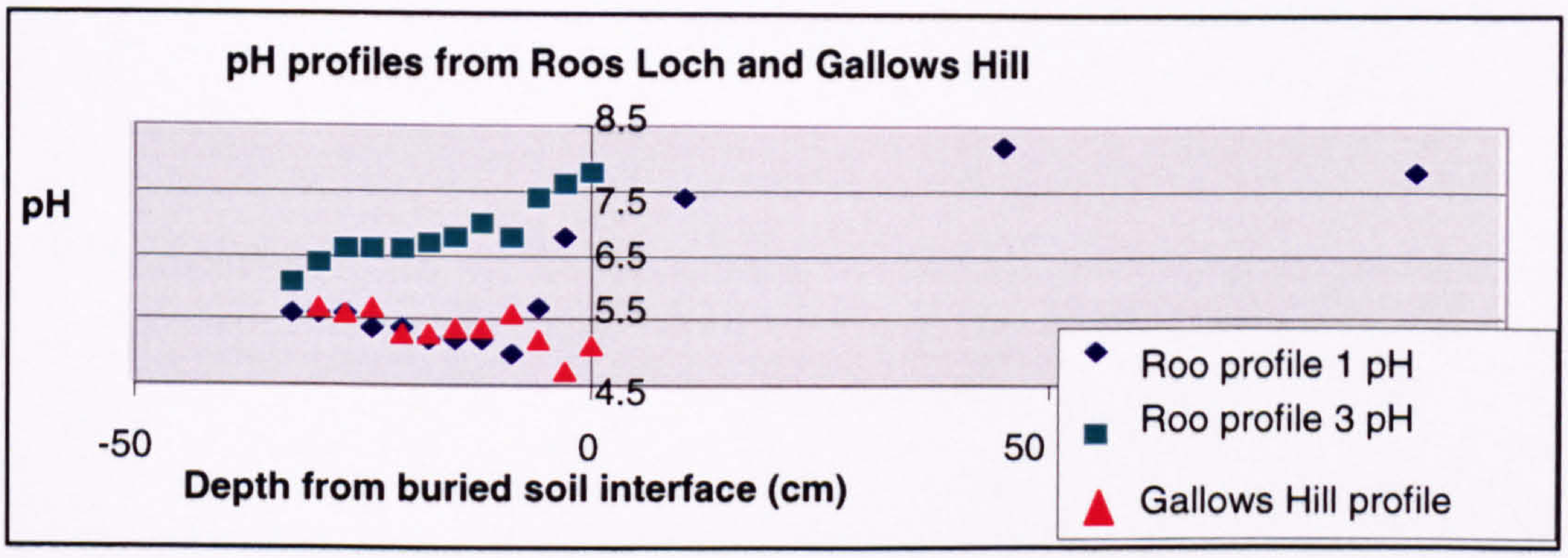
Roos Loch

Chemical and physical analysis of the soils and sediments of Roos Loch, (table 5.8) reveals an alkaline overburden material above an acid soil profile. The upper A horizon of this deeply buried soil profile appears to have been affected by the leaching of bases from the overburden resulting in an elevated pH (pH 6.1). Figure 5.11 compares the pH of profiles 1 and 3 from this site (profile 1 is buried and profile 3 unburied) with the Gallows Hill reference profile. This graph shows how, in contrast to the reference profile, the pH of the unburied soil at Roos Loch is highest at the surface, possibly in response to the addition of salt in sea spray. The surface pH of the unburied soil is comparable with that of the overburden material. However, in comparison with the podzolised reference profile, the buried Roos Loch profile is remarkably similar with the exception of the top ten centimetres where the pH rises rapidly in response to the alkaline overburden material. Podzolisation of this buried profile prior to burial is indicated by the rise in pyrophosphate extractable iron in the B horizon (Bs). Loss-on-ignition for the buried A horizon is similar to the Gallows Hill site. The field macromorphology, micromorphology, and chemical and physical analyses classify the unburied reference soil as a shallow, imperfectly drained, podzolic soil. In view of the parent material of Old Red Sandstone derived drift deposits this falls within the Thurso soil association as an example of an intermediate phase Bilbster series soil typical of much of this island. This acid soil is typified by process of iron eluviation and precipitation to form a thin iron pan at the base of the profile, and moderate bioturbation principally through the activity of

Table 5.8: Bulk chemical and physical properties of the soils and sediments from Roos Loch.

Horizon	pH	% LOI	% Moisture	Bulk density g/cm^3	% Fe (pyr ext.)	% Fe (dith ext.)	% Fe (res.)
O. burden Top	7.8	/	/	/	0.20	1.52	1.50
O. burden Middle	8.2	/	/	/	0.11	1.82	1.57
O. burden Bottom	7.4	/	/	/	0.21	1.62	1.22
A and Ea (contexts 1-5)	6.1	17.82	36.38	0.80	0.26	1.06	0.66
Bs (context 006)	5.3	6.1	31.31	0.76	0.44	1.64	0.95
C (context 007)	5.6	2.4	24.62	1.05	0.15	0.80	0.59

5.11: The pH profile of soils and sediments from Roos Loch and Gallows Hill.

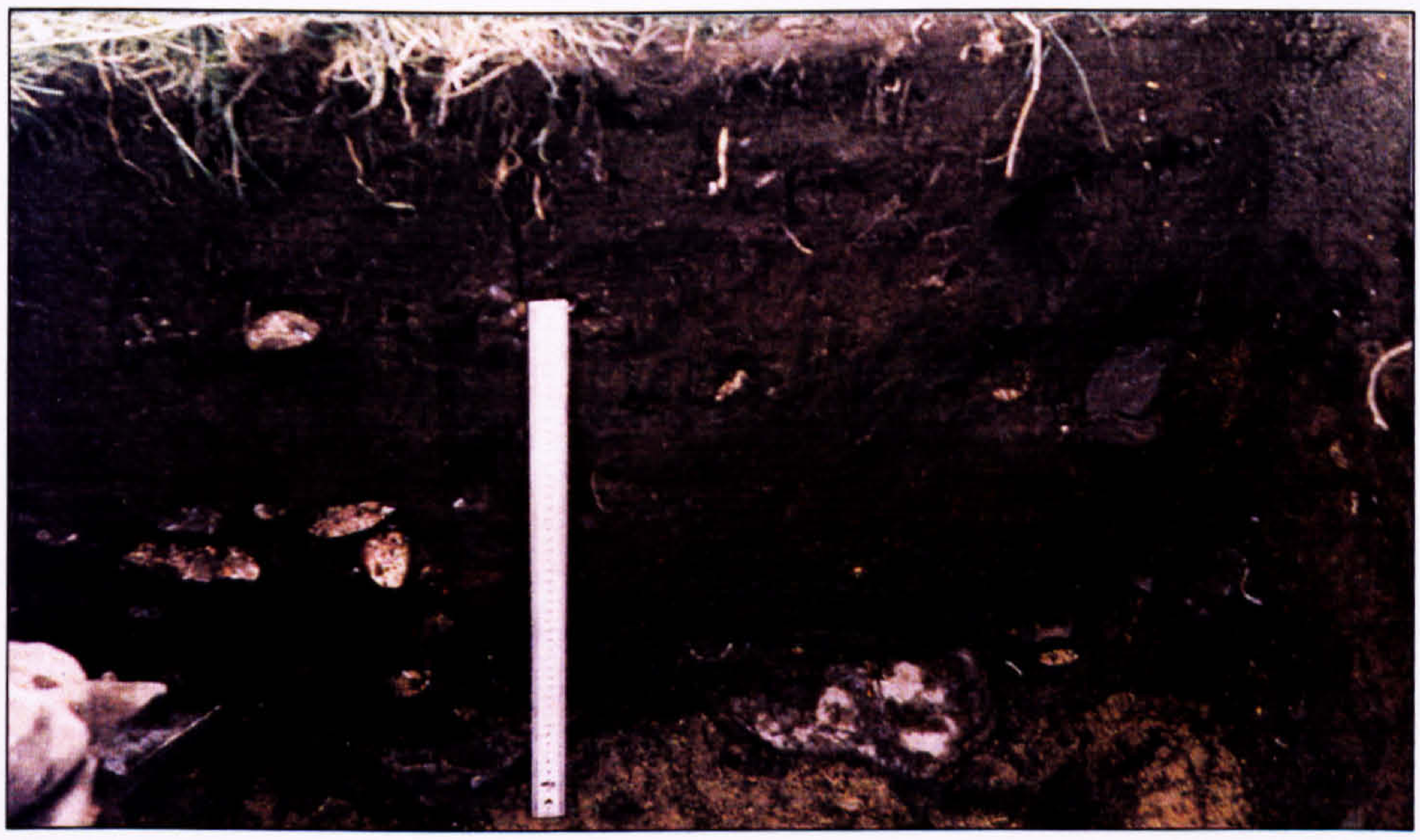


enchytraeids. This site occupies one of the most inland areas of the island and is more removed from the buffering action of salt spray that may be expected at the coastal sites.

The development of the buried soil at Roos Loch is contemporary with that of the reference profile of Gallows Hill. This pedological relationship is borne out by the similarities in the chemical aspects between the two soils and which suggest that podzolisation and acidification have been important processes. The micromorphology and field morphology of the two sites suggest that ground water gleying has affected the sub-soils of both. Since burial of the Roos Lochs soil, a number of processes appear to have been operating. The bulk chemical data suggests that the buried topsoil has become base enriched from the overlying quarry waste material. The adjacent unburied soil profile, however, also suggests that since burial the surrounding soils have also been base enriched possibly from the input of salt sea spray. The field morphology reveals a loss in thickness of the upper organic horizons with burial, the increase in bulk density suggests this is due to compression of the buried soil. The decomposition of organics and a decrease in earthworm activity following burial is also evident in thin section.

5.2.2 The 'tell' site of Seater

Figure 5.12: Seater buried soil profile, Sanday.



5.2.2.1 Field results from Seater

The site of Seater was the only Sanday site where access to a natural eroded section was not available and a test pit had to be dug (figure 5.12). The buried soil consists of a silty clay loam with a massive structure, overlain by shell rich, ashy midden deposits with little apparent structure and a relatively high organic content. At the surface a new soil profile has developed with a weak, fine to moderate blocky structure. Fine grass roots from the surface vegetation show no evidence of penetrating into the buried soil. The straight boundary between the buried soil and the overburden is moderately distinct although black flecking is frequent in the top 2cm of the buried soil. The depth of the buried soil was only 15cm, much less than that of either the reference soil or of the very recently buried soil at Roos Loch. Samples of bone and shell were collected from the midden and submitted for radiocarbon dating. Full field descriptions are given in appendix 4, pp. 368-370.

5.2.2.2 Micromorphology results from Seater

Summary tables of results are given in appendix 5 (pp. 401-402). The micromorphology of these thin sections depicts a sequence of heterogeneous organic rich midden deposits. These consist of amorphous organics, intermixed with charred organics and fully carbonised charcoal. The presence of herbivore dung is indicated by the presence of calcitic spherulites (Canti, 1997; 1998), often occurring within a yellowish, amorphous organic matrix, either in distinct layers or lining channel voids. The distribution of these elements together with the quartz dominated sand and silt mineralogy was patchy suggesting periodic deposition of different waste materials. The microfabrics have channel or spongy microstructures and both mammilate and enchytraeid type excrements are present. The importance of earthworms in the post-depositional bioturbation of this organic rich material is evident with the inclusion of midden material within the buried soil and *vice versa.* The buried soil beneath the midden material consists of a yellow brown organo-mineral fabric with a channel microstructure formed upon glacial till. Trace numbers of spherulites and very few fine fragments of charcoal are present within the buried soil itself, evidence of either mixing of the buried soil and the overburden, or of pre-burial anthropogenic activity.

Matrix impregnations of iron have formed in both the midden and buried soil material, often in close proximity to organic remnants. This suggests localised redistribution due to the acidification of the immediate matrix because of decomposition processes rather than gleying. Depletion pedofeatures are very rare so illuviation of iron seems to be insignificant. Depletions of calcium carbonate from the midden matrix, however, are present and in rare cases calcitic recrystallisation is visible within the weathered remains of limpet shells. Rare silty brown, organic rich cutans are present lining channels within the midden material. The cutans are up to 75µm thick, and show little internal organisation and orientation, they may be the result of down profile movement of material, in response to disturbance at the mound surface (Courty *et al.*, 1989). No void cutans are present within the buried soil.

5.2.2.3 Bulk analytical results from Seater

Chemical analysis of the soils and sediments from Seater (table 5.9) reveals basic pHs in the midden and buried soil material. The pH increases with depth through the overburden, from weakly alkaline topsoil down to a distinctly alkaline buried soil horizon. As at Roo's Loch, the buried A horizon has an elevated pH relative to the underlying sub-soils possibly suggesting recalcification of the buried profile from above. Bulk density within the buried soil is relatively high and loss-on-ignition within both the midden and buried soil is relatively low. Pyrophosphate extractable iron levels increase down profile peaking within the buried soil.

Table 5.9: Bulk chemical and physical properties of the soils and sediments of Seater.

Horizon	pH	% Moisture	% LOI	Bulk density g/cm^3	% Fe (pyr. ext.)	% Fe (dith. ext.)	% Fe (res.)
Modern A	/	29.7	9.76	0.80	/	/	/
Context 004	7.8	26.9	5.62	0.73	0.18	1.42	1.29
Context 003	8	26.1	3.38	0.74	0.19	1.28	1.20
Context 006	8.2	27.3	5.15	0.89	0.24	1.20	0.98
Buried A	8.3	25.0	5.12	0.99	0.29	1.31	0.98
Buried sub-soil	8.0	/	/	/	0.33	1.15	1.07

C14 dating results

Radiocarbon dating of shell and bone from Seater was carried out through the NERC Radiocarbon laboratory in East Kilbride. The shell sample is from the upper midden horizon and is from the marine horse mussel (*Modiolus modiolus*). The dating of this material involved the removal of the outer 20% of the sample, its hydrolysis in 4M HCl and radiometric liquid scintillation counting of the gas evolved. Collagen was extracted from the two bone samples from the lower midden deposits following the methods of Longin (1971). Dating was carried out using Accelerator Mass Spectrometry at the University of Arizona. Calibration of the radiocarbon ages was undertaken using the CALIB 4.2 program (Stuiver and Reimer, 1993) which uses the (Stuiver *et al.*, 1998) dataset. Marine C14 depletion effects for the shell sample were corrected by subtracting 410 +/-50 from the apparent age (Harkness, 1981). The radiocarbon and calibrated results are given in table 5.10.

Table 5.10: Radiocarbon dates from Seater, Sanday.

Sample No.	Depth from surface (m)	Sample	14-C age (1σ)	Calibrated Age BP	Age range (2σ)
SRR-6399	0.44	shell	1080 +/-45	297	444 - 234 BP 1506 – 1716 AD
AA-33826	0.46	sheep/goat mandible	735 +/-45	669	732 – 648 BP 1218 – 1302
AA-33827	0.63	sheep/goat limb bone	615 +/-45	631, 598, 561	663 – 534 BP 1287 – 1416 AD

5.2.2.4 Interpretation of the site of Seater

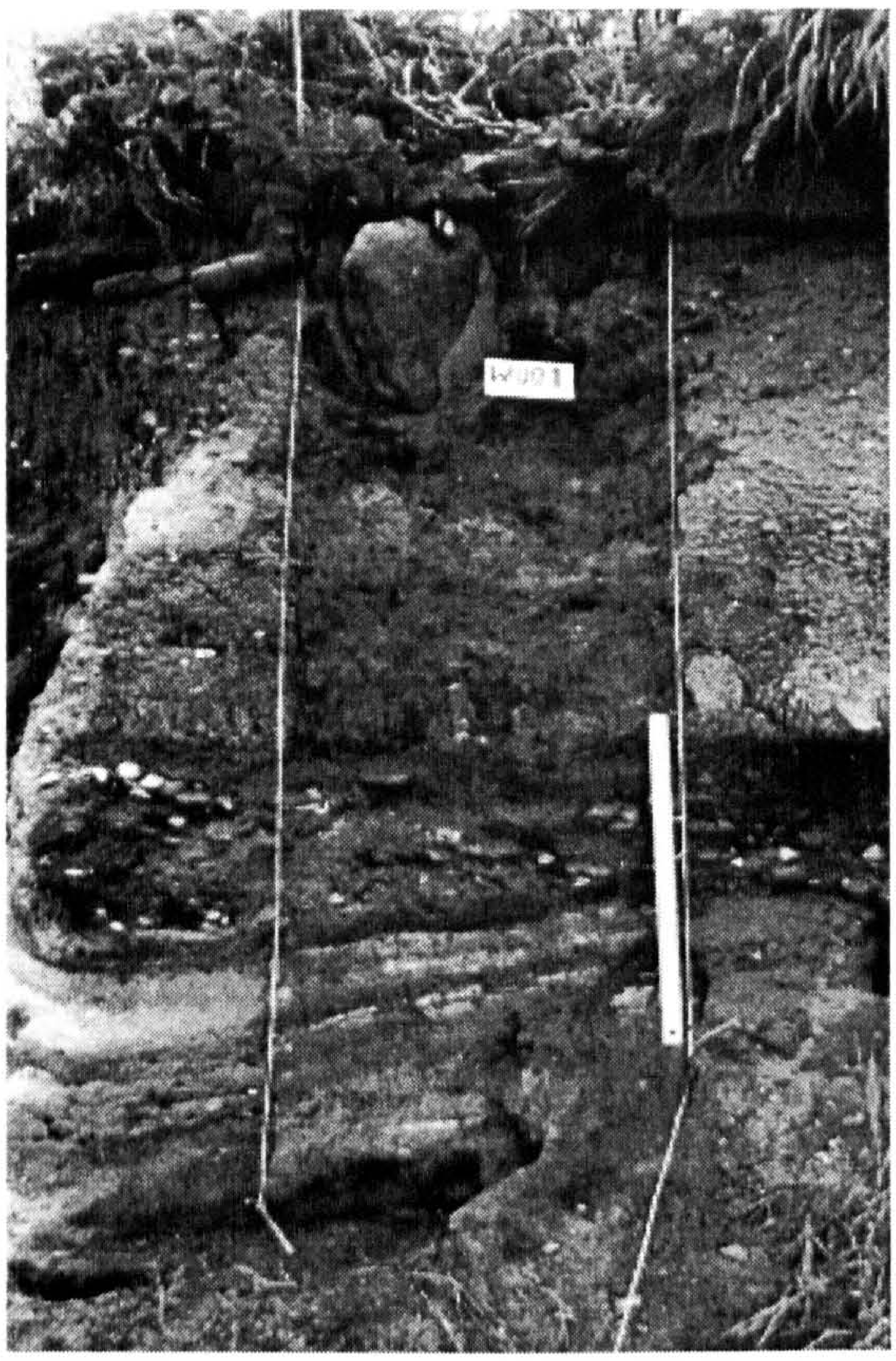
Seater provided a surprisingly basic soil environment. Locally this appears to have been the case at the time of burial, as is indicated by the high levels of spherulites within the dung component of the midden material. These features have been to shown to only form in the guts of animals grazed upon calcareous pastures (Canti, 1997; 1998). Shell fragments within the buried soil may be the source of the locally basic pH upon an otherwise acid geology. Shell, bone, spherulites, and ash residues within the midden will all raise the pH further, and the increase down profile of pH values suggests that leaching of base cations from the surface horizons downwards has occurred, chemically 'welding' the buried soil with the overburden material. The buried soil at Seater shows no evidence of podzolisation, and would have been a brown earth or calcareous brown earth. Anthropogenic activity prior to the construction of the midden cannot be ruled out. Following deposition of the base rich midden material the pedological development of the soil ceased, and the topsoil was recalcified as decalcification of the midden and leaching down profile progressed as is indicated by the depletion of calcium carbonate from areas of the midden fabric. In thin section biological activity was seen to have resulted in the physical mixing of the buried soil and overburden. Whilst redistribution of iron in response to decaying organics, has occurred within both the buried soil and the midden. Disturbance of the midden surface, possibly cultivation, is thought to have resulted in the formation of the rare silty void coatings within the midden.

5.2.3 Woo limpet midden, Sanday

5.2.3.1 Field results from Woo

The Iron Age site of Woo consists of sea eroded midden deposits up to 2m thick overlying a discontinuous buried soil. Figure 5.13 presents photographs of the profile and illustrates clearly the nature of the buried soil. Rather than soils of the Bilbster series, thin deposits of wind blown shell sand over the sandstone have resulted in the formation of a weakly developed dune soil belonging to the Fraserburgh series (Appendix 4, pp. 370-374). The buried soil consists of lenses of almost pure shell sand of 2.5 Y moist colour between very thin (ca. 2-5 mm.) dark brown and black organic layers of 10YR colours. These pre-midden layers were structureless with a loose, open consistency. The overlying midden deposits are finer textured than the sandy buried soils (silty clay loam). The midden is constructed of interwoven layers and lenses of materials of different colour and composition. The midden includes rare fish and sheep bone, occasional limpet and cockle shells, and black flecks of charcoal. These waste materials tend to be concentrated within specific horizons suggesting periodic deposition. Horizon boundaries are both abrupt and diffuse. The boundary between the buried soils and midden overburden is distinct and sharp.

Figure 5.13: Woo buried soil profile 1, Sanday.



5.2.3.2 Micromorphology results from Woo

Summary tables of results are given in appendix 5 (pp. 403-406). The Iron Age site of Woo provided 14 thin sections from the midden and buried soil section. They describe a sequence of organic rich mid-brown and yellow / brown midden deposits overlying organo-mineral and mineral, skeletal soils and shell sands. With channel, vughy and inter-grain microstructures the midden material at this site includes shell, bone, degraded fish bone, amorphous black, yellow and red organics occasionally laid in a laminar pattern, charcoal, and rare diatoms and spherulites. The percentage void space within these midden deposits is relatively small (15-20%) and is dominated by channel structures. Mammilated earthworm, ellipsoidal mite, and cylindrical enchytraeid excrements are all present within this organic rich material. Earthworm excrements within many of the midden layers contrast sharply with the surrounding matrix and instead included fabrics from adjacent contexts. The buried soils consist of monic medium shell sands, between which are thin layers of sand coated with small micro-aggregates and coatings of black organic material. Within the buried soil only earthworm and rare enchytraeid excrements are present. The mammilated features within the buried soil often consist of a microfabric similar to that of the midden overburden. Two types of void coating were identified within the midden and buried soil material (table 5.11). Rare silty, textural pedofeatures are present within the buried soil thinly coating shell fragments and channels. They are also present in trace amounts in the midden overburden where they tend to be fractured and out of context suggesting that these features have been inherited from the dumped material. Coating rare channels within the midden is a yellow, amorphous and weakly anisotropic material up to 50um thick, which tends to occur close to fragments of degraded fish bone. This material is probably calcium iron phosphate and is a breakdown product of bone (Jenkins, 1994). These phosphates are post-depositional in nature, but have not impinged upon the buried soil.

Table 5.11: The distribution of silty and phosphatic void coatings within profile 2, Woo, Sanday.

Section	Microfabric	Silty void coatings	Phosphatic void coatings
Woo/2/89cm	Midden		*
Woo/2/91cm	Midden		*
Woo/2/93cm	Midden		*
Woo/2/95cm	Midden	t	*
Woo/2/97cm	Midden		*
Woo/2/100cm	Buried soil	t	
Woo/2/111cm	Buried soil		
Woo/2/113cm	Buried soil	*	
Woo/2/115cm	Buried soil		
Woo/2/119cm	Buried soil		
Woo/2/127cm	Buried soil		
Woo/2/133cm	Buried soil	t	
Woo/2/137cm	Buried soil	t	
Woo/2/139cm	Buried soil	t	

t trace (single isolated occurrences) * <1% slide area

5.2.3.3 Bulk analytical results for Woo

Table 5.12 summarises the physical and chemical properties of the sediments and buried soils from the site of Woo. The site as expected from the large numbers of shell and bone fragments visible in thin section is basic in nature. The pH increases down profile from 8.1 to a maximum of 8.6 within the shell dominated buried soil. Pyrophosphate extractable iron is low as would be expected in a skeletal soil. The skeletal nature of the buried soil is further illustrated by low loss-on-ignition figures, which suggest that the addition of organic material has been minimal. The elevated levels of all forms of iron within the upper relative to the lower buried soils indicates mixing with the overlying midden and its inherited mineral component.

Table 5.12: Physical and chemical properties of the soils and sediments from Woo.

Horizon	pH	% Moisture	% LOI	Bulk density G/cm^3	% Fe (pyr. ext.)	% Fe (dith. ext.)	% Fe (res.)
001,002	8.1	16.1	1.28	0.76	0.14	0.54	0.29
003-006	8.6	19.2	1.46	0.73	0.25	0.65	0.34
007-009	8.4	18.5	1.96	0.85	0.19	0.65	0.33
012-015	8.4	18.6	1.80	0.62	0.09	0.58	0.39
016-018 buried soil	8.4	13.9	0.74	0.74	0.14	0.71	0.56
019-024 buried soil	8.6	15.6	0.52	0.83	0.11	0.30	0.12

5.2.3.4 Interpretation of the site of Woo

The development of soils prior to the construction of the limpet midden in the Iron Age was minimal. The deposition of calcareous shell sand must have been very recent, if not ongoing at the time of burial, allowing only minimal accumulation of organic material. The sands had not stabilised enough to allow for significant pedological development including decalcification of the profile or accumulation of organics. In this environment faunal activity would have been low. The buried soil profile, therefore, represents a skeletal Fraserburgh soil. Following burial, biological turbation appears to have been the dominant process of change within both the buried soil and the midden. The mixing of adjacent midden horizons is clearly illustrated by the mixed microfabrics of the excremental pedofeatures. Penetration into the buried soils from the organic enriched midden is evident from the surviving channels and excremental pedofeatures with midden type microfabrics. Gleying and other iron redistribution processes have not played a significant role in the alteration of this calcareous, freely draining profile. At the midden surface a calcareous brown earth has developed.

5.2.4 The farm mound site of Pool, Sanday

Figure 5.14: Pool buried soil profile 2, Sanday.

5.2.4.1 Field results from Pool.

The deposits at Pool reach almost 3m in height where the coast has eroded a section through the mound (Figure 5.14). Sampling of this entire face was not practicable. For this reason only the lower portion of the mound, identified by Hunter (1988) as the red layers and dated to the Neolithic, was described and sampled (Appendix 4, pp. 374-378). The overburden of midden material consists of sandy and silty clay loams of massive structure. Within this are degraded sandstone clasts and black flecks of charcoal, shell is absent in these older levels and the material is predominantly mineral in nature. Moist soil colours fell into the 7.5YR and 10YR categories. The midden overlies a heavily truncated soil material formed upon the red sandstone beds. This is mineral in nature, with a sandy clay loam texture, the organic topsoil having been removed or mixed with the lower midden deposits. What remains appears to be the B and B/C horizons with increasing numbers of sandstone clasts with depth and distinct mottling towards the base. Boundary distinctions are sharp and distinct, although the inclusion of black flecks within the buried soil suggests that mixing of the overburden and buried soil has occurred.

5.2.4.2 Micromorphology results from Pool

Summary tables of results are given in appendix 5 (pp. 407-410). Pool consists of deep midden deposits which excavation has suggested were deposited in three distinct phases. Only the lowermost unit of Neolithic midden sediments and heavily truncated buried soils were sampled. The midden materials that form this basal section of the mound have a greater quartz dominated mineral component than the other Sanday sites. The organics are in the form of amorphous black, yellow and occasional red organics, and black charred fragments, in some instances they are arranged in a distinctive laminar manner. Charcoal is also present, but bone and shell are very rare and heavily decalcified (figure 5.15). Within these channel and vughy microfabrics are thin layers of massive, almost pure organic material consisting of amorphous yellow organics, which are commonly impregnated with iron to form diffuse matrix nodules. The buried soil beneath consists of mineral and organo-mineral fabrics, mid-brown and grey-brown in colour (PPL), with a channel microstructure. Within this sub-soil material are rare, grey-brown dusty void coatings up to 100µm thick, lining meso-channels. These are restricted the buried soil (table 5.13) and appear to be of pre-burial age. Within the midden material very rare brown organic void coatings are present, but these have not penetrated as far as the surviving buried soil. Mammilated excrements are found throughout the midden and buried soil and are often strongly aged. Biological activity has resulted in intermixing of the mineral buried soil and midden overburden (figure 5.15). Occasional iron depletion rims around sandstone and siltstone clasts are evident, especially within the buried soil. Iron nodules from matrix and stone impregnation are common, and weak panning and coalescence of nodules is noted in the buried soils, suggesting some podzolisation of the soil prior to burial. Within the buried soil matrix nodules tend to occur close to meso and macro channel voids, whilst in the midden material they are frequently associated with organic concentrations. Different processes of iron mobilisation and precipitation, therefore, appear to have been acting within these two contrasting material types.

Table 5.13: The distribution of void cutan types at Pool, Sanday with depth from buried soil/overburden interface.

Slide	Microfabric	Brown organic cutans	Grey/brown mineral cutans
E	Midden 16cm	?	
F	Midden 9cm	?	
G	Midden 4cm	*	
H	Buried soil –1cm		*
J	Buried soil –5cm		*

? possible occurrence * <1% slide area

5.2.4.3 Bulk analytical results from Pool

The bulk chemical and physical analyses of the sediments and soil from the midden site at Pool (table 5.14) reveal an alkaline midden and buried soil profile with pHs in the region of 7.6 to 8.4. This is in sharp contrast to the acid geology and local Bilbster soils. Organic levels in both the buried subsoil and the midden are low as too are concentrations of pyrophosphate extractable iron. Whether podzolisation has affected the development of the soil prior to burial is difficult to judge because of the heavy truncation of this profile.

Table 5.14: Chemical and physical properties of the sediments and soils from Pool.

Horizon / Context	pH	% Moisture	% LOI	Bulk density g/cm^3	% Fe (pyr. ext.)	% Fe (dith. ext.)	% Fe (res.)
001; 002	8.3	23.5	3.58	1.10	0.15	1.31	1.06
004-007	7.8	23.0	3.52	0.86	0.14	0.88	0.75
008-009	8.2	25.7	4.59	0.85	0.09	1.14	0.74
buried B	8.1	16.2	1.87	0.97	0.12	0.76	0.69
B/C buried soil	7.8	25.5	3.18	0.82	0.01	1.65	1.60

5.2.4.4 Interpretation of the site of Pool

The site of Pool, because of the heavily truncated nature of the buried soil, reveals little about the pre-burial pedological processes of development. The basic nature of this site would seem contradictory bearing in mind the sandstone geology that formed the parent material and the relative paucity of bone and shell within not only the buried soil but also the midden deposits. The rare shell fragments within the midden are heavily decalcified, suggesting two alternative interpretations for the development of the section. In the first the decalcified shell is inherited from acidic soil or waste materials. In the second the midden would have originally contained more shell and bone, which have degraded after deposition in response to an acidic burial, or soil environment, the face of the profile section later being enriched through the addition of salt sea spray. The second hypothesis is supported by the acid pH profiles recorded from the Gallows Hill and Roos Loch sites. The alkaline unburied soil profile at Roos Loch also hints at the seasonal importance of salt spray. The midden deposits at Pool contain a greater proportion of quartz sand than other 'younger' midden deposits, and substantial amounts of charred organics. Although this may seem to indicate changes in the materials dumped to form these mounds over time, progressive decomposition and decalcification may also result in the relative enrichment of these more resistant midden components.

5.2.5 Summary of results from Sanday

The island of Sanday, Orkney provided the best opportunity of any of the study regions to compare sites of different ages. However, problems are also posed by the wide time scale in ensuring comparability between sites. For example, at Woo the accumulation of shell sand has shifted so that soils today mapped as Bilbster series soil, in the past formed upon shell sands. The atypical nature of the soils from Woo and the heavy truncation of the Pool soils made interpreting the pre-burial soil conditions difficult at these early sites. At the later sites, however, similar processes seem to have been operating. None of the soils contain unequivocal evidence of anthropogenic disturbance prior to site construction. After burial there is evidence of decalcification of the midden material and recalcification of the buried soils. The formation of Ca iron phosphates from the break down of fish bone was also observed. Biological changes include reworking of both overburden and buried soils, the decomposition of organics, and apparent changes in the soil fauna. Figure 5.15 contains images of some features associated with these processes. At both Pool and Seater there is evidence of textural down profile movements to form silty, brown void coatings rich in organics within the midden, in neither case has the influence of this post-burial process penetrated as far as the buried soil. The post-burial redistribution of iron and the formation of amorphous iron nodules within the midden, buried soil and sub-soil material was noted at all sites. In all cases this appears to have been the result of localised changes in the burial redox conditions, either because of waterlogging or the influence of decaying organic material rather than the action of surface podzolisation processes. The influence of salt spray also appears to have a significant influence upon the development of the coastal soils and exposed sea sections, with increased alkalinity of the soils.

Figure 5.15: Features and inclusions in the soils and sediments of Sanday.

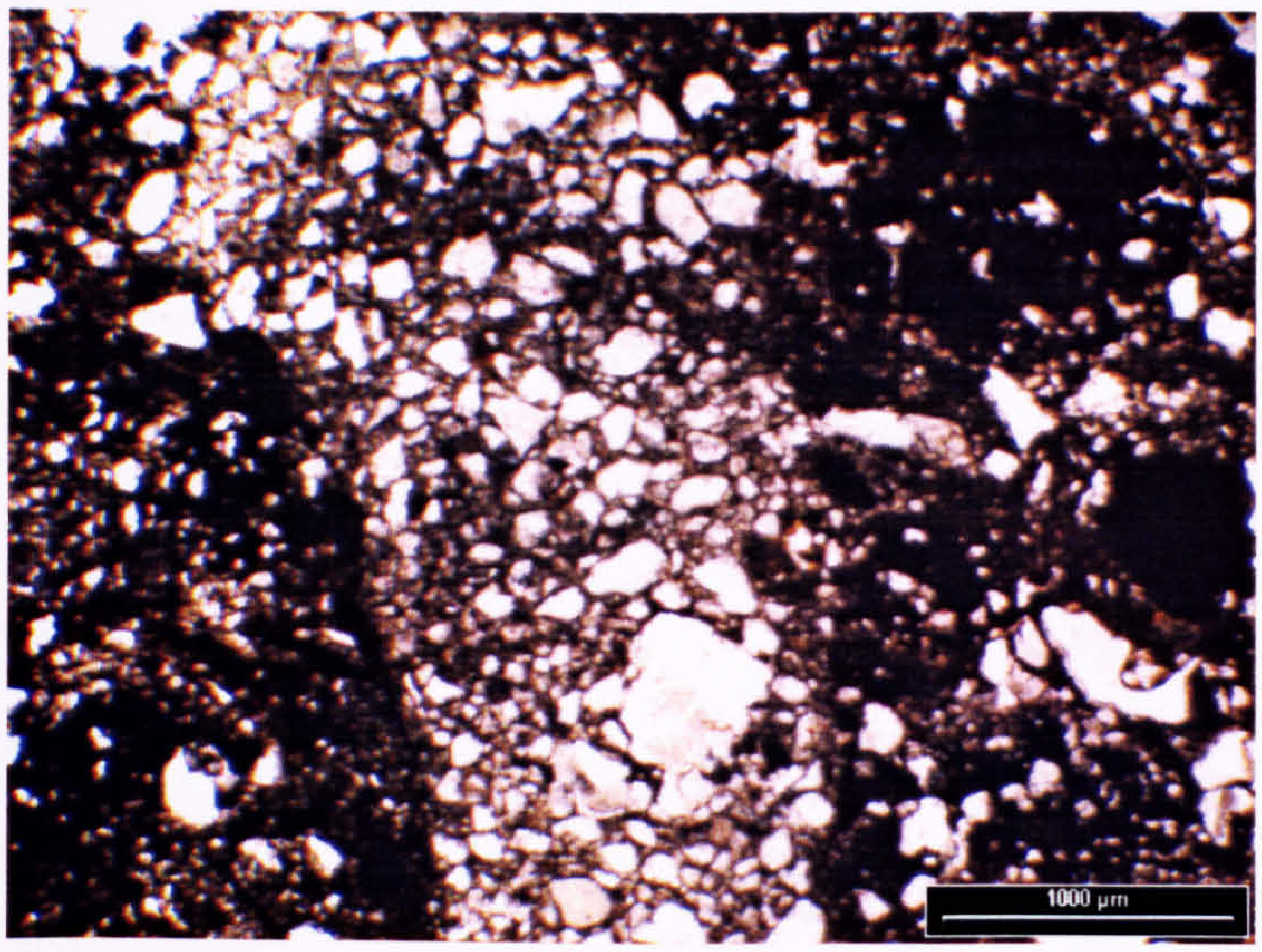


Fig.5.15a: Mineral sub-soil infilling of channel in the overlying midden material at Pool.

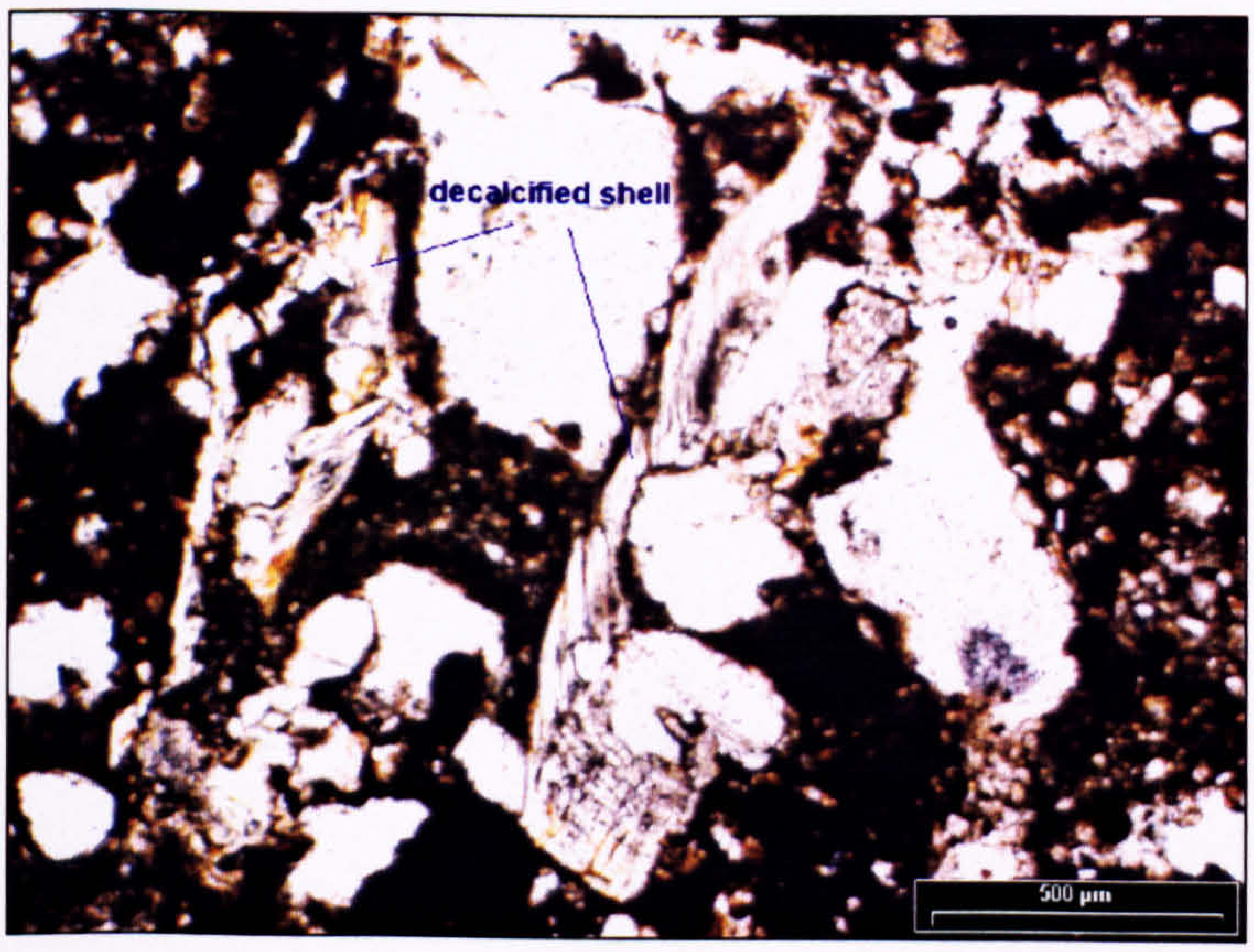


Figure 5.15b: Decalcified shell remains in the Neolithic midden at Pool.

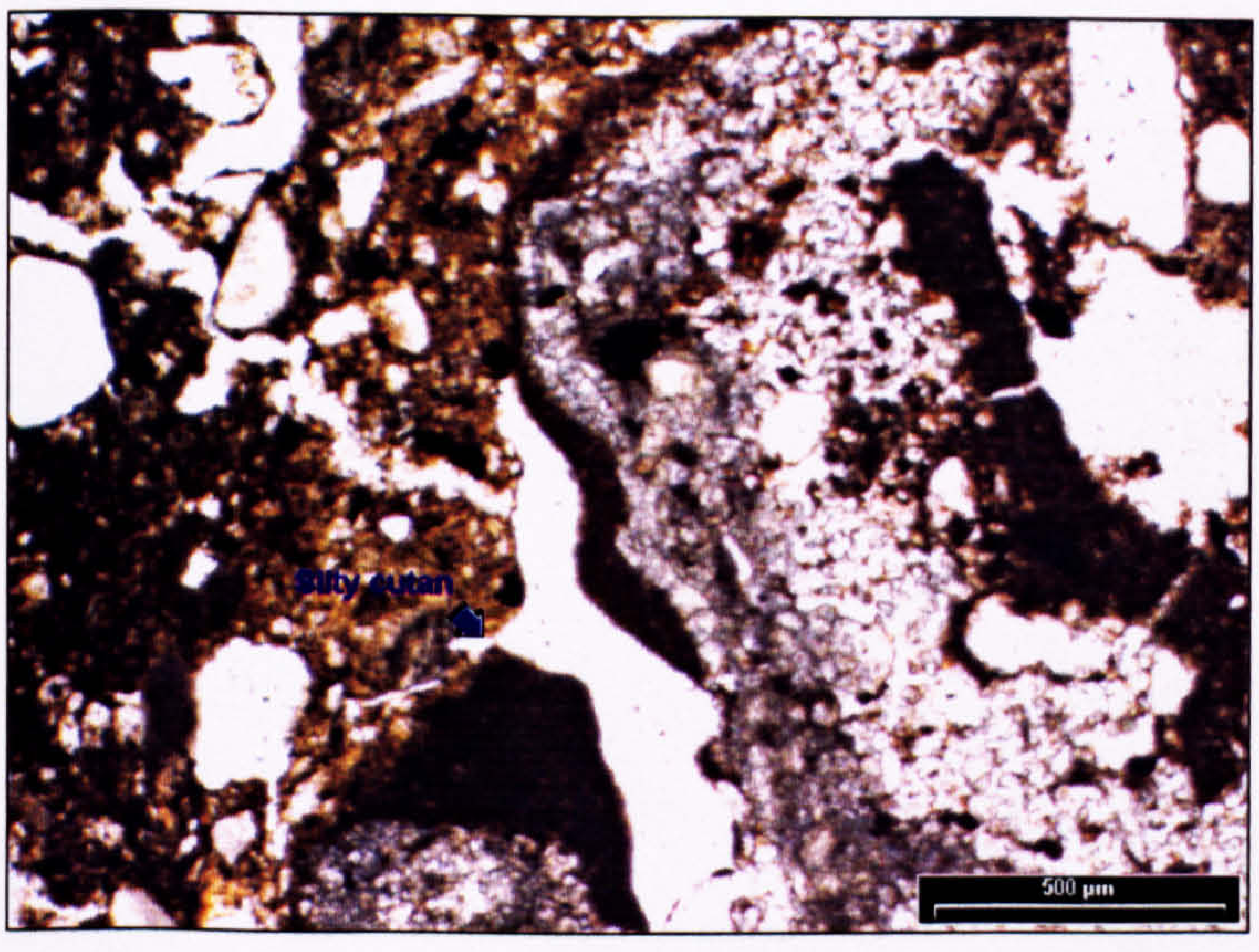


Fig.5.15c: Silty clay cutans within the midden material at Seater.

5.3 Results from the Breamish and Ingram Valley's, Northumberland

The Breamish study region involved the study of three sites, including pre-Iron Age and Iron Age archaeological sites, together with the regional reference profile. The region was chosen for study as representing an intermediate type of parent material with andesite and andesite derived drifts forming the dominant geology of the area upon which soils of the Sourhope series are formed.

5.3.1 The reference site of Plantation Camp Woods

5.3.1.1 Field results from Plantation Camp

The reference soil profile from Plantation Camp woods has developed beneath a mature mixed woodland cover with a dense field layer of *Holcus, Festuca, Juncus* and *Pteridium*, upon andesite derived till deposits. The soil pit reveals an horizonal sequence (figure 5.16) similar to the modern surface soils at the archaeological sites. This consists of a dense root mat, humic layer, and reddish B horizon of medium to coarse blocky structure with a few black, organic lenses formed by decaying bracken rhizomes. This has developed upon a heavily compacted peri-glacial fragipan horizon overlying glacial till deposits. Field descriptions given in appendix 4, pp.387-388.

Figure 5.16: Plantation Camp reference profile, Northumberland.

5.3.1.2 Micromorphology results from Plantation Camp

Summary tables of results are given in appendix 5 (p. 411). The four thin sections taken from the reference profile of this Northumberland study region, revealed a soil sequence identical to that of the modern surface soils at the archaeological study sites. Slide descriptions illustrate the accumulation of organic materials at the soil surface. The dense root mat and litter layer consists of live and fresh roots; biological activity is relatively low with occasional fresh earthworm and enchytraeid excrements forming crumb type aggregates between the matted roots. Beneath this the organic rich, dark brown, Ah horizon has a spongy and sub-angular blocky microstructure and consists of recognisable tissue residues (parenchymatic and lignified) as well as amorphous decomposition products. With depth the organic component declines rapidly into an organo-mineral blocky horizon in which heavily weathered, medium sand and silt sized feldspars form the dominant coarse mineral component. Porosity declines rapidly from the surface root mat to a stable level (c.20% slide area) throughout the rest of the underlying soil profile. It is within the organo-mineral A and B horizons that bioturbation levels peak. Earthworms are found exclusively within the A horizons, whilst dominant levels of enchytraeid excrements are present down to the level of the parent material, within channel voids and also fusing to form the microfabric. Secondary iron depletion rims are rare, although mineral weathering of biotite mica and alkali feldspar is advanced. Iron impregnation increases with depth through the soil B horizon and is dominated by iron staining of rock clasts related to the weathering of minerals within the clasts. Down profile movement of iron, therefore, appears to be relatively insignificant within this profile although the soils have acidified. Textural pedofeatures are also absent so clay illuviation has not been significant within the pedological development of the 'natural' soils in this area.

5.3.1.3 Bulk analytical results from Plantation Camp

The bulk physical and chemical properties of the reference soil (table 5.15) suggests an acid profile with significant surface accumulation of organic matter, this would be consistent with the high numbers of enchytraeid worms suggested by their excremental features in thin section. Podzolisation processes are suggested by the high concentration of pyrophosphate extractable iron oxides within the B horizon.

Table 5.15: Chemical and physical soil properties of the Plantation Camp reference profile.

Horizon	pH	% LOI	% Moisture	Bulk density G/cm^3	% Fe (pyr ext.)	% Fe (dith ext.)	% Fe (res.)
L	/	52.4	42.1	/	/	/	/
Ah	4.1	24.8	37.3	0.28	0.37	1.20	0.62
B	4.5	14.6	33.2	0.64	0.63	1.72	0.92
BCx	4.8	13.6	22.1	0.70	0.47	1.62	0.70

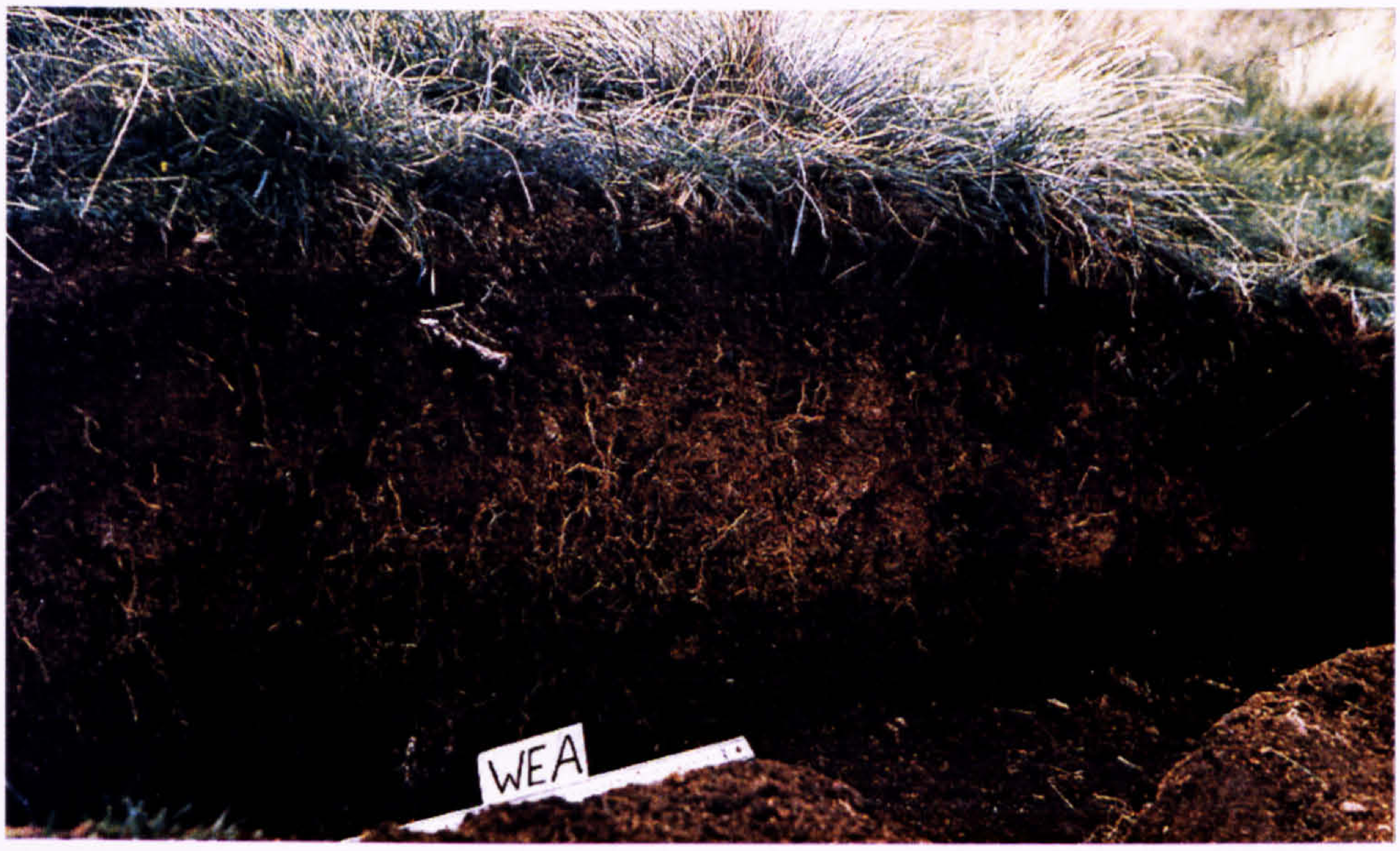
5.3.1.4 Interpretation of Plantation Camp

The reference soil for this upland region is an acid stagnopodzol, despite the intermediate geology. The dominant processes are podzolisation, mineral weathering, organic accumulation, and a moderate degree of bioturbation dominated by a mesofauna of enchytraeid worms. Their activity was limited mostly to the upper organic horizons, however where bracken rhizomes had penetrated more deeply into the soil this had allowed the soil fauna, including earthworms to follow. The reference soil had not formed beneath primary woodland, and prior to the establishment of the plantation soil development had occurred along the same paths as that under grass elsewhere in the valley. This had led to the establishment of an acid stagnopodzol soil profile.

5.3.2 The cross-ridge dyke of Wether Hill

This Iron Age cross-ridge earth dyke was originally sectioned two years prior to the sampling undertaken for this study. After it was first sectioned the section trench had been closed and when reopened it was cut back to ensure a clean, fresh face was revealed (figure 5.17).

Figure 5.17: Wether Hill buried soil profile, Northumberland.



5.3.2.1 Field results from Wether Hill

The surface soil established above the bank is very similar in nature to the reference profile. The dense grass sward creates a close root and litter layer overlying the thin humic layer (Ah). The A horizon has a complex crumb and medium blocky structure with frequent gravel sized stone clasts. The soil has developed upon an earth bank that consists of a silty clay loam with frequent gravel sized stone clasts. This gravelly horizon is heavily affected by root penetration and includes common, distinct mottling. Sealed beneath this bank material is a dark brown, organic rich buried soil horizon with thin black laminae along its top and base. Some deepening of this horizon may have occurred resulting from cut turves being used at the base of the bank mound. This silty clay loam soil with a weak, medium blocky structure sits on massively structured till deposits. The boundary between the buried soil and the overlying earth bank is abrupt though irregular, some alteration of the buried soil is suggested with few fine roots penetration and gleyic mottling of the soil fabric. Field descriptions given in appendix 4, pp. 386-387.

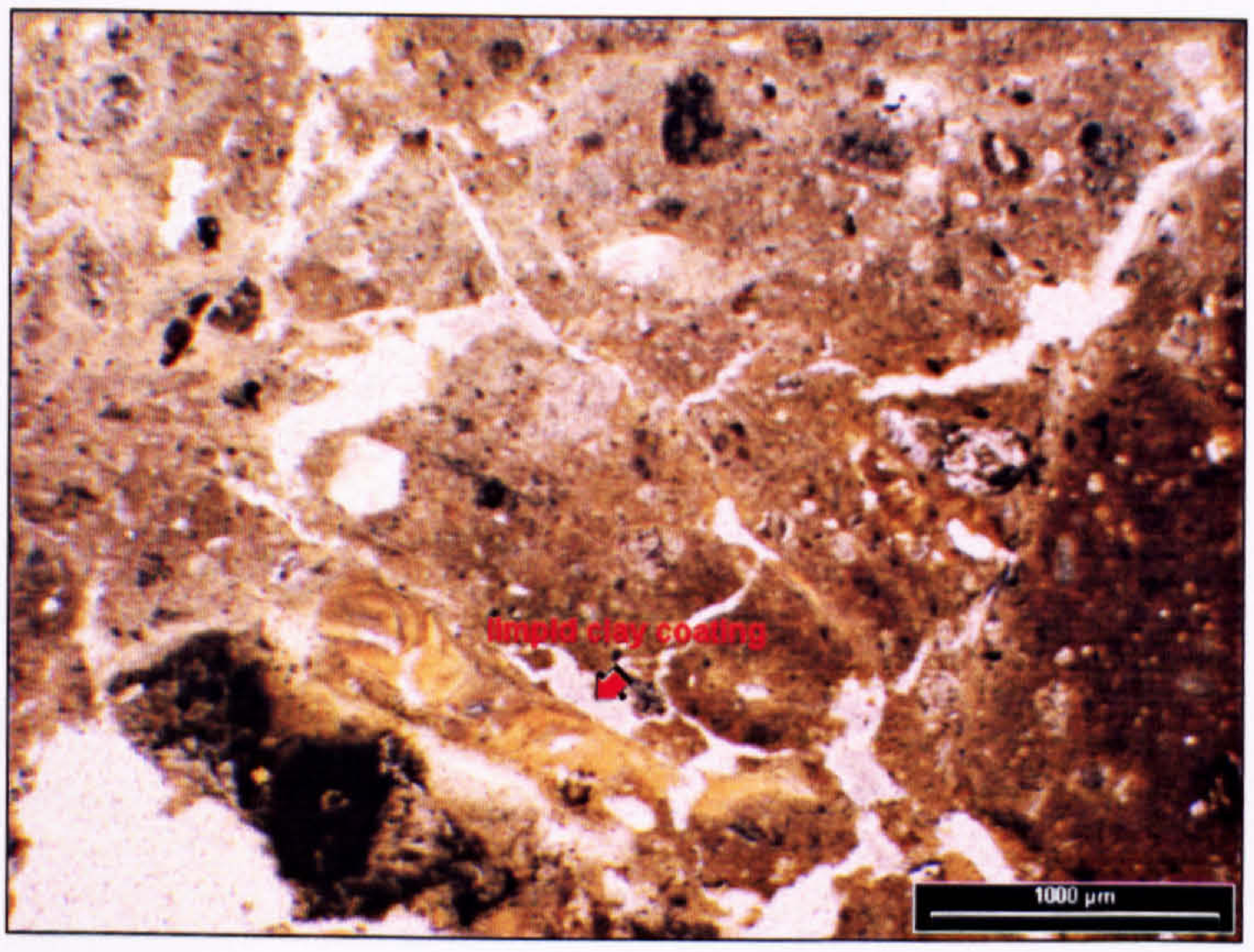
5.3.2.2 Micromorphology results from Wether Hill

The site at Wether hill provided the opportunity to sample from three profiles, allowing thorough description and classification of the soils and sediments from this Iron Age context. Summary tables of results are given in appendix 5 (pp. 414-416). The picture is of a surface profile very similar to that of the Plantation Camp reference profile. There is a dense root mat of live grass roots and fresh plant residues, above a dark brown, humified organic horizon, and red/brown organo-mineral A / B horizon.

The bank material itself includes a much greater proportion of clay sized minerals, as suggested by the strial limpidity of the grey, buff and red brown fine material. This material is almost totally devoid of organic material with traces present only within channel voids, often in association with plant roots and excremental features. Stoniness is also high in this level with common andesite and other volcanic clasts up to 3cm in diameter. Localised impregnation and depletion of the soil matrix by iron dominates the bank material and showed how gleying processes have affected this horizon after its construction (figure 5.18), presumably through the seasonal establishment of a perched water table. Rare limpid clay void coatings up to 100μm thick are also present within the bank material. The limpid nature of these cutans, and their distribution exclusively within the bank material suggests that these are inherited features formed prior to site construction within the mineral sub-soil drift deposits, which were then used to build the earth bank.

Underlying the bank, the thick, dark brown buried soil is comprised of a dark to mid brown, and yellow / brown organo-mineral fabric with a stipple speckled or organic undifferentiated limpidity. This crumb or blocky structured material includes frequent plant phytoliths of saddle, polylobate sinuate and rectangle types identified by Rapp and Mulholland (1992) as typical Gramineae types. Fungal spores and sclerotia are also concentrated within this buried horizon, but none are birefringent. Relative to the overlying bank material, elevated numbers of excremental features are present within the organic rich buried soil, with earthworm, enchytraeid, and mite type excrements all recorded. The excremental features within the buried soil are no more aged than those found at the profile surface. Iron depletion rims around weathered andesite clasts are present throughout the profile and most are greater than 100µm wide. Such rims suggest podzolisation as has been discussed in section 5.1.2.2, although direct comparisons between the Angus site and this are not possible because of the differences in geology. The incidence of these rims, however, peaks within the buried soil horizon suggesting that podzolisation, and the acidification implied, was a significant pedological process affecting the soils at this site prior to the construction of the earth bank.

Figure 5.18: Inherited limpid clay coating within mottled matrix of the bank overburden material at Wether Hill.



5.3.2.3 Bulk analytical results from Wether Hill

Bulk chemical and physical analysis of the soils and sediments from Wether Hill (table 5.16) reveal an acid, podzolised profile broadly similar to those of the reference and Turf Knowe sites. The pH increases steadily with depth suggesting a readjustment within the buried profile in response to waterlogged conditions. All these values are averages and hide finer variations, but do indicate that both the modern and the buried profiles were subject to podzolisation.

Table 5.16: Chemical and physical properties of the soils and sediments from Wether Hill.

Horizon	pH	% Moisture	% LOI	Bulk density g/cm3	% Fe (pyr. ext.)	% Fe (dith. ext.)	% Fe (res.)
001-004, Modern soil	4.4	44.3	24.3	0.25	0.39	0.55	0.13
006, Bank	4.5	24.7	7.0	0.49	0.24	1.16	0.29
008, bA	5.0	37.8	7.2	0.45	0.47	0.89	0.16
009, Till	5.1	39.3	/	0.49	0.18	1.17	0.13

5.3.2.4 Interpretation of Wether Hill

The soils at Wether Hill, both buried and unburied clearly represent humic podzols in which iron eluviation and illuviation together with organic accumulation have been significant processes in the development of these profiles. The presence of limpid clay cutans within the sub-soil microfabric indicates a period of earlier development under woodland (Fisher, 1982). The high numbers of grass phytoliths within the buried soil microfabric suggest that the woodland had been cleared and grassland was the dominant vegetation, possibly suggesting pastoral activity. Under this regime podzolisation and organic accumulation could have been initiated. No pedofeatures associated with cultivation were identified within the buried soil. Following burial, podzolisation has been ongoing as illustrated by the bleached depletion rims within the surface soil, and the raised levels of pyrophosphate extractable iron oxides at depths impinging upon the buried soil. Redoximorphic iron redistribution also appears to have operated within the bank material. The number of excremental features and fungal spores within the buried soil could indicate high levels of biological activity either immediately prior to burial, or during a more recent phase, perhaps following the initial opening of this trench in 1996. The lack of ageing of excremental features perhaps supports the latter hypothesis, although there is no way to be sure.

5.3.3 The site of Turf Knowe

The date of this field boundary monument is uncertain. Charcoal in the underlying buried soil was dated to the Neolithic; the stratigraphy suggests a pre-Iron Age date at least.

Figure 5.19: Turf Knowe buried soil profile, Northumberland.

5.3.3.1 Field results from Turf Knowe

The field morphology of this site proved to be distinctive with rig and furrow morphology preserved in the buried soil as can be seen in the photograph of the section, figure 5.19. The upper modern soil profile consists of a dense root mat formed by the local *Festuca – Agrostis* grass sward. Beneath this is a black humic layer, overlying the blocky structured A and B horizons. These have formed upon the boundary bank and colluvial deposits. The stone and earth bank is welded within this modern profile, but beneath this and the surrounding colluvial deposits lie the buried rig and furrow soil. The cord rig has been cut into very heavily compacted stony deposits with a silt matrix and is brittle when wet, but very hard when dry. This layer is interpreted as a fragipan as micromorphology confirms the lack of a cementing agent (Avery, 1980). The soil filling these rigs consists of an orange / brown (7.5YR 4/4), silt loam, structureless or with a very weakly developed sub-angular blocky structure. Some root pentration into this layer was observed. Beneath the rig and furrow and the compacted mineral layer are deep andesite derived tills. Both the upper and lower horizon boundaries with the bank material and the fragipan are distinct and abrupt. The buried soil horizon exists as a distinct and easily visible layer throughout the section. Field descriptions are given in appendix 4, pp. 388-389.

5.3.3.2 Micromorphology results from Turf Knowe

The modern surface soil, described in the field, was further investigated through micromorphological description. Summary tables of results are given in appendix 5 (pp. 411-413). In thin section the organic surface horizons show that biological activity by the soil mesofauna is high in these horizons. Enchytraeid excrement is common and forms a total excremental fabric within the black, blocky Ah horizon. Earthworms and mites are also active at these levels. Beneath this is a heavily weathered B horizon, in which the dominant process is chemical weathering of feldspars and micas releasing iron and clay. The soils have a blocky and crumb microstructure and an organo-mineral and mineral fabric. The mineral component consists of gravel sized andesite clasts, and fine and medium sands of quartz and feldspars. Occasional iron depletion rims around these gravel clasts suggest some down profile eluviation of clay through processes of podzolisation. The dark 'turfy' layer of the buried soil, although readily visible in the field, is far less distinct in thin section. This organo-mineral horizon has a sub-angular blocky microstructure. Organics include moderately and strongly humified tissue remains, very rare fine charcoal, phytoliths, occasional fungal spores, rare amorphous organics and brown staining of the fine material. The fine charcoals, phytoliths and micas are often found intimately mixed in coatings on the sand grains. This is evidence of turbation of the soil and has been cited as one strand of evidence for cultivation (Courty *et al.*, 1989; Macphail and Goldberg, 1995). Also present within the buried soils are angular fragments of the fragipan into which the cultivation furrows are cut. Decayed bracken rhizomes penetrate to the level of the buried soil. Within the rhizomes, excremental features of earthworm and enchytraeid origin formed from surface soil microfabrics are present together with pollen grains and fungal spores. Depletion rims are rare within this buried soil suggesting only minimal podzolisation of this soil has occurred. Table 5.17 shows the frequency of excremental features down the Turf Knowe profiles.

Table 5.17: The distribution of excremental pedofeatures within Turf Knowe.

Sample depth (cm)	Earthworm excrement	Enchytraeid excrement
0-2	****	**
2-4	**	*
4-8	*	*****
29-37	*	****
46-54	*	***
58-64	t	*
62-65	t	*

t trace * <1% slide area ** 1-2% slide area
*** 2-5% slide area **** 5-10% slide area ***** 10-20% slide area

The depth dependent nature seems to suggest that excremental features within the buried soil are the result of post-burial biological activity, consistent with the establishment of the modern surface profile. The compacted layer into which cultivation furrows have been cut is found to consist of tightly interlocking silt and sand quartz grains. No cementing agent is present confirming this horizon as a fragipan. Rare limpid clay cutans are present in channel voids. The clay rich till material below includes examples of silt cappings, formed under periglacial conditions, and exhibits areas of relative iron depletion and concentration suggesting ground water gleying.

5.3.3.3 Bulk analytical results from Turf Knowe

Bulk chemical and physical analysis of the Turf Knowe soils (table 5.18) reveals an acid profile in which the buried soil horizon is a highly acidic pH 3.9. Organic accumulation at the modern surface is suggested by the high loss-on-ignition figure, with little apparent integration of this material deeper into the profile. The high levels of pyrophosphate extractable iron recorded throughout the profile suggest podzolisation.

Table 5.18: Bulk chemical and physical properties of the Turf Knowe soils.

Horizon	pH	% Moisture	% LOI	Bulk density g/cm3	% Fe (pyr. ext.)	% Fe (dith ext.)	% Fe (res.)
Ah	4.5	15.2	24.35	0.52	0.41	1.05	0.35
Bw (Eb)	4.0	16.1	7.10	0.65	0.42	1.37	0.70
Buried A	3.9	21.7	7.19	0.75	0.48	1.49	0.88
BCx	5.0	/	/	/	0.13	1.06	0.94
C(g)	4.9	/	/	/	0.01	1.61	1.45

5.3.3.4 Interpretation of Turf Knowe

The parent material is andesite derived till deposits, modified through the action of periglacial processes to form silt capping pedofeatures and an indurated, clay depleted fragipan horizon. The buried soil upon the basis of field morphology can be classified as a cultivated soil profile. Rig and furrows cut into the hard, silt and stone fragipan horizon would have helped to increase the effective soil depth for supporting plant growth. Further evidence of cultivation within the soil is provided by thin section description with angular fragments of fragipan mixed into the soil and intimate mixing of finely divided charcoals, organics and phytoliths in coatings around the stone clasts. There is no evidence of any anthropogenic inputs to the soil and loss-on-ignition figures indicate only low levels of surviving organic matter. Information regarding the nature of the soil prior to cultivation has been destroyed by this anthropogenic disturbance. The lack of iron depletion rims around stone clasts suggests that podzolisation of this ancient soil horizon was not as advanced as within the modern soil, however, and the formation of limpid clay void cutans within the fragipan indicates a phase of soil development under a woodland cover. The modern soil developed upon the boundary bank is that of an acid podzol, although podzolisation at this site is not as advanced as at Wether Hill.

5.3.4 Summary of results from the Breamish and Ingram Valley's

The Breamish region charts prehistoric soil development from the cultivated brown earth at Turf Knowe to the podzolised profile at Wether Hill that may have developed under a grassland, grazing regime. The soils within this region have, therefore, seen development under woodland prior to clearance, cultivation and pastoral activities. These later anthropogenic disturbances may have helped initiate podzolisation and organic accumulation by opening the soil surface. No post-burial redistribution of fine particulates is noted at either of the buried archaeological sites, nor have iron pans such as those at Fordhouse Barrow formed at their bases. Biological reworking and organic decomposition appear to have been dominant post-burial processes. At Wether Hill, a perched water table has caused gleying of the overburden material, whilst surface podzolisation processes may be impinging upon the buried soil in a form of chemical 'welding' of surface and buried profiles.

5.4 Results from South Cadbury, Somerset.

The South Cadbury study region includes three archaeological sites all dated to the Bronze Age. All sites were built of local soil materials, however, one of these sites was sited upon a contrasting soil type. Two reference profiles were, therefore, also studied, one for each of the parent material types.

5.4.1 Milsoms Corner and Weston Farm

The archaeological site and its reference profile are situated upon Lias clays with Oolitic limestone.

5.4.1.1 Field results from Milsoms Corner and Weston Farm

The soil profiles developed upon these very heavily textured clays derived from micaceous siltstones of the Upper and Middle Lias formations were shallow. The undisturbed reference profile has formed only to a depth of 20cm. The soils upon this geology are mapped as brown earths of the Martock series, prone to gleying of the subsoil. Field descriptions are given in appendix 4, pp. 384-386.

Little Weston Farm

Developed under mature woodland this was probably the least disturbed of all the reference profiles. The woodland surrounds an apple orchard and appears to be the result of assarting practices, amongst the mature trees there is no evidence of coppicing activities. Some dumping of building material, however, has occurred. The shallow profile revealed by the soil pit is that of an imperfectly drained, calcareous brown earth (figure 5.20). The organic A horizon consists of a well developed, medium crumb and fine to medium blocky structure. Many fine and medium roots from grass and trees are concentrated within this horizon. The sticky B horizon has a moderately developed, medium angular blocky structure with significant root penetration. Within this horizon rare, fine, rounded limestone clasts are also present. The B horizon diffusely blended into a B/C horizon and then the clay rich C horizon of Lias clays with a coarse angular blocky structure and fine clasts of limestone, siltstone and mudstone. The B/C and C horizons shows evidence of groundwater gleying, with abundant diffuse grey and orange mottling and common purple / black flecks in the parent material thought to be segregations of manganese.

Milsoms Corner

This Bronze Age section with a weakly developed buried soil represents a Bronze Age bank and ditch upon which pedogenesis has acted before the surface was buried by clay rich bank deposits (figure 5.21). The modern surface and cultivated soil together with the gravelly hill wash deposits, which have buried this site, had been removed at the start of excavation and the section had been cut almost six months prior to sampling. Scraping of the surface revealed fresh grey faces but the possibility of localised affects of post-excavation aeration cannot be ignored. The burying sediment is a slightly sticky silt clay loam with a very weakly developed sub-angular blocky structure producing a very dense material. The boundary with the underlying buried soil is distinct, but diffuse. The reddened horizon interpreted as a buried soil is 10cm thick and similar in texture to the burying sediment with a fine sub-angular

Figure 5.20: Little Weston Farm reference soil profile, Somerset

Figure 5.21: Milsoms Corner buried soil profile, Somerset.

blocky structure. This material has abundant orange and grey mottles with sharp boundaries and the lower boundary formed with the Lias clays is diffuse in nature. The organic content of this material is very low. The Lias clay is massively structured with frequent gravel sized mud- and siltstone clasts. This horizon is heavily mottled and pools of standing water are a feature of this site.

5.4.1.2 Micromorphology results from Milsoms Corner and Weston Farm

Little Weston Farm

Summary tables of results are given in appendix 5 (p. 424). The micromorphology of the reference soil reveals an organo-mineral, A horizon microfabric with occasional fine quartz sand and a sub-angular blocky microstructure. Biological activity is moderate with earthworm, beetle, mite and rare enchytraeid excremental features present in the surface horizon. Even at this shallow depth, weak iron impregnation of the soil matrix has developed. Their frequency increases with depth, becoming the dominant soil feature at the base of the profile. Porosity is low, between 15% and 8% of the slide surface area, and is dominated by planar, crack structures. There is no clear evidence of clay illuviation within this profile, oriented clay domains around channel voids lack the internal organisation and limpidity that would be expected of natural clay illuviation features. These are probably stress features (poro-striations) formed by pressure at the void walls.

Milsoms Corner

Summary tables of results are given in appendix 5 (pp. 425-426). Milsoms Corner presents a relatively simple field morphology of only three contextual horizons. Each of these was looked at in thin section and their micromorphology described. The burying bank sediments consist of yellow / brown, mineral and rare organo-mineral microfabrics, with a clay and silt fine matrix in which are very fine sands of quartz and feldspar. Void space accounts for 20% to 25% of the slide area and are mostly channel type features. Occasional textural pedofeatures show distinct variation in texture and colour. Three types, brown silty, orange limpid and dusty, and orange /

red limpid, are present (table 5.19). All three types are present within the upper context 001; table 5.20 shows their relative distributions throughout the entire profile. Occasional stone clast and matrix iron impregnations are recorded, the stone clasts impregnated are mostly ooids weathered out of the oolitic limestones and have been completely replaced with iron and / or manganese. The possible buried soil horizon is identified as organo-mineral and mineral material with a channel dominated microstructure, and includes rare black and red amorphous organics and a brown organic pigmentation. There are a greater number of iron nodules of larger size at this level than within the overlying sediment. Within this, and the underlying horizon, the frequency of orange and orange / red limpid and dusty void cutans rises relative to the brown silty cutans that are more prevalent within the burying sediment. The lower horizon is comprised of a yellow / brown or colourless (PPL) mineral clay with common, very fine quartz sand grains. Occasional orange limpid clay cutans line channel voids, whilst only trace numbers of brown silty cutans are present at this depth. Evidence of gleying of this sub-soil horizon is present in the form of matrix mottling; iron impregnations are frequent around channels and greyer areas of depletion are present within the body of the soil peds. Biological activity is very low throughout the entire profile with very rare vermiforms the only surviving evidence of earthworms.

Table 5.19: A typology of textural pedofeature types within Milsoms Corner.

Textural pedofeature type	**Description**	**Distribution**
Orange limpid / dusty clay void coatings	Pale yellow to dark red / orange (yellow and orange in OIL). Few with silty laminations. Often fractured. Extinctions clear, but haphazard. May account for up to 2% slide area.	Relict and infilled channels, v. few within contemporary, surviving channels. Throughout bank, buried soil and parent material. Occasionally coated by brown silty cutans.
Brown silty void coatings	Mid-brown and red / brown PPL, dull orange in OIL. Fine, well sorted silts. Extinctions diffuse, occasionally clear. Up to 200μm thick (modal 20-50μm). Most lining channels up to 500μm wide (modal 100-250μm). Very few fractured.	Few within relict channels. Most frequent within bank (up to 2% slide area) very few within buried soil and parent material.

Table 5.20: The distribution of textural pedofeatures within Milsoms Corner.

Context	**Depth (cm)**	**Orange clay cutans**	**Brown silty cutans**
001 – bank	3	*	**
002 – incipient buried soil	-8	*	*/**
002 – incipient buried soil	-20	*	*
003 – Lias clays	-25	**	*

t trace * <1% slide area ** 1-2% slide area

5.4.1.3 Bulk analytical results from Milsom's Corner and Weston Farm

Little Weston Farm

Chemical and physical properties suggest a slightly acid soil, with some calcification of the B horizon (table 5.21). The field data from this site suggests that this is a localised effect produced by small clasts of Oolitic limestone. Bulk density is high, a result of the heavy texture of this soil, and there is no evidence of podzolisation as pyrophosphate extractable iron decreases uniformly down profile. The textural character of the soil changes rapidly from the A horizon down, with a decrease in the proportion of sand and an increase in the clay content. The percentage of iron oxides in their 'aged' crystalline forms (extracted by dithionite) is high and levels increase down profile. The very low rate of decline in moisture with depth probably reflects the impeded drainage of this profile.

Table 5.21: Bulk chemical and physical properties of the Little Weston reference soil.

Horizon	% LOI	pH	% Moist.	Bulk density G/cm^3	% Fe (pyr ext.)	% Fe (dith ext.)	% Fe (res.)	% Sand	% Silt	% Clay
A	21.42	5.6	26.9	0.77	0.41	1.24	1.16	60.2	35.8	4.0
B	11.7	6.1	20.9	0.72	0.30	2.03	1.57	28.6	60.0	11.4
B/C	/	5.9	/	/	0.19	2.36	1.97	20.7	62.4	16.6
C	9.2	5.8	19.9	0.82	0.17	2.46	2.11	16.1	62.5	21.3

The laboratory analysis of the bulk soil samples from this site, summarised in table 5.22, reveal a sequence of alkaline silt dominated sediments. The peak in combustibles within context 002 supports the field interpretation of this horizon as a buried soil. Pyrophosphate extractable iron levels are very low throughout proving that processes of podzolisation are insignificant at this site. Clay content increases down profile whilst the proportion of very fine sands decreases. The sand content of context 001 the burying sediment, is significantly higher than in the underlying soils.

Table 5.22: Chemical and physical properties of the soils and sediments of Milsoms Corner.

Context	pH	% Moist.	% LOI	Bulk density g/cm3	% Fe (pyr. ext.)	% Fe (dith. ext.)	% Fe (res.)	% Sand	% Silt	% Clay
001	8.1	18.4	3.99	1.18	0.03	3.20	2.67	27.5	63.1	9.5
002 bA	8.1	17.4	4.65	1.11	0.02	3.00	2.85	18.0	72.1	9.8
003	8.1	17.1	4.53	1.33	0.02	2.63	2.38	13.1	77.4	9.5

5.4.1.4 Interpretation of Milsoms Corner and Weston Farm

The reference profile at Weston Farm suggests that undisturbed soils developing upon the silty Lias clays form as shallow, imperfectly draining brown earths subject to seasonal waterlogging and gleying of their lower horizons. These redoximorphic processes are dominant throughout this profile except at the very surface where moderate levels of biological activity operate.

Gleying is also a dominant process in the waterlogged sub-soils of Milsoms Corner. The orange limpid / dusty cutans appear to represent an early phase within the development of these soils as these are found within relict channels and are, in some cases, with brown silty cutans. Those present within the topsoil and overburden are interpreted as inherited features. The brown silty cutans are concentrated within the overburden but penetrate into the buried soil. These are interpreted as post-constructional features related to later disturbance of the new soil surface through agricultural activity. This site was under intensive cultivation prior to excavation.

5.4.2 The sites of Sigwells, CHB2, and Slait Farm

The Bronze Age barrow sites at Sigwells of Sigwells 1 and CHB2, along with the Slait Farm reference profile, are situated upon Jurassic sands with Oolitic limestone. A fault with the camera meant no images of these profiles were captured; field sketches and descriptions are given in Appendix 4, pp. 378-384.

5.4.2.1 Field results from Sigwells, CHB2 and Slait Farm

The soils of this regional group have developed upon the sandy facies of the Middle and Upper Lias formations. The deep, very fine sandy soils belong to the Atrim series of brown earths.

Slait Farm

Beneath mature deciduous trees along a farm path, this sandy reference profile is deeper than that from Weston Farm and represents a freely draining brown earth. The thin litter layer consists of *Acer* sp., *Ulmus* sp., and *Urtica* sp. The A horizon consists of a fine sandy silt loam with a well developed granular structure. This horizon is organic rich, including recognisable fragments of bark, leaf, twig and root; rooting at this level is heavy. All horizon boundaries in this profile are diffuse. The A/B horizon, with a weakly developed blocky structure, increasing stoniness and moderate organic content blends into the lower B horizon. This mineral horizon with a sandy clay loam texture has a moderately developed sub-angular blocky structure. The underlying parent material mapped as sands with limestone, is a sandy loam material with significant root penetration down to a depth of at least 80cm. No limestone clasts are visible within this material unlike the Little Weston Farm profile.

CHB2

The profile through the side of a Bronze Age barrow reveals a complex sequence of modern plough soil, gravelly barrow material, and a sequence of very sandy red and grey layers interpreted as the old land surface and soil profile. The barrow cap material consists of a structureless deposit with abundant sandstone gravel set in a matrix of fine sand. Occasional flecks of charcoal are present in this material and root and animal disturbance are evident. At the interface between the cap material and the underlying land surface runs a thin, discontinuous iron pan beneath which is a bleached sandy horizon. Beneath this are layers of relative iron enrichment and natural gully features. The lowest horizon (context 018) is similar in nature to the capping material and is interpreted as the parent material. Animal disturbance is evident down to the level of the buried soil.

Sigwells

This second Bronze Age barrow is formed from and upon similar sands to the previous monument and reveals a similar, although more complex, profile. A deep brown earth soil profile has formed at the top of the sequence within the barrow material. Pockets of reddened burnt material survive towards the base of this pedogenically altered horizon. Beneath this, the barrow consists of a mixed soil and gravel cap overlying lenses of pure white sand, and an ashy grey material. Animal disturbance is also noted at this level. Beneath this the reddened brown horizon, interpreted as the 'turf line' or old land surface, presents itself as a firm compact layer with occasional fine roots, charcoal flecks and a single flint microlith identified as Neolithic (Tabor pers. comm.). The boundary between this horizon and the overlying sand lenses is clear and abrupt, the lower boundaries characterised by frequent red mottling is diffuse. Beneath the 'turf line' are white sands and red mottled horizons overlying a yellow silty material. This infills a feature interpreted as a natural gully cut into the parent material of stony orange sand.

5.4.2.2 Micromorphology results from Sigwells, CHB2 and Slait Farm

Slait Farm

Slides from the A, A/B, and B soil horizons of this freely draining brown earth soil were manufactured. Summary tables of results are given in appendix 5 (p. 417). The organo-mineral A horizon is dominated by very fine quartz sand set closely within a silt and clay matrix. The microstructure is defined by the presence of channel voids. Mammilated earthworm and unidentified large ellipsoidal excrements are present at this level together with lignified and parenchymatic plant organ tissues, red, yellow and black amorphous organic residues. This upper A horizon grades into the mineral B horizon through a diffuse A/B level with a gradually decreasing organic content. The B horizon presents a massive, or compact grain microstructure in which organics and excremental pedofeatures are found only within channel voids and form no part of the surrounding soil matrix. The mineralogy is dominated by quartz sand, closely packed to produce a horizon with low porosity. No textural void coatings or grain cappings were identified at these levels. Occasional matrix impregnations of iron are present throughout the profile, sometimes in association with organic remains.

CHB2

Slides taken from the lower section of this Bronze Age barrow reveal a sequence of deposits and soils dominated by processes of clay and iron illuviation. Summary tables of results are given in appendix 5 (pp. 421-423). At the top of the sequence, the blocky sandy loam of context 2016 consists of a mid-brown and yellow brown, mineral and organo-mineral microfabric, dominated by very fine quartz sands with sandstone clasts of medium - coarse sand size. Frequent void coatings of orange dusty clay and rare silty clay are recorded. The typology of textural pedofeatures from this site consists of five types (table 5.23).

The stony cap material, context 2008, consists of a mineral, inter-grain microaggregate type fabric. Quartz sand and sandstones are the dominant coarse fraction. Yellow limpid and orange dusty clay void coatings are common, whilst a heavily fractured iron pan feature appears to have been inherited with the constructional material. Beneath this cap there is a thin iron pan above an iron-depleted horizon (context 2013) interpreted in the field as a buried land surface. In thin section this layer is mid-brown and formed from mineral and organo-mineral microfabrics with a higher silt content than the overlying sediments. The iron pan is not present in the thin section, but yellow limpid and orange dusty clay cutans are found, as are very rare mammilated excrement. Beneath this, contexts 2017 and 2014 are predominately mineral horizons in which very fine quartz sand is frequent and sandstone is absent. All cutan types are present at this level.

Sigwells

Summary tables of results are given in appendix 5 (pp. 418-420). No thin sections were taken from the stony cap material because of sampling difficulties. The sand and ash layers below this, and immediately above the reddened horizon assumed to be the original 'turf line', were sampled. These are mineral and organo-mineral deposits in which very fine, sub-angular, quartz sand is the dominant element. Channels and simple packing voids account for most of the 25% void space. Both limpid and dusty void coatings are present in these horizons, as through most of the profile, with the same cutan types identified as at the CHB2 site (table 5.23). Similar distributions and variations in silt are observed at both the CHB2 and Sigwells sites. Iron matrix nodules are present but are rare and small compared to those further down the profile. Context 6105 consists of a mixed mineral and organo-mineral fabric coloured brown and yellow / brown, with a bridged grain microstructure. Void space is slightly less than above (20% slide area) with an increase in vughyness. Amorphous black organics and brown pigmentation, together with charcoal and traces of amorphous yellow and red organic residues are present. Within this horizon an increase in the number of orange dusty void coatings is recorded, whilst rare brown dusty, and orange limpid cutans are also present. Beneath this context, the remaining, predominantly mineral, deposits are characterised by frequent iron nodules and rare orange dusty cutans. The amorphous iron pedofeatures include not only discrete nodules, but also a fractured iron pan consistent with the level of the red mottling of context 6109. A filtering process appears to have operated in the deposition of the

Table 5.23: A typology of textural pedofeatures from CHB2, Somerset.

Textural pedofeature type	Description	Distribution
Yellow limpid clay void coatings	Yellow / orange in PPL, yellow / grey in OIL. Up to 125µm thick (modal 5-25µm). Typic and crescentic, most with normal orientation. Extinctions clear, few fractured.	Usually within sandstones and packing voids, capped and coated with siltier features. Very rarely coat iron nodules, strongly tend to occur within and beneath iron pans rather than above. Very rare, within channels up to 60µm diameter.
Orange dusty clay void coatings	Orange to orange / brown in PPL, orange with no punctuations in OIL. Extinctions clear. Dusty to silty, siltiest where an impediment to flow. Typic and crescentic, micro-laminated with silt.	Throughout overburden and also in buried soil, within packing voids and channels up to 500µm wide. Found coating, iron nodules and pans, brown silty cutans, charcoal and black organics.
Orange / red dusty clay void coatings	Orange with occasional red staining in OIL. Otherwise very similar to orange dusty cutans.	Occasional within buried soil and overburden, within packing voids and channels up to 500µm wide.
Brown silty clay void coatings	Orange / brown in OIL, with common organic punctuations. Extinctions weak and clear to diffuse. Typic and cresentic, normally oriented. Very heavily fractured, part. In cap material.	Tend to have a mutually exclusive distribution with orange dusty cutans (obscuration of former?), rare coated by orange dusty type features. Within buried soil and overburden.
Silt cappings	Brown silt (PPL), waxy yellow / orange in OIL, indicates presence of clay. Intergrades with orange / brown cutan features.	Occur upon upperside of sandstone clasts within stony cap material.

orange type cutans that has determined the relative texture of these features. Where clay is found capping stones and the fractured iron pan, the illuviated clay is very dusty in nature, whilst progressively lower through the impeding feature the cutans tend to contain less silt until limpid clay coatings are deposited. No evidence of biological activity in the form of excremental features is present.

5.4.2.3 Bulk analytical results from Sigwells, CHB2 and Slait Farm

Slait Farm

The chemical and physical analyses upon the bulk samples taken from the Slait farm reference profile reveal a relatively homogeneous profile (table 5.24). Soil pH is slightly acid, but shows no increase with depth. Bulk density is high, reflecting the close packing of the very fine sand and silt grains and increases uniformly with depth. No podzolisation processes are evident and although clay content increases slightly with depth the textural characteristics remain similar through the profile.

Table 5.24: Bulk chemical and physical properties of the Slait Farm reference soil.

Horizon	% LOI	pH	% Moist.	Bulk density g/cm^3	% Fe (pyr ext.)	% Fe (dith ext.)	% Fe (res.)	% Sand	% Silt	% Clay
A	2.8	5.0	30.1	0.81	0.21	1.28	0.91	51.2	45.6	3.2
A/B	3.1	4.4	23.5	0.89	0.28	1.23	0.98	49.1	47.4	4.5
B	3.5	4.7	15.0	0.91	0.27	1.38	1.13	50.8	43.9	5.3
C	3.6	4.8	15.6	1.11	0.25	1.53	1.37	52.6	41.1	6.3

CHB2

The Bronze Age site of CHB2 has a more acidic pH than Sigwells that more closely resembles those of the reference profile (pH of 4.4 to 5.5). Otherwise the chemical and physical properties of these two sites are broadly comparable (table 5.25). The buried 'turf line' with low loss-on-ignition and pyrophosphate values may be an eluviated Ae horizon, the original soil having been truncated, or it could be an anthropogenic sand deposit similar to that at the Sigwells site.

Table 5.25: Chemical and physical properties of the soils and sediments of CHB2, Bronze Age barrow.

Context	pH	% Moist.	% LOI	Bulk density g/cm3	% Fe (pyr. ext.)	% Fe (dith. ext.)	% Fe (res.)	% Sand	% Silt	% Clay
2004	4.4	18.3	2.06	0.95	0.29	1.43	1.09	59.3	36.1	4.6
Cap 2008	5.5	17.2	2.08	0.96	0.13	1.48	1.29	65.6	31.0	3.4
2013, bEA	5.3	17.8	1.92	1.02	0.04	1.47	1.27	64.0	31.8	4.2
2017	5.4	19.3	2.24	1.29	0.16	1.78	1.55	66.5	29.9	3.6
2014	5.3	20.0	1.99	1.02	0.23	1.79	0.99	63.3	31.2	5.5

Sigwells

The bulk chemical and physical properties of the soils and sediments from Sigwells (table 5.26) illustrate the textural similarities between the overburden material (6102; 6103) and the ultra-local sub-soils (6108; 6110). There is also evidence to support the interpretation of context 6105 as a buried turf line as the elevated loss-on-ignition figures suggest a raised organic content relative to the overlying deposits, as expected of a buried A soil horizon. The high concentration of pyrophosphate extractable iron also supports this hypothesis. This iron oxide fraction is also concentrated at the level of the red, mottled 6109 horizon identified as a fractured iron pan in thin section. This indicates that the iron pan has formed through the illuviation of iron in association with organic acids through podzolisation, and not through more localised redoximorphic processes as seen in other site profiles.

Table 5.26: Chemical and physical properties of the soils and sediments of Sigwells, Bronze Age barrow.

Context	pH	% Moist.	% LOI	% Fe (pyr. ext.)	% Fe (dith. ext.)	% Fe (res.)	% Sand	% Silt	% Clay
6102; 6103	6.2	18.1	0.60	0.19	0.81	0.62	64.4	30.7	4.9
6105 turf line	6.1	16.8	1.64	0.43	1.42	0.94	64.5	29.4	6.0
6106	5.9	15.2	0.40	0.37	1.54	1.00	61.4	33.6	5.0
6107	6.2	17.8	0.56	0.24	0.67	0.43	61.9	33.2	4.9
6108; 6109	6.1	19.1	0.37	0.26 (0.40)	0.71 (0.52)	0.44 (0.34)	63.1	31.7	5.2

5.4.2.4 Interpretation of Sigwells, CHB2 and Slait Farm

These sandy soils dominated by very fine quartz sands exhibit evidence of both the movement of iron and fine particulate matter within the buried soils and the archaeological overburden material. The question at these sites, therefore, is whether these movements were prior to, or after, the construction of the monument. The brown silty cutans present at both of the archaeological sites are interpreted as evidence of pre-burial, anthropogenic disturbance processes. They clearly pre-date at least one phase of yellow clay movement as a few brown cutans coated by yellow clay were noted. Small quantities of charcoal and flint within the buried soils offer further proof of anthropogenic activity prior to burial. No such disturbance indicators (brown clay cutans) are present within the reference profile of Slait Farm. Iron redistribution has also affected these archaeological soils both prior to and following burial. The iron pan formed at depth within the buried soil of Sigwells appears to be a relict feature, predating the construction of the barrow, that has been heavily fractured by biological activity. The reddening of the upper buried soil horizon of this site noted in the field, however, together with increased numbers of iron nodules suggests that some post-burial iron enrichment has occurred. At the slightly more organic rich CHB2 site a thin but continuous basal pan was present, which auger testing confirmed persisted beneath both of the conjoined barrows but was absent within the adjacent plough soil. Yellow clay coating the pan, iron nodules and fragments of charcoal within both sites, suggest a post-burial phase of clay illuviation. The argument for post-constructional clay movements is supported by the presence of clay and silt cappings upon the upper surfaces of sandstone clasts, within the stony cap material of the barrows. However, similar cutans present at depth within the buried soil could have an alternative pre-burial origin. Organic matter content of the buried soils is low in comparison to the reference soil and the lack of decomposition products in thin section suggests that they were depleted prior to burial. Excremental features indicative of biological activity are likewise rare and biological reworking of these sites appears to have been very limited.

5.4.3 Summary of results from South Cadbury

The South Cadbury study region provided three archaeological sites all dated to the Bronze Age, but covering two distinctive parent material types. The pre-burial pedological development has involved the evolution of brown earths at all sites. Prior to burial, anthropogenic disturbance of each site has been experienced. Despite significant differences in textural characteristics between the sites, the processes of post-burial change appear to have been similar. Biological reworking of the buried soil at all three sites is characteristically low and at the two sandy sites there is no evidence of significant loss of soil depth after burial. The two key processes operating at these sites, involving the movement of iron oxides, and of clays and silts. In the heavier clay soils of Milsoms Corner this movement of organic, silty clay appeared to

Figure 5.22: Post-burial textural features within the South Cadbury sites.

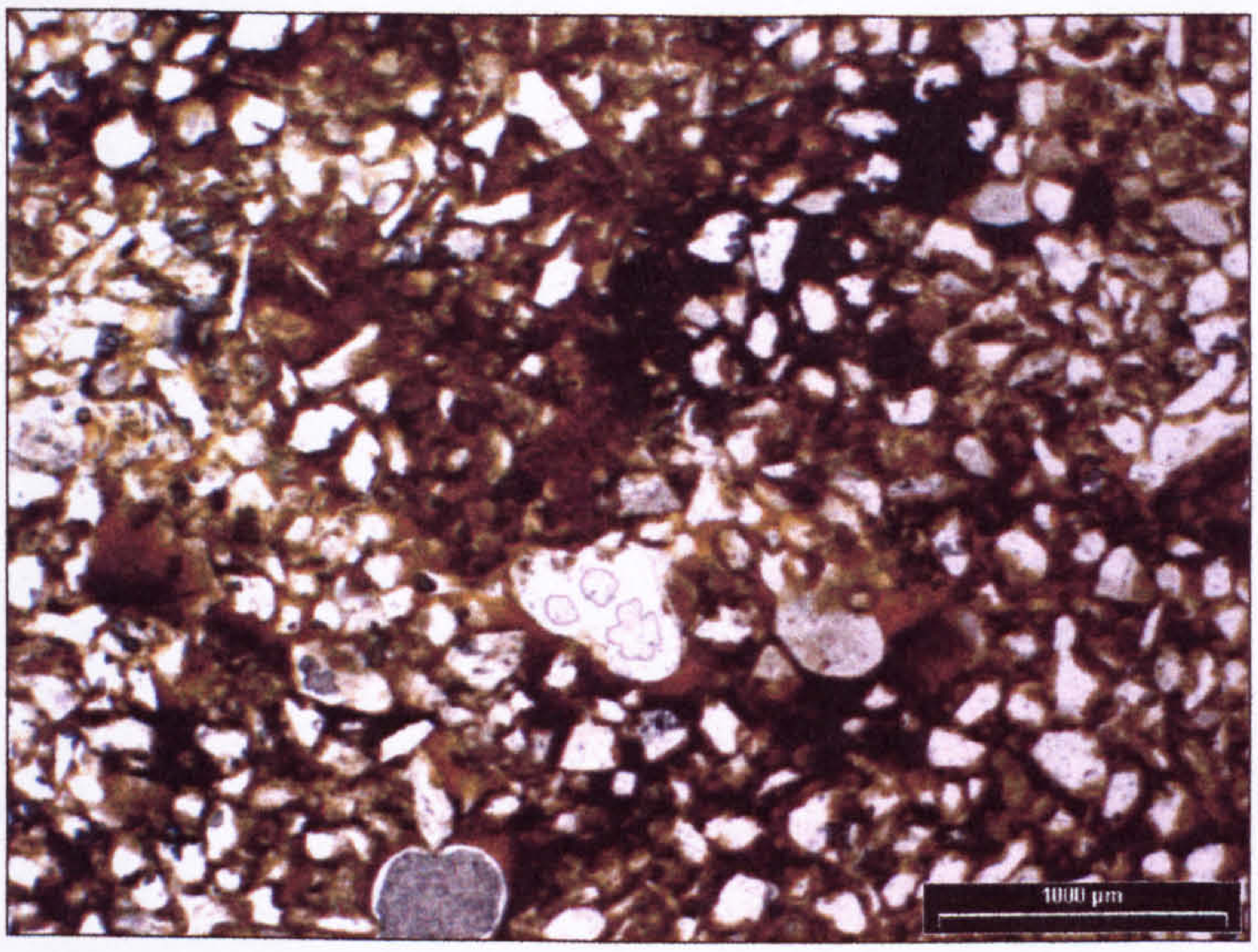


Fig.5.22a: Post-burial clay coating in buried soil of Sigwells.

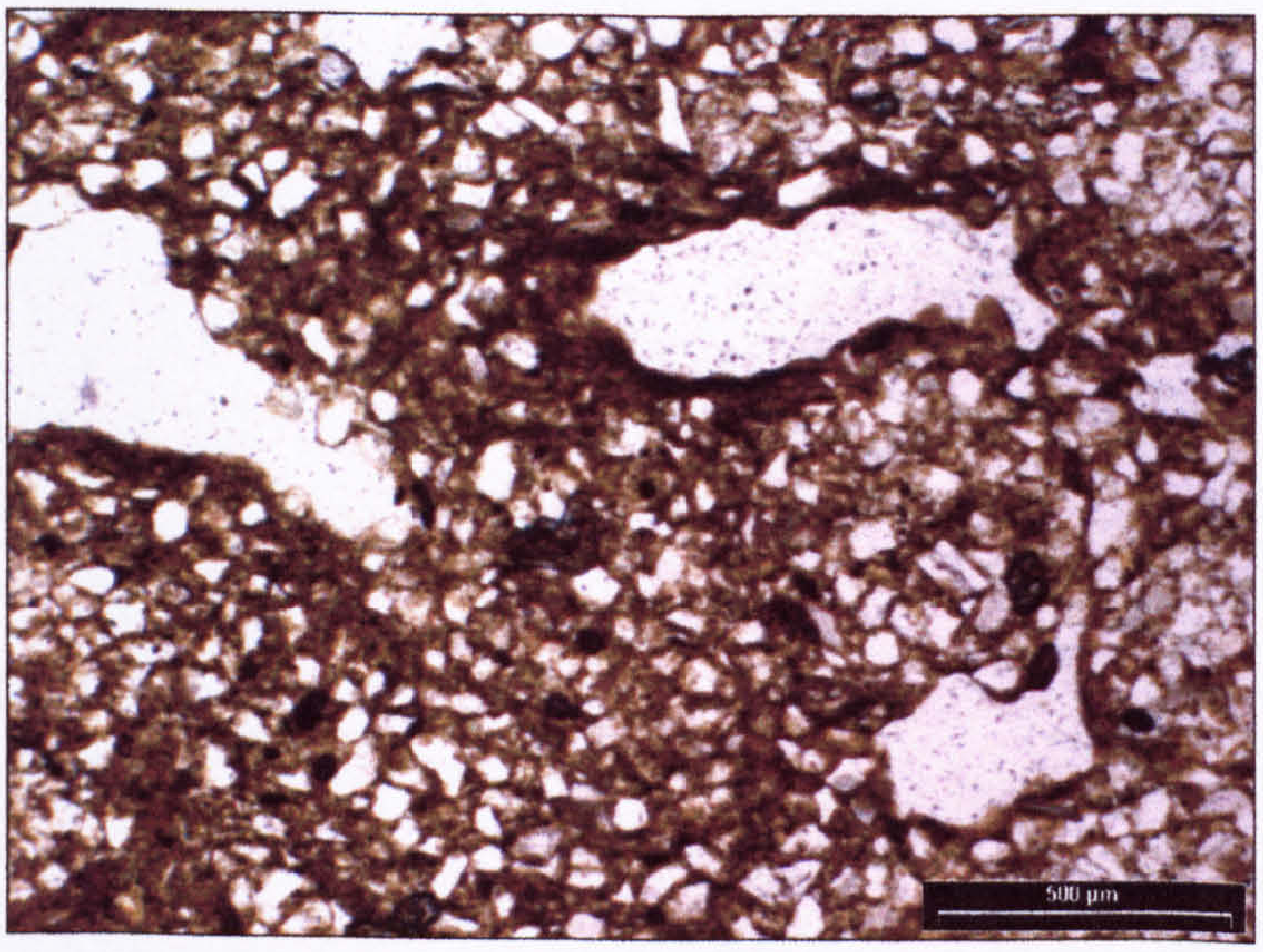


Fig.5.22b: Post-burial silty clay coatings within the bank overburden material at Milsoms Corner.

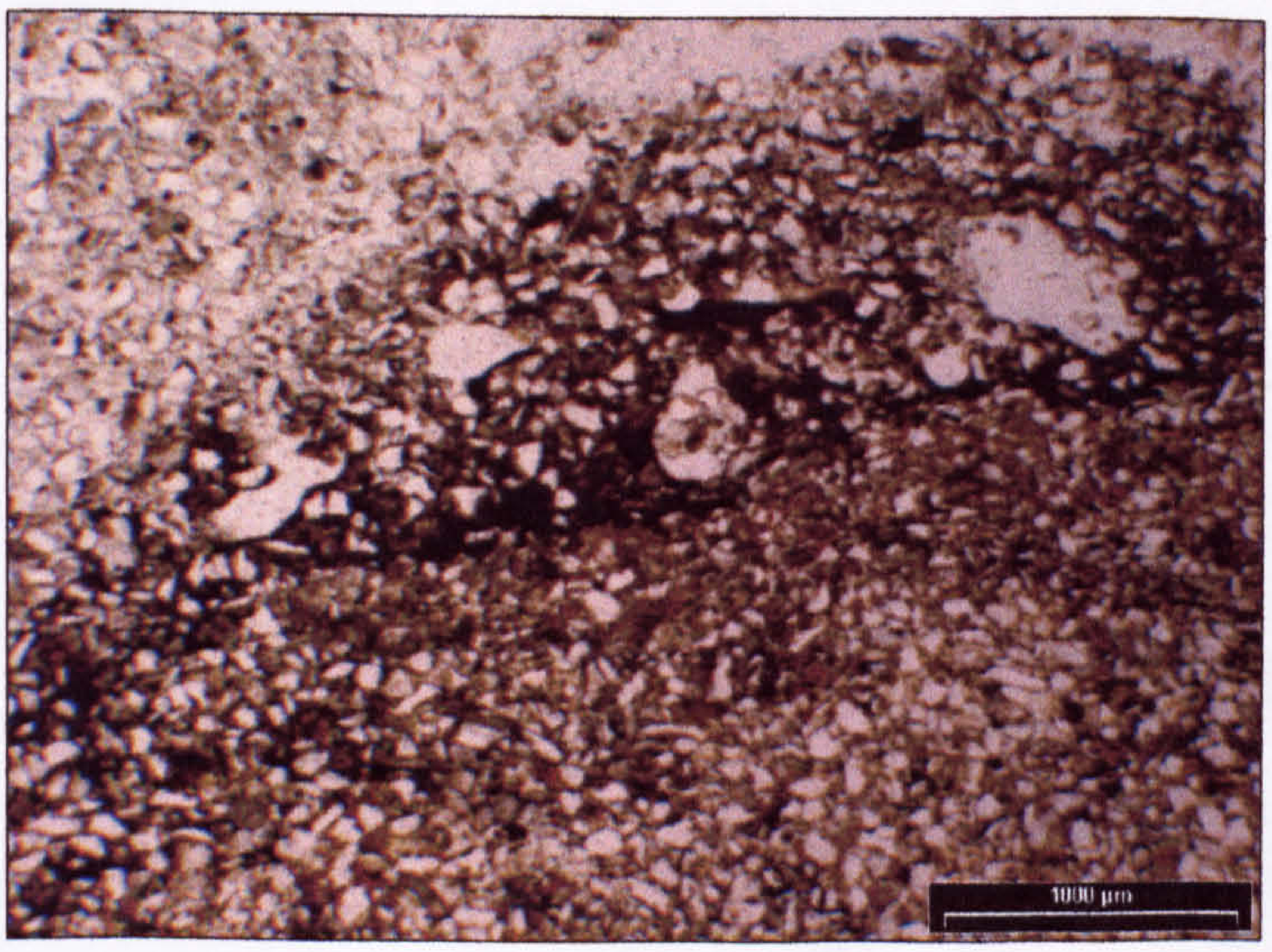


Fig.5.22c: Post-burial silt and clay capping upon sandstone within the barrow overburden material at site CHB2.

have been initiated by disturbance of the surface soil possibly by cultivation. Within the sandier sites of Sigwells and CHB2, the clay and silts mobilised bore more resemblance to those from Fordhouse Barrow and possibly relate to the disturbance of the soil derived construction materials during site construction. Images of the post-burial textural pedofeature types are given in figure 5.22. Iron redistribution in these sites has operated both prior to and following burial. At Milsoms Corner gleying of the sub-soil is a feature of both the reference and archaeological profiles, whilst at the sandier Sigwells sites pre- and post-burial iron pans nodules have developed. Those formed prior to burial correspond with peaks in the level of pyrophosphate extractable iron and so probably the result from podzolisation. The post-burial features have formed at the interface between the buried soil and the overburden and extend across most of the area of the barrow.

5.5 Processes of post-burial change observed within the study sites.

The effects of post-burial change are visible in all of the buried soils studied in this thesis. The nature, severity and consequences of these changes, however, vary widely between sites. The features observed in thin section can be listed as follows: amorphous iron features, textural void coatings and cappings, excremental features, depletion features, crystalline features and structural features.

Amorphous iron features, include nodules, pseudomorphs, pans and mottling of the soil fine fabric, and are some of the more ubiquitous post-burial features. They are present within the Angus, Breamish and Somerset study regions as well as certain sites from Sanday. Amorphous iron nodules, often found in association with both amorphous and tissue organic residues and, in the latter case rarely forming pseudomorphs of the plant cellular form, are found within all of the regions studied. Amorphous iron pans formed at the boundary of the overburden with the top of the buried soil, and occasionally within the overburden itself, are recorded from two sites in Angus and Somerset. Weak impregnation of the soil fine matrix found in association with organics and matrix depletions of iron, within both the lower buried soil and the overburden material, produced the mottled effect recorded within archaeological sites from Sanday, Breamish and Somerset. The diverse nature of the features formed suggests that the conditions of burial, and the processes operating in response to these, are different. Determination of the processes leading to the formation of each of the amorphous iron features recorded relies upon profile by profile, and site by site consideration of the features present and the biological, physical and chemical conditions with which they are associated. This falls outside of the remit of the regional overview given in this chapter.

Textural pedofeatures, in the form of silt and clay void coatings and cappings, are present within sites from each study region. However, the attribution of these features to post-burial processes through study of their spatial and inferred temporal distributions reveals that only buried soils within Angus and Somerset have been affected after burial. A single site within Sanday showed evidence of post-construction, textural pedofeature formation within the overburden, but this had not affected the buried soil. The nature of these textural pedofeatures was varied both in texture, colour, width and distribution. Clay void coatings (dusty and silty) have formed within the overburden and buried soil of Fordhouse Barrow. These coatings varied in colour between orange/brown, orange and red as a presumed result of iron and organic content. In Somerset there is greater variation in post-burial pedofeature type, but this is split between parent materials. In the sandier soils, yellow, orange and red post-burial coatings are present together with silty cappings upon sandstone clasts, textural differences arise throughout the profiles seemingly as a result of filtering effects. Within the heavier clay site, post-burial cutans consist of silty and dusty brown cutans more similar in nature to those pre-burial textural pedofeatures recorded within the buried soil of Angus and the sandier Somerset sites. These textural features are formed by the translocation of clay and silt through the agency of soil water, but for this to occur the fine material must first be released from the soil matrix.

Excremental features provide one of the best means of assessing bioturbation within the buried soils. Distinction between pre- and post- burial excremental features relies upon a study of their ageing (degree of coalescence and disintegration), their internal fabric, and their disturbance of other post-burial features. These features are recorded within the Angus, Sanday and Breamish study regions. They were notably absent from all the archaeological sites in Somerset. Analysis of these features not only suggests the degree of bioturbation to which each buried soil has been subjected, but may also be used to draw inferences concerning the buried soils chemical and physical properties. Other biological processes that have operated within the buried soil includes the decomposition of organic material.

Depletion features are rare and largely consist of matrix areas depleted of iron as part of the mottling features discussed earlier in this section. Some of the Sanday sites, however, also appear to have overburdens which are depleted of calcareous materials; in one case this has been redeposited as calcite crystals within the lower overburden. Other crystalline pedofeatures include the deposition of calcium iron phosphate within voids also in Sanday.

Structural effects of burial are not the focus of this thesis, and because of the potential complexities of describing and quantifying such alterations in thin section the assessments made here are the broadest possible. Structural effects may include changes in porosity and void orientation in response to forces of compression, and are likely to be site and profile specific. However, a laminar orientation adopted by amorphous organics and tissue remains at the base of one of the middens studied in Sanday is evidence, as too is the laminar orientation of plant pseudomorphs within the iron pan at Fordhouse Barrow, Angus. Bioturbation and the reworking of the soil structure after burial appears to have been the most widely encountered form of structural alteration.

5.6 Summary of results

The regions and sites studied and described provide examples of buried soils developed under widely different environmental conditions. Consequently these soils have developed along very different pedological pathways. Similarly, the evidence for anthropogenic disturbance of these soils varies from site to site. Clearance, pasture, cultivation and waste dumping activities have affected some of the buried soils studied (table 5.27). After burial the processes operating, and the conditions developed within the buried soils, are likewise varied and include physical, biological and chemical processes of change. All the buried soils studied as part of this research include visible evidence of some form of post-burial alteration (table 5.28).

Table 5.27: Summary table of anthropogenic effects observed within the buried soils.

Site Name	Anthropogenic activities				
	Nil	Clearance	Pasture	Cultivation	Dumping
Fordhouse Barrow		Y			
Pool		?			Y
Woo	Y				Y
Seater					Y
Roos Loch			Y		Y
Turf Knowe		Y		Y	
Wether Hill		Y	Y		
Milsoms Corner		Y			
Sigwells		Y		Possible	
CHB2		Y		Possible	

(Y= yes/present)

The commonest forms of post-burial alteration include biological reworking of the buried soil and overburden and the redistribution of iron. Reworking of the buried soil by mesofaunal groups led to the destruction of original microstructure and mixing of the buried soil and the overburden material at their interface. At Fordhouse Barrow, however, the biological effects appear to be mostly the result of root penetration, and the activity of the soil fauna seems to have been confined to these organically enriched channels. Iron redistribution within both the overburden and the buried soil involves a number of different processes operating at different sites. Gleying processes in response to ground water and perched water tables were recognised at a number of sites. A second redoximorphic process appears to have involved localised redistribution of iron in response to the processes of organic decomposition; this process may have been involved in the formation of the basal iron pans noted beneath some of the sites. Finally, the effects of ongoing processes of podzolisation at the surface is affecting the buried soils also. The redistribution of clay and silt after burial is recorded from the Bronze Age sites of Fordhouse Barrow and Somerset. Recalcification of the buried soil profile, from the leaching of base cations down profile, was identified in Sanday.

Table 5.28: Summary table of observed post-burial change affecting the buried soils.

Site	Post-burial changes				
	Textural	Iron	Compression	Biological	Calcification
Fordhouse Barrow	Y	Y	?	Y – slight plant root.	
Pool		?		Y	
Woo				Y	
Seater			Y	Y	Y
Roos Loch		Y – gley	Y	Y	Y
Turf Knowe		?	?	Y	
Wether Hill		Y – gley		Y	
Milsoms Corner	Y	Y – gley	?		?
Sigwells	Y	Y			
CHB2	Y	Y			

(Y = yes/present)

The interpretations made in this chapter are mostly concerned with the pre-burial soil development phases but have also considered the processes operating after burial. The hypothetical model of post-burial change given in section 2.1 (figure 2.1) consists of a soil upon which processes of post-burial change act, and the final product in the form of the altered soil micro-fabric. The factors of burial, conditions within the burial environment, and actual processes of change have only been touched on in this chapter. It is the observed effects of the three research variables of depth of burial, time since burial, and parent material upon the burial environment and the processes of post-burial change that form the subject of the following discussions in chapters 6, 7, 8 and 9. These chapters attempt directly to answer the research questions and aims and to test the hypotheses outlined in chapter 3.

6. The effect of parent material upon processes of post-burial change.

The sampling scheme described in chapter 3 (Section 3.1) was based upon a hierarchical nested system in which parent material represents the first level of variation, with variables of time since burial and depth of burial nesting sequentially within the parent material framework. For this reason the effects of parent material upon the post-burial alteration of archaeologically buried soils should be described and analysed first. It is this discussion of the apparent effects of parent material and of burial itself that form the focus of this chapter.

Parent material was hypothesised in chapter 2 to have an effect on the nature of post-burial change in archaeologically buried soils. Parent material is a determinant of soil chemistry, texture and biology, and hence it is expected to affect the response of that soil to burial. The effect of parent material upon buried soil was addressed in this study by the identification of sampling 'regions' with contrasting parent material types. Acid, intermediate and basic parent materials, with both sand and clay dominated textures, were represented within the sampling regions studied. Local soil materials had often been used in the construction of the archaeological monuments above the buried profiles. In these cases local parent material is also a determining factor in the nature of the overburden material. In this chapter the distinctive nature of the soils and overburden materials within each of the study regions are described to characterise their physical, chemical and micromorphological properties. The assumption is that these properties are the result of parent material differences. The specific processes of post-burial change identified from the thin sections described in chapter 5 are considered in relation to parent material and other possible regional effects.

The sampling strategy included three sampling regions and a preliminary study site that will be considered in its own right as a fourth study region. The study regions are Fordhouse Barrow (Angus), Sanday (Orkney), Breamish (Northumberland), and Cadbury (Somerset). The Cadbury region within Somerset is divided geologically, and consequently two distinct parent material types are present. This study region, therefore, has been divided into two; Sigwells which includes the sites and reference profile upon sands, and Milsoms Corner with a site and reference profile formed upon Lias clays. Five study regions, therefore, have been identified and these form the basis of this chapter's discussion; because of the nested sampling scheme, these regional divisions will be continued in the following chapters. Another consequence of the nested sampling scheme is that within each of the study regions, internal variation as a result of site age, depth of burial and any unaccounted for environmental differences is also included within the regional figures. The unavoidable uneven spread of site ages and depths between each of the study regions means that regional effects may in part be accounted for by the other two study variables. The extent of this interaction is examined in Chapter 8. To characterise the regional soil properties micromorphological, physical and chemical data have been collated and examined. The micromorphology of the regions has been examined through the level 1 and 2 micromorphology tables (Appendix 5), and chi-square and general log-linear statistical analyses have been applied to the results from the buried soil, reference soil and overburden materials. Bulk physical and chemical data have been statistically described to characterise each site and to assess between and within region variation. To achieve this confidence intervals around the mean and General Linear Model (GLM) repeated measures ANOVA have been used.

6.1 Regional characteristics of the buried and reference soils.

The sampling design aimed to provide three sampling regions within each of which the parent material type was constant, but between which there was significant variation. Contrast between parent material types was achieved and will be discussed very briefly in this section. However, homogeneity within each of the study regions was more difficult to obtain, noticeable intra-regional variation was found both in the Sanday and Somerset regions. Four distinctive parent material types were represented within the three study regions. Both Fordhouse Barrow and Sanday are based upon Old Red Sandstone and glacial tills. The soils developed upon these sandstone parent materials are, however, very different from one another. Old Red Sandstone could be expected to produce a coarse grained, freely draining soil. Upon the till type materials, however, a slightly finer grained soil may be produced with a wider range of inherited minerals. The porphyric Andesite of the Breamish Valley is an intermediate rock type, which could be expected to produce slightly finer grained, silty soils. On account of the high levels of plagioclase and alkali-feldspars occurring both as phenocrysts and forming the fine matrix of the andesite rocks, these soils could also be expected to have elevated pH and base cation levels. The Somerset region contains two parent material types, both of which include inputs of oolitic limestone. However, one parent material consists of Lias clay whilst the other is very fine quartz sands. The textural difference between these two materials, therefore, is the dominant contrast, whilst the inclusion of calcareous oolitic limestone characterises the parent materials of this region.

6.1.1. Regional bulk physical and chemical characteristics of the buried sites and reference soils.

Bulk chemical and physical data was collected from the reference profile of each study region to characterise and assess the physical and chemical properties of the soils developed upon the contrasting parent materials. The same analyses applied to the archaeological materials and buried soils were designed to characterise the physical and chemical nature of the burial environment. The aim was to elucidate the effect of burial upon physical and chemical soil properties.

General linear model repeated measures allow the calculation of analysis of variance (ANOVA) for each of the chemical and physical properties. This test explores the between factor (parent material, time since burial and depth of burial) effects upon the soil property, and analyses the nature of the effects within each factor at specified depths from the buried soil / overburden interface. The between factor results for region / parent material are shown in table 6.1. These results confirm that at the regional level the soils and archaeological materials of each study region differ from one another in their physical and chemical properties. With the exception of loss-on-ignition these differences are significant at the 95% threshold level. Such physical and chemical differences were expected because of the contrasting parent materials upon which each of the regional soils had developed.

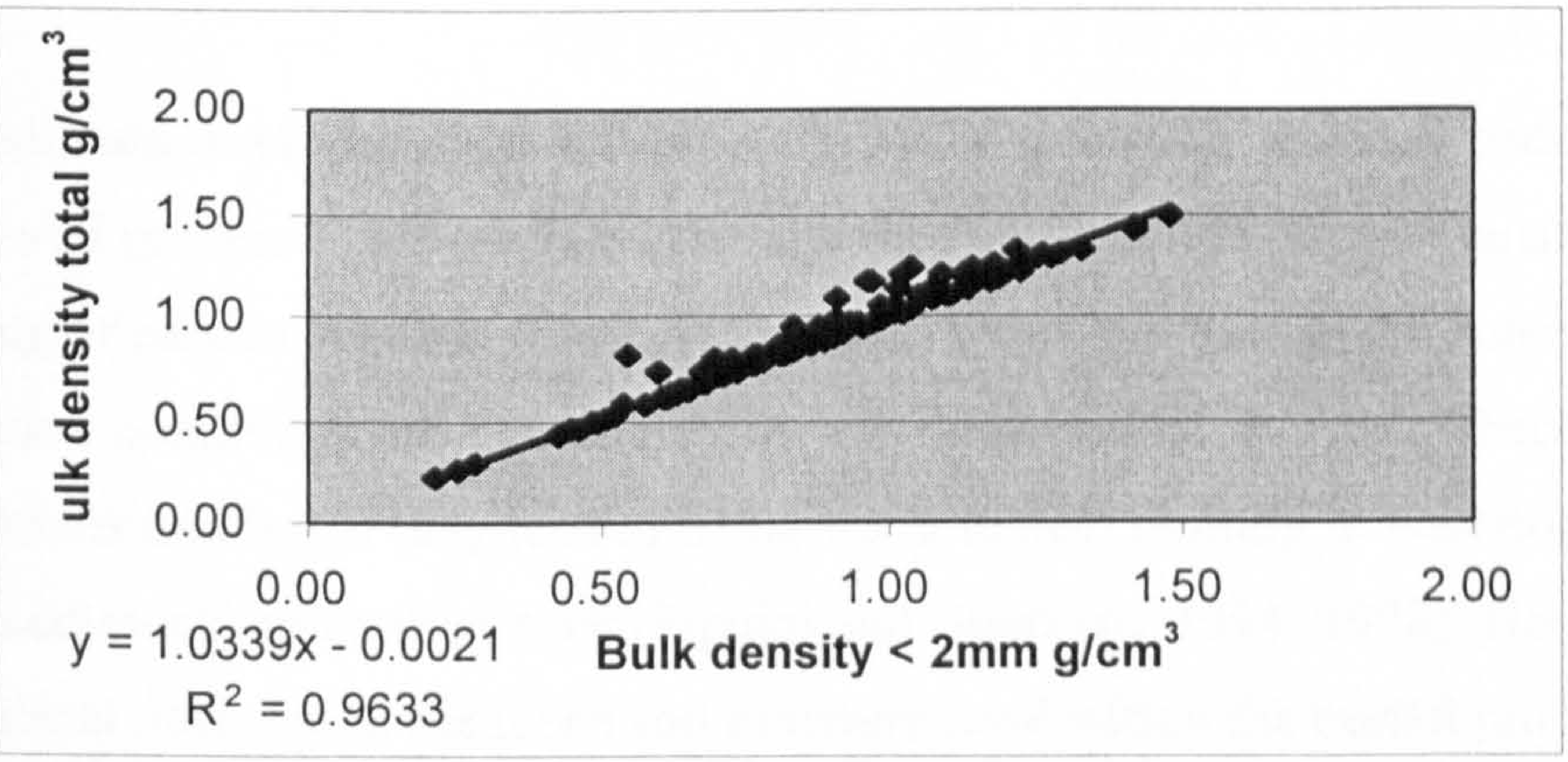
The bulk density values refer to total bulk density. Two measures of bulk density were determined: the total bulk density and the bulk density of all particles less than 2 mm (Chapter 4, Appendix 2). The strong linear relationship between these two measures is shown in figure 6.1 and suggests the effect of stoniness, which the less than 2mm bulk density analysis was designed to counteract, was minimal. Therefore, in this and subsequent discussions only total bulk density has been considered.

Table 6.1: Between factor (region) effects for all samples using GLM repeated measures ANOVA.

Variable	Sum of Squares	Df	Mean Square	F	Sig.
Bulk density	5.506	4	1.376	12.585	.000*
Moisture	3135.542	4	783.886	5.045	.007*
pH	488.700	4	122.175	8.969	.002*
Pyroph. extract. iron	2.496	4	0.624	5.517	.016*
Dith. extrac. iron	49.286	4	12.321	5.602	.012*

* Significant at 0.05 (95%) confidence interval.

Figure 6.1: Scatter graph showing the relationship between total bulk density and the bulk density of the <2 mm size fraction.



Error bar graphs are given in figure 6.2 to highlight significant differences between the regional sample means at the 95% confidence interval. The error bar graphs illustrate significant differences in the bulk physical and chemical properties of the reference soils and archaeological materials between regions. The error bars also illustrate the differences between the reference and buried sites within each region and highlight possible effects of burial upon the physical and chemical properties of the buried soils.

Figure 6.2 shows that although there is no significant difference between the mean bulk density of the regional reference profiles there is a general increase in the mean bulk density of the buried profiles relative to the unburied reference profiles. This trend of increased bulk density after burial is expected in buried soils subjected to compression. Mean loss-on-ignition tends to be lower in the buried soils than the reference profiles; in both the Sanday and Sigwells profiles this is a significant decrease. Loss-on-ignition was determined as an approximate measure of soil organic matter and a decrease in organic material in the buried archaeological soils would be expected as organic components decay and are mineralised over time. At some sites sub-soil materials with a very low organic content had been used to construct the overlying site, and this may have affected the mean loss-on-ignition values of the buried profiles. However, a decrease in loss-on-ignition with burial was also recorded for the Sanday region where organic rich midden material formed the archaeological overburden. The decline in loss-on-ignition in this region, therefore, suggests that decomposition and mineralisation of the organic material has been significant.

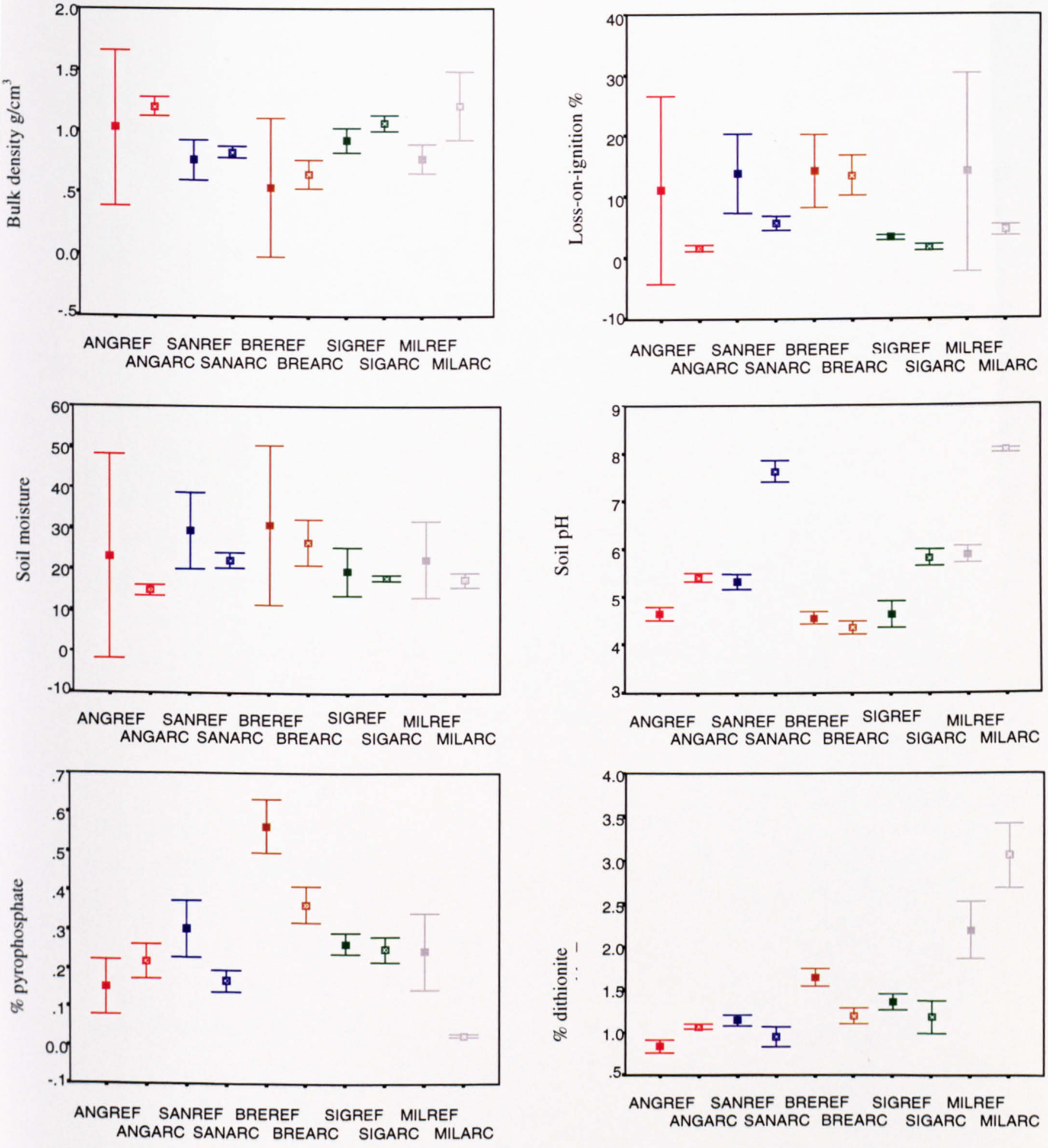
Soil moisture is an important soil property within this study as many pedological and post-burial processes are mediated through the action of soil water. Translocation and leaching of particulates and solutes relies upon water as a transport mechanism, whilst soil redox conditions are determined by the saturation of the soil. There have been suggestions that burial may lead to rising water tables resulting in waterlogging of the lower sediments and buried soils (Pipujol and Buurman, 1994; 1998). However, there is a general decrease in the mean soil moisture level within the buried profiles relative to that of the reference soils although none is significant. It must be remembered though that this measure of soil moisture represents only the hydrological conditions prevalent at the time of excavation.

Mean soil pH is significantly different between and within the study regions. Figure 6.2 illustrates how the reference profile from Milsoms Corner has a significantly higher mean pH than that of Sanday, which in turn is significantly higher than the mean pH of the other three regions. Comparison between the reference and buried profile shows how in all regions but Breamish the pH of the buried profile is significantly higher than that of the reference profile.

The pyrophosphate extractable iron fraction includes organic and amorphous forms of iron, the dithionite extraction measures the 'aged' crystalline forms together with amorphous iron, and analysis of the pyrophosphate residue allows quantification of the amorphous forms (Chapter 4, Appendix 2). Levels of pyrophosphate extractable iron have decreased significantly following burial in the archaeological sites of Sanday, Breamish and Milsoms Corner. Pyrophosphate levels at Sigwells show very little difference between the reference and the buried profiles whilst at Angus the level of extractable iron increases slightly. Overall a decrease in levels of pyrophosphate extractable iron following burial appears to be common. The mean levels of dithionite extractable iron are significantly different between each of the reference soils. The Angus based reference site has the lowest mean levels and Milsoms Corner the highest; this property, therefore is strongly related to parent material type. Intra-regional variation between reference and buried profiles is less clear. In Angus and Milsoms Corner the archaeological sites contain significantly higher levels of dithionite extractable iron whilst in Sanday and the Breamish Valley the buried profiles contain significantly less dithionite extractable iron than the respective reference soils. The dithionite extractable iron within the pyrophosphate residue follow a very similar pattern to that of the dithionite extractable iron, suggesting that most of the dithionite extractable iron represents the crystalline forms of iron rather than the amorphous.

The between factor ANOVA effects given in table 6.1 at the start of this section were arrived at using General Linear Model repeated measures. The repeated measures refer to the individual analytical values that were obtained from soil samples taken from distinct depths within each of the measured soil profiles. The samples are standardised relative to the interface of the overburden and buried soil so that each repeated measure belongs to a specific depth above or below this level. The within

Figure 6.2: Error bar plots at the 95% confidence interval of soil physical and chemical properties from regional archaeological and reference profiles.



REF = Reference profile, ARC = archaeological profiles region effect, therefore, refers to depth trends in the soil property in each study region. It was hoped that this approach would help to elucidate the effect of region upon the soil properties of the buried soils separately from the overburden deposits. To comply with the assumption of sphericity inherent in this test, Huynh-Feldt epsilon values were used to adjust the final F-values (Kinnear and Gray, 1999). No significant within region effects were recorded, and so no trends within the profiles of each region exist for any of the soil properties measured.

In summary the regional variation in parent material has affected the bulk physical and chemical properties of the soils that have developed upon them. The 'natural' soils of each region have a distinctive set of soil characteristics which may affect the way those soils respond to burial. The differences between the reference and buried soil profiles also appear to vary regionally although some broad trends such as increased pH and bulk density, and decreased loss-on-ignition and pyrophosphate extractable iron within the archaeological sites have been identified. Variation within the regional populations is often high and is probably the result of bulking samples within profiles and between sites.

6.1.2 Micromorphological characterisation of study regions, buried and unburied sites.

The micromorphological characterisation of each of the regions includes the characterisation of pre-burial soil fabrics and the identification of regionally distinctive post-burial features. Hierarchical cluster analysis was applied but chaining effects made this technique unsuitable for application to this data set. Chi-square tests were also carried out upon the recoded micromorphology data (Appendix 5.3) to identify relationships between parent material / region and particular soil features, and to identify relationships between different soil features. The examination of observed counts against the expected helps to elucidate the nature of any relationship. As with the bulk chemical and physical data, the relationships between region / parent material and soil features may be biased by the other two study variables of time since burial and depth of burial. General log-linear analysis has also been applied which allows multi-factorial cross-tabulations and comparisons to be made.

Pearson's chi-square test was used where more than 85% of expected values were greater than 5 (Kinnear and Gray, 1999), and Fisher's exact test using 2x2 presence/absence tables was employed when they were not. In some cases study regions had to be grouped together, these regional groupings were made upon the basis of known similarities in parent material type. The resulting characterisations refer not to the most visible features within the thin sections, but to those features which occurred more regularly than expected according to the chi-square null hypothesis. The null hypothesis assumes that each soil feature is randomly distributed between the thin sections. Significant regional differences were identified for each of the soil features included in table 6.2. Table 6.2 shows how many elements of soil mineralogy, soil organic matter, the occurrence of certain soil pedofeatures, and soil structure, texture and organisation are significantly correlated with region and in particular parent material. The chi-square results have been used to identify features whose prevalence or absence is characteristic of particular study regions.

The mineralogy of the different regions can best be described by adopting four regions in which Sigwells and Milsoms Corner are integrated into a single Somerset region. The legitimacy of this combination was verified by the micromorphology results that showed that the two regions both have a quartz dominated mineralogy. Where the chi-square results deviated from those observed in thin section, the characteristics of the two regions are given separately. Table 6.2 outlines the regional soil micromorphology characteristics in mineralogy, organics, pedofeatures and soil structure and organisation as determined using the chi-square test.

In almost all of the thin sections, quartz was identified as the dominant, coarse mineral element. However, only in Angus do large quantities of quartz occur within more slide sections than expected if the null hypothesis is assumed. Besides quartz, Angus is characterised by the occurrence of silt- and sandstone, feldspar, horneblende and biotite. This differed from Sanday, which although also sited upon Old Red Sandstone derived tills, includes the characteristic occurrence of siltstone, sandstone and shell, this contrasts with the Angus region which in comparison more frequently contains the ferromagnesian minerals. The shell in Sanday is the result of anthropogenic inputs to the midden deposits and of the aeolian deposits covering the

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sandstone flags at the Iron Age site of Woo. Andesite and feldspar are more characteristic of the Breamish region, while ooids from oolitic limestone and muscovite are more frequently found within the soils and sites from Somerset. Weathered biotite refers to the mean level of alteration of this micaceous mineral within each thin section. Those study regions in which the presence of biotite is not above the expected level may still have a characteristic degree of alteration of the mineral grains that are present. In Breamish and Somerset high levels of biotite alteration are recorded. In Angus this alteration is more moderate, and in Sanday the absence of biotite is the key characteristic. In Sigwells and Angus the coarse to fine ratio is moderate and high indicating the proportion of mineral matter over 10µm in diameter exceeds that of the finer fraction. In all other regions, the coarse to fine ratio of the soils and sediments is low indicating a soil fabric dominated by fine silt and clay.

Characteristic organic fractions for each of the study regions are also given in Table 6.2. The Sanday and Breamish soils and archaeological sediments are characterised by a wide range of organic fractions, both fresh and degraded, compared with the Somerset and Angus sites and soils which are both characterised only by the relatively more frequent occurrence of charcoal. Charcoal is mineralised within the combustion process and, therefore, is a more resistant form of organic by-product.

The differential occurrence of soil pedofeatures is of particular interest in this thesis as many of these features relate to specific processes of soil development, anthropogenic disturbance, and post-burial alteration. Regional differences in the frequency of occurrence of specific pedofeatures are presented in table 6.2. The Angus study region is characterised by the frequent occurrence of iron nodules, coatings and pans, iron depletion features, spherical excrements (enchytraeid), and dusty and silty, pre- and post-burial clay coatings around voids. The sites and soils of Sanday are characterised by the occurrence of mammilated excrement formed by earthworms rather than the enchytraeids, possibly related to the higher pH values associated with this region. It is excremental pedofeatures, iron coatings and iron nodules that are characteristic of the Breamish region. Limpid and silty clay coatings, pre- and post-burial coatings, formed by processes of translocation are characteristic of the Somerset region, whilst iron mottling is relatively frequent in Milsoms Corner and iron pans are more characteristic of the Sigwells sites.

Soil organisation in terms of void space, void type, microstructure, limpidity, fine material and coarse: fine related distribution were also assessed. Table 6.2 shows the characteristic soil and sediment arrangements for each of the study regions. The Breamish and Sanday regions tend to have fine fabrics rich in organic material whilst Angus and Somerset frequently have fabrics of mineral and organo-mineral material. In Angus and Somerset (Sigwells) the microstructure of the soils frequently tends to be determined by the c:f arrangement with inter-grain micro-aggregate, pellicular and bridged grain types common. Sanday and Somerset (Milsoms Corner) tend to have apedal microstructure types which are dominated by the arrangement of voids, i.e. channel, vughy and spongy. The Breamish study region include more soils with pedal structures than expected (crumb and blocky microstructures), although other microstructures are also frequently recorded. Porosity is high in Angus and Breamish, characterised by the greater than expected occurrence of packing voids and planar voids. Porosity in Somerset is low and includes planar voids (Milsoms Corner). At almost all sites channel voids are the dominant type but no significant differences in their occurrence were recorded between the regions.

Significant differences between buried and non-buried soil thin sections are present for the soil features shown in table 6.3. This illustrates significant differences in the occurrence of particular soil features between the buried and non-buried soils irrespective of region, and highlights possible effects of burial upon the micro-fabric of the buried soils. The chi-square test results of feature against burial illustrates not only the presence of soil features formed in response to processes of post-burial change, but also reflects the heightened level of anthropogenic disturbance and artefactual inputs at the buried, archaeological sites. Other differences appear to be the result of inherent local variability not fully described by the sampling scheme, for example the reduced occurrence of volcanic rocks and biotite within buried as opposed to non-buried soils. Elevated levels of charcoal and shell in the buried soil profiles relative to that expected in the non-buried, reference soils, almost certainly reflect anthropogenic inputs to the archaeological sections. The absence of biotite from the buried soil relative to the non-buried soils, probably reflects local mineralogy and the addition of organic rich / mineral poor material to the overburdens of some sites.

Of those differences which could reasonably be expected to result from processes of post-burial change, those relating to the organic fractions, excremental features, and void space are less frequent than expected within the buried soils. The presence of dusty clay and silty clay void coatings and iron nodules are more common than expected within the buried soils. No significant differences are found between the buried and non-buried profiles in the occurrence of iron mottling.

Table 6.3: Soil features for which significant differences in distribution were identified between the buried and non-buried soil profiles using the Chi-square test.

Soil feature	**Sign**	**P value**	**Soil feature**	**Sign**	**P value**
Biotite	-	.004	Pollen	-	.001
Volcanic	-	.000	Mammilate excrement	-	.037
Shell	+	.006	Spheroidal excrement	-	.003
Charcoal	+	.018	Iron nodule	+	.022
Lignified tissue	-	.000	Fabric pedofeature	+	.041
Parenchymatic tissue	-	.000	Silty clay coating	+	.000
Yellow amorph. organic	-	.024	Post-burial clay coating	+	.000
Red amorph. Organic	-	.014	Fine matter		.001
Fungal spore	-	.000	Void space	+	.048

These buried versus non-buried differences in occurrence should also be considered regionally if the effects of parent material upon the nature of post-burial change are to be isolated. However, using regional sub-sets the reduced number of samples proved to be incompatible with achieving the expected values of 5 or greater required by the chi-square statistic. Log-linear analysis has been used to perform 3 way cross-tabulations to address this problem.

6.2 Regional variation in the processes and effects of post-burial change.

In chapter 5 (table 5.28) the observed processes of change were identified as clay and silt translocation, iron redistribution, compression, biological reworking and calcification; some other effects were also recorded. These processes can be grouped further as physical, chemical and biological processes and effects as shown in table 6.4.

Table 6.4: Classification of observed post-burial processes as physical, chemical or biological.

Physical processes / effects	**Chemical processes / effects**	**Biological processes / effects**
Compression	Iron redistribution / segregation	Faunal reworking
Clay and silt translocation	Calcification and decalcification.	Root penetration
Structural change	Chemical weathering	Decomposition

In addition to the processes identified in thin section, there are bulk chemical and physical data which show differences between the buried and non-buried profiles for soil bulk density, pH, loss-on-ignition, moisture and iron levels. The first of these properties is physical and may be related to soil compression; loss-on-ignition will be regarded here as a biological property and the remaining variables relate to chemical soil properties.

The buried versus non-buried profiles show an increase in artefactual features and a decrease in excremental pedofeatures, organics and void space. However, there is a significant increase in the occurrence of dusty and silty clay coatings and iron nodules within the buried profiles. These variations, therefore, appear to be biological and physical responses to burial; these and other responses are discussed in the following sections. Those processes that have been focused on in this thesis are clay and silt translocation and iron redistribution. The former results in physical changes to the textural characteristics of the soil and so has been included within the discussion of physical processes whilst the latter is considered within the chemical processes of post-burial change.

6.2.1 Regional differences in physical processes of post-burial change.

The physical post-burial effects identified fall into two main categories. There are those associated with the process of clay and silt translocation to form textural clay void coatings, and those associated with increased bulk density and structural change in response to compression. The soil properties that will be considered in this section therefore are bulk density, textural clay coatings, void space, void type, and microstructure. The field descriptions contain evidence of soil depth, which may be affected by compression, however, this information is compromised by the possibility of soil truncation prior to site construction and so has not been included in this discussion.

The formation of clay and silt coatings around voids within the fabric of the buried soil and overburden will be considered in the sense of their regional occurrence. However, the post-burial void coatings should also be considered in terms of their occurrence alongside other soil features in order to understand the physical, chemical and biological burial conditions in which the processes of their formation occur. The chi-square analysis results of the post-burial void cutans regional distribution are shown in table 6.2. The presence of post-burial void coatings is more frequent than expected in the regions of Angus, Sigwells and Milsoms Corner. However, the nature of the post-burial clay coatings does vary between regions. Those of Sigwells and Angus, both upon parent materials with a predominantly sandy matrix, are yellow / orange coatings which in some cases are stained by organic material (yellow / brown) and iron (orange / red). These post-burial coatings are predominantly mineral in nature, any organic material being present as pigmentation rather than as discrete punctuations. The textural characteristics of these post-burial coatings vary between limpid and occasionally silty. The post-burial cutans at Milsoms Corner, however, are silty brown, poorly orientated and have a distinct organic component. These features bear more resemblance to the pre-burial 'disturbance' cutans recorded within soils of

Angus and Sigwells and are interpreted as the result of post-burial agriculture of the raised surface profile.

When the presence and absence of post-burial void coatings is cross-tabulated alongside the occurrence of pre-burial void coatings (table 6.5), another significant relationship is determined. In this case there is a positive relationship between the presence of both pre- and post-burial textural void cutans. Where pre-burial textural void cutans form in response to pedogenic and anthropogenic disturbance processes, therefore, there is also a heightened possibility that after burial there will be a further phase of clay and silt translocation.

Table 6.5: Chi-square analysis of pre-burial and post-burial void coatings.

		Post-burial	cutans
Pre-burial cutans		Absence	Presence
Absence	**Observed**	**107**	**34**
	Expected	*86.4*	*54.6*
Presence	**Observed**	**26**	**50**
	Expected	*46.6*	*29.4*
Pearson's Chi-square	Value	df	Asymp. Sig.
	36.152	1	.000*

The remaining sources of evidence of physical changes in buried soils relate to the identification of a response to compression. In thin section this evidence involves the identification of microstructure and the assessment of porosity and void type. This information is supported by determinations of bulk density (section 6.1.2). Significant regional differences were also observed in soil microstructure, void type, and void space (table 6.2). Whilst significant differences were recorded for the level of porosity (void space) between the buried and non-buried soils (table 6.3), no burial differences are present for microstructure and void type. As no particular void structure could be associated with post-burial alterations, the relationship between buried and non-buried soils at a regional level becomes a three-way comparison that cannot be solved by simple chi-square tests. In order to assess regional differences between buried and non-buried soils, therefore, general log-linear analysis was used. This technique allows relationships between multiple factors to be evaluated together by multi-dimensional cross-tabulation. The effect of each factor and its interactions with the other factors can then be assessed. Log-linear analysis shows that region is the main factor related to void space, but that the interrelationship of region and burial further explains the nature of the void space (table 6.6). The nature of this relationship is that in Angus and Breamish greater void space is more frequent than expected, whilst in Sigwells and Milsoms Corner it is the lower void spaces that are most frequent. Following burial in Angus and Breamish it is the lower void spaces (<19% slide area) that decrease and in fact the frequency of higher void space (>35% slide area) increases after burial. In the two Somerset regions this trend is reversed as the incidence of lower total void space increases in thin section following burial.

Table 6.6: Log-linear analysis results from comparisons of void space characteristics against the factors of region and burial.

Model	**Final relative difference**	**Chi-square**	**df**	**Sig.**
Region + Void space	1.718 E-06	43.521	8	7 E-07
Void space + Burial	9.411 E-06	6.063	2	0.483
Region + Burial + Void space	7.916 E-06	71.021	22	4 E-07

Regional differences in soil bulk density were highlighted by GLM analysis (table 6.1). This showed that there is also a general increase in the mean soil bulk density within the buried soil relative to the non-buried reference soils; in the Somerset study region (figure 6.2) the increase in bulk density following burial is significant.

6.2.2 Regional differences in chemical processes of post-burial change.

Alteration of the soil chemistry after burial is suggested both by the features evident in thin sections and by analysis of bulk soil samples. In thin section the features associated with chemical soil changes are iron pans, nodules, mottles and pseudomorphs, decalcification and calcification, and the chemical alteration and weathering of mineral components. The interpretation of these soil features is supported by the bulk soil properties of soil pH, moisture, and extractable iron concentrations.

The textural pedofeatures formed after burial and discussed in section 6.2.1 are classified upon the basis of their texture, colour, and composition and study of their distributions allowed the discrimination of pre- and post-burial features. There is great variation in the nature of the amorphous iron pedofeatures that includes iron nodules, iron pseudomorphs, rock impregnation, iron pans and mottling of the soil groundmass. However, each of these features may have been formed both before and after burial with no obvious typological differences. Inherited versus *in-situ* formation was also not easily and consistently discriminated, and so profile distribution was of little use in determining the relative age of formation of iron pedofeatures. Many are undoubtedly post-burial, and have formed *in-situ* within the overburden or have been affected by other post-burial processes; however, consistent interpretation on these grounds was not possible. The approach taken, therefore, was to use log-linear analysis allowing the comparison of the buried and non-buried profiles at the regional level (Table 6.7). No significant relationships were recorded for iron pan and iron pseudomorph features, perhaps because of their relative rarity in thin section.

The distribution of these amorphous and cryptocrystalline iron pedofeatures between regions, and buried and non-buried profiles shows that the presence of iron mottling is associated with region and burial. However, it is the relationship between region, mottles and depth from the buried soil surface that is most significant. A similar pattern is observed for the iron nodules, although burial perhaps has less of an effect upon nodule formation than upon mottling, possibly because iron nodules are relatively ubiquitous. The presence of iron impregnated rock fragments again follows the same pattern of regional, burial and depth relationships as mottling. Rock impregnation is high in Angus and low in Sigwells, and slightly higher in the buried profiles of all regions than of the unburied. In Angus and Breamish rock impregnation is more frequent than expected towards the top of the profile, whilst in Sanday and Sigwells they are highest at the base of the overburden and within the buried soil. Mottling due to gleyic processes is high at Milsoms Corner, but is absent from the Sigwells slides. Where mottle features are found they are at a higher than expected frequency within both the buried soils and parent materials. Iron nodules are more frequent than expected in Angus, Sigwells and Milsoms Corner, and lower than expected in Breamish. Burial increases nodule frequency in Angus and to a lesser extent Sigwells and Sanday, but decreases it in Breamish. In Angus, these nodules are found most frequently towards the top of the profiles whilst elsewhere their relative distribution is highest in the buried soils and lower overburden material. The distribution of these amorphous iron nodules, therefore, suggests a post-burial effect that impinged most heavily upon the buried soils themselves.

The nature of the iron fractions associated with those regions within which significant iron redistribution had occurred after burial of the soil appears to follow no clear pattern. Pyrophosphate and dithionite extractable iron fractions do show regional variation in their mean levels (table 6.1), however no one fraction appears to correspond with the occurrence of the post-burial amorphous iron pedofeatures upon a regional level. This may be due in part to the bulking of samples from whole profiles whereas, for example, the distribution of post-burial iron pans appears to closely relate to the buried soil, overburden interface and the position of turves used within the construction of the overlying archaeological site. Within region effects at specified soil depths, however, also produced no significant results.

Table 6.7: General log-linear analysis results from comparisons between different iron pedofeatures against factors of region, depth and burial.

Model	**Final relative difference**	**Chi-square**	**df**	**Sig.**
Region + Mottle	.0005	15.031	4	.0046
Region + Mottle + Burial	3.124 E-06	45.189	13	2 E.-05
Region + Mottle +Relative depth	.0002	137.261	49	3 E-10
Region + Nodule	.0006	30.826	4	3 E-06
Region + Nodule + Burial	6.099 E-06	58.335	13	1 E-07
Region + Nodule + Relative depth	4.818 E-05	201.695	49	.0000
Region + Rock	.0003	34.267	4	7 E-07
Region + Rock + Burial	1.030 E-05	60.913	13	4 E-08
Region + Rock + Relative depth	.0003	123.4112	49	2 E-08

Other chemical alterations after burial included raised mean pH in the order of 0.5-2.2 pH within all regions. Within Sanday this effect may be due in part to the level of calcareous material (shell, bone and ash) in the overburden material and also to salinity effects from sea spray. At the other sites this rise may be due to the effect of unleached sub-soil materials being used in the construction of the overburden, which is sufficient to raise the mean bulked pH. Also, if the buried soil and lower overburden becomes waterlogged in response to either raised ground water levels or the development of a perched water table, there will be a trend towards neutrality (Harris *et al.*, 1989). The importance of a sub-soil derived overburden is perhaps best illustrated at the Milsoms Corner site where the post-burial rise in pH is particularly marked, from pH 5.9 to pH 8.1. At this site of heavy clay with limestone inputs, the effect of leaching upon the clay rich overburden material will have been less severe than within profiles with a coarser texture, hence the maintenance of very high pH relative to the reference soil profile.

The continuation or otherwise of chemical weathering of soil minerals within the buried soils was another question of interest to this thesis, as weathering severity has been seen as an approximate measure of the isolation of the buried soil from the effects of surface processes (Ferrari and Magaldi, 1983). The degree of pitting and alteration of the biotite mica mineral appears to have been the best guide to this chemical alteration. However, after burial an absence of weathered and non-weathered biotite appears to have been characteristic. This absence may be reflecting local mineralogy and non-mineral additions to the buried profiles. A further chemical alteration process identified, involved the formation of calcium iron phosphates that were present within thin section from Woo, Sanday. These phosphate minerals are a decomposition product of bone (Jenkins, 1994), and chi- square analysis shows a significant positive relationship between the occurrence of these phosphates and the occurrence of degraded fish bone.

6.2.3 Regional differences in biological processes of post-burial change.

Biological processes of post-burial change were evident in both the thin sections and bulk soil samples. The biological processes that may operate in a soil are mediated by soil fauna, flora, and micro-organisms. The effects of soil fauna observed in thin section are excremental pedofeatures which provide evidence of reworking of the soil fabric, disturbance of both pre-and post-burial soil features, and intermixing of soil fabrics from different horizons. Channel features may also be faunal in origin, but are difficult to distinguish from those formed by plant roots. Another effect of plant disturbance after burial is the addition of plant material through the decomposition of roots that have penetrated into the buried soil. This is evidenced by the amorphous organic material that has survived around void walls or been incorporated within the matrix of the soil. The action of soil micro-organisms is vital to the decomposition of organic material and the maintenance of soil structure. Their effects in thin section are evident in the level of organic decomposition and the presence of fungal spores. Loss-on-ignition values provide an estimate of the level of soil organic matter and so are also a useful guide to the degree of decomposition and mineralisation of the soil organic material.

The identification of pre- and post-burial biological soil features proved difficult and involved the assessment of ageing (coalescence and disintegration) of excremental pedofeatures, and the nature of the organic material, (amorphous versus identifiable tissue residues). Both with and without aged features the presence of excremental pedofeatures showed a significant decrease within buried versus non-buried soils, this effect was observed for both spheroidal and mammilate excrements. Mammilate excrements are formed by earthworm activity whilst spheroidal excrements are formed predominantly by enchytraeids. One effect of burial appeared to be a marked reduction in the activity of the soil fauna (table 6.3). In order to study the regional influence of this post-burial decline, log-linear analysis was carried out, applying the factors of region, burial and depth from the buried soil against each of the excrement types (table 6.8). The relative regional occurrence of the two dominant soil fauna types (earthworm and enchytraeid) differed; earthworms are characteristic of Sanday and Breamish and the enchytraeids of Angus and Sanday. The log-linear analysis shows for both mammilated earthworm excrements and spheroidal enchytraeid excrements strong regional relationships. Burial has a second, but less important, effect upon the incidence of earthworm and enchytraeid excrement. The burial effect took the form of a decrease in observed counts relative to the expected, for both excrement types. The depth of the sample relative to the buried soil / overburden interface, however, does appear to be related to the occurrence of spheroidal, enchytraeid excrements at the regional level. The importance of the interaction between depth from the buried soil and region is also highlighted. The nature of this interaction means that the observed counts significantly exceed the expected (high positive residuals) at depths of 83 to 41cm in Angus, at depths of –1 to –65cm in Sanday, and depths of 83 to 41 and –1 to –11cm in Breamish. The Somerset sites have such low numbers of enchytraeid excrement that at no depth is the observed higher than the expected. Although the distribution down profile differs between regions, the highest occurrences are always within either the buried soil or at the very top of the overburden profile where a new soil surface may have established. This suggests either that the buried soils are still sufficiently rich in organic material and have other appropriate physico-chemical factors to encourage enchytraeid activity, or that some of the seemingly fresh excrements are in fact pre-burial in age.

Table 6.8: Log-linear analysis results comparing the presence of spheroidal and mammilate excrements against the factors of region, burial and depth.

Model	Final relative distance	Chi-square	df	Sig.
Region + Mammilate	.0002	90.527	4	.0000
Region + Burial + Mammilate	.0008	108.091	13	.0000
Region + Mammilate + Depth from buried soil	9.970 E-07	223.125	49	.0000
Region + Sheroidal	7.394 E-06	61.8803	4	1 E-12
Region + Burial + Spheroidal	8.676 E-06	86.553	13	1 E-13
Spheroidal + Depth from buried soil	8.145 E-05	15.354	5	.0090
Region + Spheroidal + Depth from buried soil	.0006	174.229	49	7 E-16

The organic content included lignified and parenchymatic tissues, pollen, fungal spores, and red and yellow amorphous organic residues. As would be expected within a buried soil isolated from the surface, the presence of all these organic fractions declines following burial. Regionally the organic fractions identified in thin section were concentrated within the Sanday and Breamish slides. Loss-on-ignition values show no such regional association, but do indicate the reduction in organic material after burial. Log-linear analysis allows the within profile distribution of these organic fractions to be examined at a regional level (table 6.10). The results in table 6.9 show how region and burial are important factors in relation to the occurrence of lignified tissue.

Table 6.9: Loglinear analysis of comparisons between the different organic fractions against factors of region, burial, and depth from the buried soil surface.

Model	**Final relative difference**	**Chi-square**	**df**	**Sig.**
Lignified tissue + Region	.0009	47.926	4	1 E-09
Lignified tissue + Burial	7.761 E-06	69.2937	1	1 E-16
Lignified tissue +Region + Burial	.0004	134.016	13	.0000
Lignified tissue + Region + Depth from buried soil	2.398 E-06	180.241	49	1 E-16
Parenchymatic tissue + Region	.0002	42.003	4	2 E-08
Parenchymatic tissue + Region + Burial	6.587 E-05	95.569	13	1 E-14
Parenchymatic tissue + Region + Depth from buried soil	1.063 E-06	158.180	49	2 E-15
Yellow amorph. + Region	1.173 E-06	58.434	4	6 E-12
Yellow amorph + Burial	5.295 E-06	4.618	1	.0316
Yellow amorph. + Region + Burial	.0002	86.765	13	6 E-13
Yellow amorph. + Region + Depth from buried soil	.0003	168.995	49	4 E-15

Lignified tissues are most common within Breamish and Milsoms Corner, and following burial their frequency decreased in all regions except that of Breamish. Parenchymatic tissues are most strongly related to region and depth from the buried soil surface. These thin walled organic tissues are most frequent within the slides from

Angus and Breamish; within these regions and also that of Sanday they have a tendency to be most frequently present within the thin sections from the top of the sampled profile and from the buried soil. Yellow amorphous organics also tend to be most significantly related to the region and depth of burial factors; burial itself apparently has only a more minor effect. The yellow amorphous residues are most frequent within the Sanday and Breamish study regions. In Angus these residues are more common than expected only at the very top of the buried profiles within the overburden material. In Sanday their presence is elevated throughout the entire profile, and in Breamish elevated levels are found at the top of the profile and within the buried soil. The two Somerset sites both have depressed levels of amorphous yellow organic material throughout their profiles.

6.2.4 The observed influence of parent material versus other regional effects upon processes of post-burial change

A problem which still remains is to recognise those processes of post-burial change that are responding specifically to the nature of the parent material upon which the buried soil has originally formed and which, if any, are the result of other regional factors. The study regions were selected to provide the solid and drift geological conditions necessary to this thesis (chapter 2). However, a consequence of this was a wide spatial distribution of regions from Somerset in south-west England to the northern Scottish islands of Orkney. Comparisons of the Somerset sites in which parent material differed but the sites were still sited so close together that macro environmental differences will not have been important, provides one means of assessing regional versus parent material effects. Comparisons between Sanday and Angus may also be considered to be revealing as these two regions had a similar solid geology but environmentally were very different. However, the till parent materials appeared to have different mineralogies (table 6.2). The difference in overburden type between Angus and Sanday also rendered any such comparison relatively meaningless.

The two sub-regions within Somerset (Sigwells and Milsoms Corner) do appear to show distinct differences in the nature of post-burial features. This would seem to suggest that the physical and chemical differences between the soils developed upon the two parent materials has resulted in differences in the way in which they respond to burial. The site of Milsoms Corner is situated upon heavy Lias Clays that produce thin soils with a high pH, and clay loam textures subject to gleying. The post-burial iron features here are dominated by mottles indicative of gleying, the textural features by brown, organic rich clay coatings thought to derive from tillage activities. The Sigwells sites are situated upon very fine sands that have produced deep, sandy loam soils with relatively low pHs, and loss-on-ignition values. The features formed in these sites include iron nodules, iron pans and mineral, textural void coatings that strongly resemble those identified at Fordhouse Barrow, Angus. The inter-regional differences between these two Somerset sub-regions with contrasting parent materials, therefore, indicate the importance of parent material in the determination of processes of post-burial change. The similarities in soil type between the Angus and Sigwells sites included sandy loam textures, low pH, and loss-on-ignition. The sandy loam textures of these two regions reflect the nature of the parent material, which in turn produces a free-draining, acid soil. There is the important finding, therefore, that upon such sandy parent materials the processes that lead to the formation of post-burial void coatings are encouraged.

However, the sites of Angus and Sanday, which have very similar parent materials (tills derived from Old Red Sandstone) demonstrate remarkably different processes of change. In Angus post-burial change appears to have been dominated by processes of clay translocation and iron redistribution. On Sanday, biological activity has been the most active process of change along with recalcification of the soil in response to the alkaline overburden material formed of midden deposits, and also due to the salinity effects of salt spray. These differences can be related to the very different nature of the overburden materials between the soil based, organic poor barrow at Fordhouse Barrow and the organic rich and often alkaline midden materials of Sanday. Also, the relative sea salt impacts on the island of Sanday versus mainland Angus appear to have been substantial. Regional differences in both overburden type and environmental conditions or, as will be considered in chapter 7 and 8, regional differences in site age and depth of burial, do seem to be more important in this specific scenario than the parent material type.

6.3 A discussion of parent material as a factor in the nature and occurrence of processes of post-burial change.

Parent material, its effect upon soil development and the response of that soil to burial, have been the main themes of this chapter. This discussion will bring together all of the evidence so far, the characterisation of each regional type, and the nature of the processes of post-burial change that have since operated within the buried soils. This section will also explore the links between the physical, chemical, and biological processes in order that the regional burial environment as a whole may be better understood.

The process of clay translocation depends upon three key stages, the release of fine particulates, their transportation within the soil profile, and their deposition as coatings around void walls. Transportation of clay requires a free flow of water through the soil profile. Within those buried profiles where post-burial clay translocation was identified soil moisture content was no greater than in those where no clay translocation has occurred. The regional effects of parent material upon soil moisture at the time of sampling appear not to be important in determining the post-burial onset of clay translocation. Textural differences resulting from parent material will affect soil drainage and moisture retention and although no links between soil moisture today and clay translocation can be made, textural differences may possibly have been important under different climatic conditionsin the past. Both the Sigwells and Angus sites, which included post-burial clay cutans that could not be related to agricultural disturbance had sand dominated textural properties.

The deposition of clay from suspension in the soil water may involve two different processes. The first of these is suspension retention in which down profile water flow is impeded due to changes in soil texture and soil porosity or because of the presence of physical barriers such as an iron pan, stone or water table level. Clay held in suspension, may, under conditions of stagnancy as experienced in a perched or ground water table, settle out to coat the surrounding void wall (Sullivan, 1994). Alternatively, the clay may be deposited when the soil water flowing through macro and meso voids, the preferred paths of soil water flow (Beven and Germann, 1981), is absorbed into the surrounding soil matrix through the micro-void system. This absorption may occur when the conducting voids are saturated relative to the surrounding soil matrix; i.e. the water potential of the voids is greater than that of the soil matrix. Particulates held in suspension will then be deposited upon the void walls as the soil water is filtered through. Within the archaeological profiles studied in this thesis, discontinuities in terms of material type and porosity could be expected to be common and may include the buried soil / overburden interface, junctions between various constructional units, and the possible enhanced presence of iron pans. Again, therefore, the opportunity for clay deposition is not expected to be a limiting factor in the formation of void cutan features. No significant relationship between void space or type, and the presence of clay coatings has been found, however, the Angus and Somerset sites where clay coatings were present do have significantly higher bulk densities than the regions without clay coatings. These bulk densities, however, are mean values and cannot be considered as a direct measure of porosity at the point of clay deposition; void space as measured directly in thin section may be more reliable. Regional void space, as presented in table 6.2, shows high percentage void spaces at Angus and a tendency for low percentage void space in the two Somerset region; no consistent pattern between void space and clay coatings, therefore, emerges. This suggests that drainage is not the limiting factor in the formation of post-burial clay cutans.

The remaining stage in the process of clay translocation is that of the release of clay and silt from the soil groundmass. This obviously assumes that clay is a component of the soil fine fabric. The buried soils and overburdens of all sites studied in this thesis have loam or clay loam textures which include between 5 and 40 % clay (Hodgson, 1976) and are a direct result of the parent material type. The sites of Sigwells are some of the poorest in clay (very fine sandy loam and sands), but clay translocation was still a significant process both prior to and following site construction. A source of clay and silt, therefore, also appears to be a non-limiting factor in the formation of clay cutans in the sites studied. The clay and silt particulates are normally held within the soil ped structures, the stability of which depend upon the presence of organic compounds (Chaney and Swift, 1984; Fortun *et al.*, 1989), fungal and root structures and exudates (Molope *et al.*, 1987), and chemical compounds including polyvalent iron (Giovanni and Segui, 1976; Chisch *et al.*, 1978).

Table 6.10 presents results analysing the relationships between the occurrence of void coatings and of those soil features that are indicative of the compounds known to stabilise soil structure. The occurrence of fungal spores is negatively related to that of both pre- and post-burial clay coatings, so in those samples where void cutans are present there is a significant tendency for fungal spores to be absent. Although this pattern is not proof of a causal relationship, it does support the hypothesis that fungal hyphae and exudates are important in stabilising the soils and preventing the release of clay for translocation. The presence and absence of all the organic fractions identified and recorded in thin section, both fresh and degraded, show a similar negative relationship and so support the hypothesis that soil organic content are also important in preventing or encouraging processes of clay translocation. Those amorphous and cryptocrystalline iron pedofeatures whose presence is significantly related to the void coatings, produced positive relationships. These two types of features (textural and amorphous iron), therefore, tend to occur within the same thin sections. If the release of clay from the soil structure is the key process that determines which buried sites experience post-burial clay translocation, and if iron compounds were playing a significant role in stabilising the soil, a negative relationship would be expected. This is not the case and the positive iron-textural pedofeature relationship infers that the processes of clay translocation and iron redistribution operate within similar burial environments. If the amorphous iron pedofeatures relate to post-burial movements of iron this process may have added to the destabilisation of the ped structures, and so it may be hypothesised that iron redistribution could indirectly have affected post-burial clay translocation. The coarse to fine ratio was drawn at a diameter of 10μm. A high coarse:fine ratio, therefore, indicates predominance of medium and coarse silt and clay. The significant positive relationship between the coarse to fine ratio and both pre- and post burial cutans indicates that in the sites studied, clay translocation is most prevalent in the coarser textured soils. Further information as to the nature of post-burial clay translocation within archaeological sites and their buried soils may be gained from the study of the time since burial and depth of burial variables which will be considered in chapters 7 and 8.

Soil compression is the second physical process of post-burial change that has been identified. The susceptibility of a soil to compression could be expected to relate to structural stability, as was explained in Chapter 1, and thus is also of interest to the discussion of clay translocation as well as being an important process of post-burial change in its own right. Bulk density is found to increase after burial and would suggest that the percentage void space in the soil blocks had declined. Void space estimated in soil thin sections shows that following burial Angus and Breamish tend to have a high percentage void space whilst in Somerset void space tends to decrease in thin section as would be expected (Table 6.2). This suggests that soil compression is more complicated than it at first seems. The low level of biological activity at the Somerset sites may be one reason for this apparent anomaly.

Iron redistribution is the chemical process of post-burial alteration that this thesis has concentrated upon. Again however, the complexity of the soil and burial systems studied was such that this process could not be understood without some recognition of the complementary physical and chemical conditions and processes. The relationship between clay coatings and iron pedofeatures has already been discussed, but table 6.11 outlines their relationship with other soil features including void space and organic material. The table shows how the relationships between organic materials, voids and the iron pedofeatures are mostly negative, iron pedofeatures tend to be present in thin sections from which organic material is absent and the total percentage void space is low. As was discussed in section 6.2.2 iron pedofeatures tend to be found within the buried soil and sub-soils areas where organic levels may also be low. Whether this relationship is incidental or causal is unknown, however, as it contradicts the observational evidence from thin section that in many cases iron nodules and pans are found alongside organic materials. The relationship between void space and iron pedofeatures is also negative. Iron mobilisation and deposition, therefore, tend to occur in slides with low void space. The void types with which this relationship is significant are packing voids and channels, the two void types that were most usually dominant in thin section.

The relationship between the formation of these iron pedofeatures and the nature of the soils as a result of parent material type is of principal concern to this chapter. The iron nodule features are most prevalent within Angus, Sigwells and Milsoms Corner. The first two regions are formed upon sandstone derived till and sands respectively,

Table 6.10: Chi-square analysis of the relationships between the presence of pre- and post-burial cutans, and the presence of fungal spores, organic fractions, and iron features.

Row	**Column**	**Chi- square value**	**df**	**Sig.**	**Relationship**
Pre-burial cutans	Fungal spore	65.538	1	.000*	negative relationship
	Lignified tissue	27.431	1	.000*	negative relationship
	Parenchymatic tissue	12.433	1	.000*	negative relationship
	Black amorph. Organic	4.728	1	.041*	negative relationship
	Yellow amorph. Organic	56.088	1	.000*	negative relationship
	Red amorph. organic	15.158	1	.000*	negative relationship
	Iron matrix nodules	15.606	1	.000*	positive relationship
	Iron pan	10.051	1	.003*	positive relationship
	C:f ratio	7.574	2	.023*	positive relationship
Post-burial cutans	Fungal spore	48.584	1	.000*	negative relationship
	Lignified tissue	27.458	1	.000*	negative relationship
	Parenchymatic tissue	12.980	1	.000*	negative relationship
	Black amorph. Organic	11.435	1	.001*	negative relationship
	Yellow amorph. Organic	43.170	1	.000*	negative relationship
	Red amorph. organic	27.088	1	.000*	negative relationship
	Iron matrix nodule	17.010	1	.000*	positive relationship
	Rock impregnation	8.602	1	.003*	positive relationship
	Iron mottles	20.052	1	.000*	positive relationship
	C:f ratio	11.610	2	.003*	positive relationship

Table 6.11: Chi-square analysis of the relationships between the presence of iron pedofeatures, and void space and organics.

Row	**Column**	**Chi-square**	**df**	**Sig.**	**Relationship**
Rock	Black amorph. Organic	9.875	1	.002	negative relationship
Mottle	Black amorph. organic	19.759	1	.000	negative relationship
	Packing voids	15.813	2	.000	negative relationship
Iron nodule	Fungal spore	8.270	1	.004	negative relationship
	Lignified tissue	21.974	1	.000	negative relationship
	Parenchymatic tissue	7.111	1	.008	negative relationship
	Yellow amorph. organic	13.142	1	.000	negative relationship
	Void space	11.163	2	.004	negative relationship
	Channel voids	11.507	1	.001	positive relationship
	Packing voids	14.433	2	.001	negative relationship
Pan	Fungal spore	5.227	1	.022	negative relationship

and share relatively low pHs and sandy, free draining textures. It is in these situations that iron pans and post-burial, mineral clay coatings also form. The Milsoms Corner region is characterised by high pH, a clay rich texture, high bulk density and low void space. This site is also characterised by iron mottling in response to sub-soil gleying. The processes of formation of iron pedofeatures may differ between regions according to parent material type and the properties of the local soils. In the freely draining regions of Angus and Sigwells, down profile redistribution may be invoked to explain at least partially the preferential formation of iron pedofeatures, whilst in the poorly drained gleyic soils of Milsoms Corner more localised redistributions in response to localised redox conditions may play a larger role. The amorphous and organic iron complexes represented by the pyrophosphate extractable iron fraction have been argued to be the mobile elements involved in podzolisation processes (cf. Runia and Buurman 1987; Runia 1988). The levels of pyrophosphate extractable iron within the buried profiles of Angus and Sigwells are moderate although not exceptionally high, but in Milsoms Corner pyrophosphate extractable iron levels are very low (figure 6.2). The importance of this fraction in the redistribution of iron at Milsoms Corner, therefore, is probably minimal. The iron fraction that dominates the Milsoms Corner soils and sediments are the aged crystalline and amorphous forms extracted using citrate dithionite, a form much less abundant within the Sigwells and Angus soils (figure 6.2).

The weathering of soil minerals and bone was also recognised in thin section and has been described in section 6.2.2. The weathering processes described are chemical processes affecting soil minerals and bone fragments. Alteration of biotite and also feldspar minerals leads to the release of iron, magnesium and other cations and alteration products may include kaolinite, mica, silica and aluminium, the specific nature of which will be determined by the soil environment (Wilson, 1975). The alteration of bone is another complex series of processes, heavily influenced by the soil chemistry, particularly soil pH but which in this study are considered only in terms of the formation of calcium iron phosphate compounds that are distinctive in thin section. These processes, therefore, are strongly influenced by the prevailing chemical conditions, and in turn the severity of these processes within the burial environment may reveal more about conditions within the overburden and buried soils. The identification of these processes within each study region assumes that the materials were present within the soil prior to burial. Bone is present within the soils and overburden materials in Angus and Sanday, but not in any other of the regions. In both of these regions there are archaeological sites in which calcium iron phosphate was identified, in Sanday this was within the midden overburden material and the conditions within this material are not related to the regional parent material. The archaeological site of Fordhouse Barrow is an acid site with a mean pH of 5.4 and a relatively high percentage of void space, it is under these conditions that the features interpreted as calcium iron phosphate had formed. The calcium iron phosphates, found as coatings on void walls, were all in relatively close proximity to the bone fragments from which they originated i.e. within the same soil slide and usually less than 0.5 cm from the nearest bone. Unless bone is a component of the original soil, therefore, these post-burial features are unlikely to impinge upon the fabric of the buried soil.

The distribution of earthworms and enchytraeids is known to be affected by soil pH. Earthworms tend to be found only at higher soil pHs (above pH 4), whilst enchytraeids may also be found at much lower pHs (Dawod and FitzPatrick, 1993). Within this study, earthworms, as indicated by levels of mammilate excrement, tend to be present within the soils and sediments of Sanday and Breamish, whilst enchytraeids are present within Angus and Breamish. Enchytraeids, therefore, did tend to be frequent within the more acidic soils whilst the earthworms, which should have been restricted to the more neutral soils, are a significant presence not only within Sanday, but also within Breamish. Soil pH is a factor not only of parent material but also of environmental conditions. The textures of those soils within which excremental features are present at significant levels have moderate and low levels of sand. The regions of Somerset include only very low levels of earthworm excrement and are characterised by either very sandy or very clayey soils. Moderate textural characteristics of the parent material and soils could, therefore, be expected to encourage biological activity and increase the likelihood of the buried soil being reworked. Levels of both taxonomic families decreased within the buried soils, despite the general rise in soil pH. This would seem to suggest that after burial the conditions within the burial environment are largely non-conducive to biological activity. Of the other soil properties, bulk density tends to increase after burial and loss-on-ignition decreases, compression of the soil is known to decrease earthworm numbers (Pizl, 1992) whilst a lowering in organic levels would also make the substrate less attractive.

The decomposition of organic material is one of the most frequently recognised alteration processes in thin sections. Organic material plays a key role in soil structure formation (Chaney and Swift, 1984) and so would be an important factor in determining the resilience of a buried soil to compressive forces, and may help to prevent the break down of soil structure. Organic matter is also implicated in the post-burial movement of iron; organic pseudomorphs are present within the iron pan at Fordhouse Barrow and amorphous organics are frequently found alongside iron nodules. Iron impregnation of channel walls containing decaying root remains is also a common feature noted in thin section (Appendix 5.2, Iron pedofeature table). Besides its own alteration and its importance in supporting the soil biota, soil organic matter has also been implicated by the results presented in this chapter in the processes of clay translocation and iron redistribution, which are of primary interest to this thesis.

The processes of clay translocation and iron redistribution are, therefore, strongly related to the regional setting of the sites, the contrast between which, is their parent material type. Section 6.2.4 showed that although there were other environmental differences between the study regions, there was evidence for accepting that much of the inter-regional variation both in soil properties and the nature of post-burial change within the buried profiles is related to differences in parent material type. The correlation between post-burial features of soil micromorphology and soil properties of pH, bulk density, texture, loss-on-ignition and iron content also supports the hypothesis that parent material plays a significant role in the determination of processes of post-burial change.

6.4: A summary of the effects of parent material upon the processes of post-burial change.

The effect of parent material upon processes of post-burial change was an integral part of the conceptual model that provided the framework for sampling. Parent material was included as a burial factor, with the expectation that it would influence the development of the burial environment and the associated post-burial processes.

The results presented in this chapter support the long held view that parent material affects the properties of the soils developed upon it (Jenny, 1941), but they have also shown that parent material is an important factor in determining the response of a soil to burial. This chapter has, however, also highlighted that parent material alone cannot explain all regional variation. Table 6.12 summarises the physical and chemical properties of the burial environment, the properties of the soils and sediments and the features and processes of post-burial change within each of the study regions.

Table 6.12: Summary table of regional burial environments, soil properties and post-burial features.

Region	**Burial Environment**	**Soil Properties**	**Post-burial features / processes**
Angus (Old Red Sandstone derived till)	Low loss-on-ignition, low soil moisture, high bulk density, low pH, moderate iron levels.	Siltstone, sandstone, quartz, feldspar, horneblende, biotite, moderate c:f ratio, enchytraeid excrement, high void space, organo-mineral fine matter.	Clay translocation / clay void coatings. Iron redistribution / iron nodules, iron pans, iron pseudomorphs. Bone weathering / calcium iron phosphate.
Sanday (Old Red Sandstone derived till)	moderate loss-on-ignition, high moisture, moderate bulk density, high pH, low iron levels. Sandy clay loams and clay loams.	Siltstone, sandstone, shell, low c:f ratio, fish bone, charred organic material, diatoms, yellow and red amorphous organic, organic fine matter.	Biological reworking / excrement, Calcification and decalcification. Weathering of bone / calcium iron phosphates.
Breamish (Andesite and till)	High loss-on-ignition, high moisture, low bulk density and pH, high pyrophosphate extractable Fe. Silt loam	Andesite, feldspar, low c:f ratio, lignified and parenchymatic tissues, yellow and red amorphous organic, fungal spores, diatoms, high void space, organic fine matter.	Biological reworking/ excrements. Iron redistribution / rock impregnation.
Sigwells (very fine Lias sands and oolitic limestone)	low loss-on-ignition, moderates soil moisture, high bulk density, moderate pH, moderate iron levels. Sand and sand loams.	Ooids, muscovite, high c:f ratio, low void space, mineral and organo-mineral fine matter, charcoal.	Clay translocation / clay void coatings. Iron redistribution / iron nodules, iron pans.
Milsoms Corner (Lias clay and oolitic limestone)	moderate loss-on-ignition, moderate moisture, high bulk density, high pH, low pyrophosphate extractable iron, high dithionite extractable iron.	Ooids, muscovite, very low c:f ratio, low void space, planar voids, mineral and organo-mineral fine matter, charcoal.	Clay translocation / silty clay void coatings. Iron redistribution / iron mottles and nodules.

The nature of the burial environment is characterised by the physical and chemical soil properties, this was determined by laboratory analysis of bulk soil samples. The micromorphological characteristics identified in thin section serve to illustrate the soils physical properties, and the processes and features of post-burial change field is a summary of the micromorphological features identified as post-burial and the processes that have formed them.

As has been concluded, some of these regional differences in soil properties, burial conditions and post-burial processes can be at least in part be explained by the regional differences in soil parent material. Some properties of the burial environment and the nature of the processes of post-burial change may also be the result of age and depth of burial site factors, as hypothesised in chapter 2. The processes of clay translocation and iron redistribution, together with evidence for soil compression, biological activity, organic decomposition, weathering, decalcification and calcification will, therefore, be discussed in chapters 7 and 8 in terms of these two alternative burial factors.

7. Time since burial as a factor influencing processes of post-burial change in archaeologically buried soils.

Time since burial was the second burial factor hypothesised in chapter 2 to affect the processes of post-burial change in archaeologically buried soils. The date of burial for each of the sites studied in this thesis is given by the archaeological age of the monument / deposits that form the overburden material burying the old land surface. The site ages included in this study range from modern to Neolithic. This time span is important because different processes operate at different rates and so their expression within buried soils will only become apparent over a range of time scales. Experimental work upon processes of post-burial change in archaeologically buried soils and their overburdens has begun to be addressed at Overton Down and Wareham experimental earthworks (Bell *et al.*, 1996). These earthworks have provided vital information about the rapid and sometimes short-term changes that may operate in buried soils immediately after burial. One aim of this thesis is to address these issues of change over archaeological time scales. This chapter sets out the bulk and micromorphological results as they relate to buried soils of different 'age', and then discusses the interrelationships between the effects of age upon post-burial change and the effects of parent material that have been previously discussed in chapter 6.

7.1 Characterising buried soil profiles of different age.

The site ages that were studied spanned nearly 5000 years, a period that covers the ages of almost all soils in Britain that have been buried beneath anthropogenic structures. Earlier archaeological sites include buried soils, but these are usually beneath natural or cave sediments. The age results from the sites covered within this thesis, therefore, are applicable to almost all archaeologically buried soil sites within Britain.

Sites have been grouped in categories according to the archaeological period in which they were constructed. Analysis of age and time variables is complicated as although time can be represented over a continuous linear scale against which process rates can be measured, the effects over time are rarely so simple because of possible environmental change. Time effects, therefore, may not conform to a linear scale; this was dealt with statistically by treating time as a categorical variable.

The ages covered and the number of sites studied within each time period is shown in table 7.1. This shows the span of sites covered and the logarithmic nature of the time line with ages in the range of 1, 100 and 1000s years. Bockheim (1980) suggested that pedogenic processes operate over logarithmic timescales and so by having such a wide range of ages, it was hoped that the action of all archaeologically relevant processes would be covered. The same statistical techniques that were used to analyse the effect of region / parent material are used in this chapter to study the effect of time since burial.

Table 7.1: Age categories and the numbers of sites in each period.

Age period	**Approx. date BP**	**Sites included**
Modern	3-7	Roos Loch
Late Norse/Medieval	400-700	Seater
Iron Age	2500-1950	Woo, Wether Hill
Bronze Age	3800-2500	Fordhouse Barrow, Sigwells, CHB2, Milsoms Corner
Neolithic	6000-3800	Pool, Turf Knowe

7.1.1 Characterising the bulk physical and chemical properties of buried soil profiles of different age.

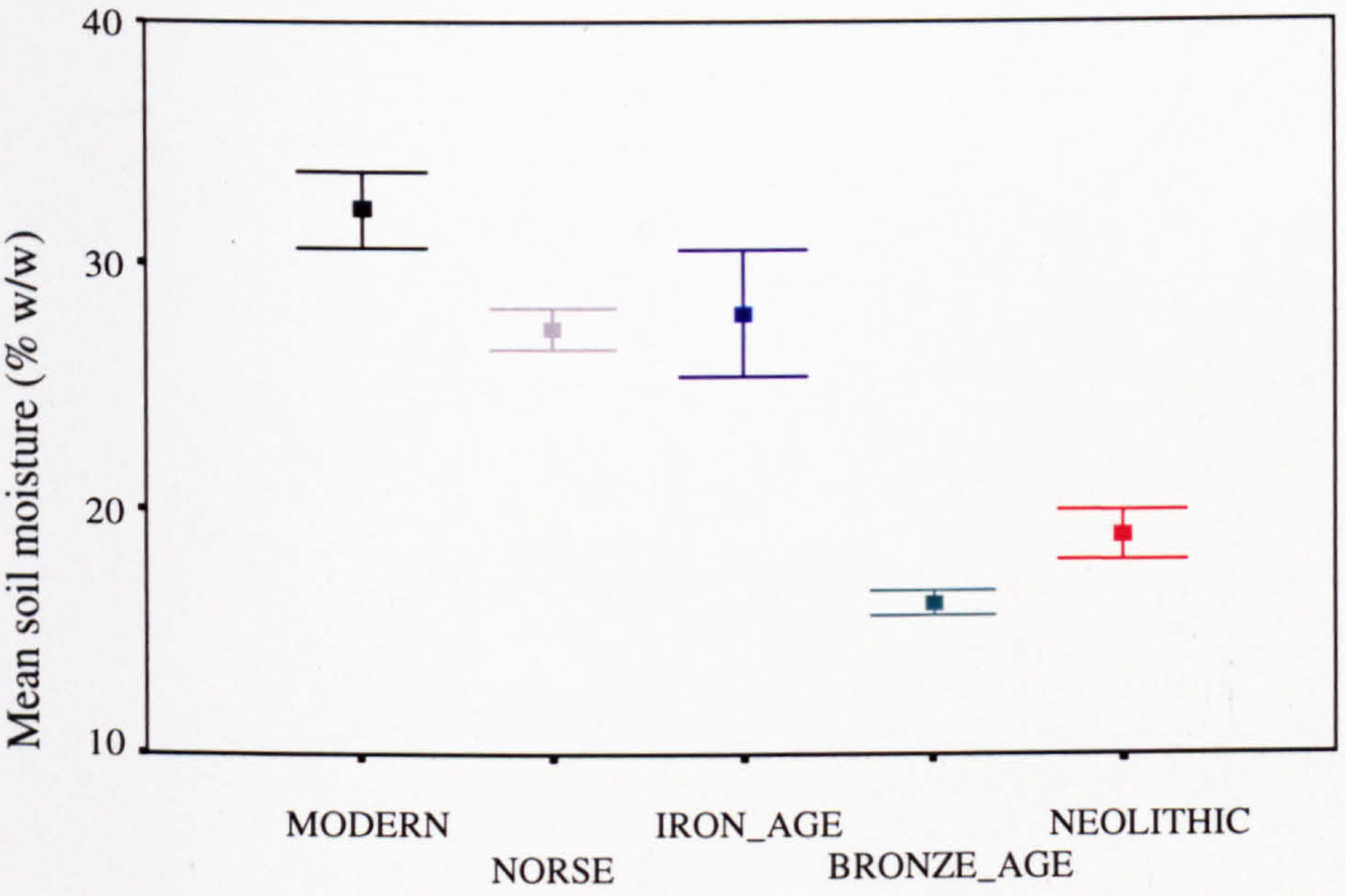
Between factor differences in the mean physical and chemical properties of each age category were evaluated using GLM repeated measures. The results for between factor (age) effects are given in table 7.2. This shows that significant differences exist in the mean values of soil moisture between the different age categories. No significant differences are recorded for bulk density, loss-on-ignition, pH, pyrophosphate extractable iron or dithionite extractable iron between age classes. The repeated measures within factor (age) effects which correspond to differences at depths from the buried soil surface will be considered later in this section and the region / age interactions will be considered in section 7.2.

Table 7.2: Between factor (age) effects upon bulk physical and chemical soil properties as determined by GLM repeated measures ANOVA.

Variable	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Within factor contrast**
BetweenFactor						
Soil moisture	3734.13	1	3734.13	63.89	.000*	
Within factor						
Soil moisture	761.96	3.57	213.32	4.39	.006*	quadratic
Soil pH	7.281	5.70	2.238	4.597	.002*	linear

The nature of the significant between age class variation in soil moisture is illustrated in figure 7.1. The mean soil moisture levels within the modern, Norse and Iron Age buried soil profiles, are significantly higher than that of the Bronze Age and Neolithic sites. The Norse sites had significantly lower soil moisture contents than the modern buried sites, and the Neolithic sites had a significantly higher soil moisture content than those dating to the Bronze Age. Overall there appears to be a trend towards decreasing soil moisture over time. Soil moisture, however, is highly variable and the results reflect hydrological conditions immediately prior to sampling. Within age variation, however, was found to be significant for both the soil moisture and soil pH properties. This shows that variation of the repeated measures (depth from buried soil surface) within each age class is significant at the 0.05 confidence level. Within the modern soils, pH tends to decrease with depth from the surface, and in all other soils tended to increase with depth. Soil moisture either peaks or troughs at the level of the buried soil.

Figure 7.1: Error bars at the 95 % confidence level around mean soil moisture values for each of the age classes.



Although only soil moisture has a significant relationship with site age, general trends appear to exist in soil pH and levels of phyrophosphate extractable iron over time. Both soil properties show a general decrease in their mean values over time (table 7.3).

Table 7.3: Mean physical and chemical properties of each age category and its standard deviation.

Soil Property	**Modern**	**Norse**	**Iron Age**	**Bronze Age**	**Neolithic**
pH	6.79 (1.10)	8.06 (1.56)	6.65 (1.10)	6.00 (.64)	6.02 (1.10)
Pyroph. extrac. iron	.385 (.134)	.233 (.134)	.209 (.095)	.130 (.060)	.232 (.095)

Between factor effects of age appear to be a less important source of variation in the bulk physical and chemical properties of buried soils than the regional effects which produce significant between regional differences for bulk density, soil moisture, pH and both pyrophosphate and dithionite extractable iron (chapter 6, section 6.1.1).

7.1.2 Characterising the micromorphology of buried soil profiles of different age.

For chi-square analysis the unburied reference profiles were removed from the data set prior to analysis so that the buried / non-buried variable was not being included within the analysis of age effects. Following the scheme adopted in chapter 6, age class properties have been analysed to characterise the thin section micromorphology of each age class. They are examined to determine what, if any, effect time since burial has had upon the presence of those features identified in chapter 5 as having formed after burial.

The influence of time since burial upon soil mineralogy and texture should be minimal since these soil properties are determined principally by parent material type. Time since burial could only affect soil mineralogy through the alteration of weathering rates and the effect of this upon the most easily weathered soil minerals. Likewise, weathering and alteration are the processes most likely to affect the features identified as anthropogenic inclusions in section 6.1.2 (shell and bone). Mineralogical and artefactual relationships with age, besides those that can be explained by these processes of alteration, suggest that regional differences are having 'knock-on' effects upon the relationship between certain soil properties and the time since burial variable. Table 7.4 outlines the characteristic micromorphology of the soils in each age class. The presence of particular mineral assemblages within each age class is indicative of some regional influence, particularly as there are no clear trends in the weatherability of the characteristic minerals with increasing age. The shell component is mostly artefactual consisting mostly of limpet shell remains within the midden overburdens of the Sanday sites. The characteristic presence of shell within

Table 7.4: Soil micromorphology characteristics of mineralogy, organic matter, pedofeatures and soil structure and organisation whose occurrence is significantly related to site age.

Age categories	**Soil features significantly related to age at 95% confidence interval**			
	Mineralogy	**Organic material**	**Pedofeatures**	Soil structure and organisation
Modern	Siltstone.	Parenchymatic tissue, Yellow and red amorphous organic, Fungal spores.	Iron coatings, Depletions, Spheroidal excrement, Rock iron impregnations	Moderate void space, Void determined microstructure, Low and moderate c:f ratio, Laminar arrangement.
Norse	Shell, Charcoal.	Black, yellow and red amorphous organic, Fungal spores.	Spheroidal excrement	Void determined microstructure, Low c:f ratio.
Iron Age	Shell, Sandstone.	Black and yellow amorphous organic, Fungal spores.	Mammilate excrement, Spheroidal excrement	High void space, C:f determined microstructure, Pedal microstructure, Low c:f ratio.
Bronze Age	Biotite, Siltstone, Charcoal.		Iron nodules and coatings, Silty and dusty clay coatings, Pre-burial and post-burial clay coatings.	Low void space, C:f determined microstructure, High c:f ratio.
Neolithic	Sandstone Siltstone.	Yellow and red amorphous organic.	Iron nodules, Depletions, Mammilate excrement, Rock iron impregnations,	Low void space, Pedal microstructure, High c:f ratio.

Norse and Iron Age sites and its relative absence from the Neolithic site, however, could be interpreted as a real age effect because shell is rapidly weathered once the pH has been sufficiently lowered. The Neolithic site of Pool in Sanday evidently contained shell at the time of its construction as the remains of heavily weathered shell fragments were identified in thin section.

The characteristic occurrence of organic fractions between the different age categories is also outlined in table 7.4. With age, decomposition effects are expected to reduce the quantity of organic material within the buried soils and to produce different fractions. The rate of decomposition and the fractions formed may be dependent upon the nature of the burial environment and the time that has elapsed. Organic content, therefore, is largely dependent upon the soil environment as influenced by parent material. The sites within each study region, therefore, will have contrasting natural levels of organic carbon at the time of burial. This will have consequent effects upon organic matter over time because of the uneven spread of ages between regions. These differences are the occurrence of parenchymatic tissues within the Modern buried soil sites and their relative absence from all older sites, characteristically high levels of black amorphous organics at Norse and Iron Age sites and relatively low levels of presence in both the younger and older buried soils. Red and yellow amorphous organic residues are found relatively frequently within all but the Bronze Age soils. Fungal spores are present within more thin sections than expected within the Modern, Norse, and Iron Age buried soils but not in the Bronze Age and Neolithic sites. The sequential occurrence of organic fractions over time is, therefore, hinted at by this data.

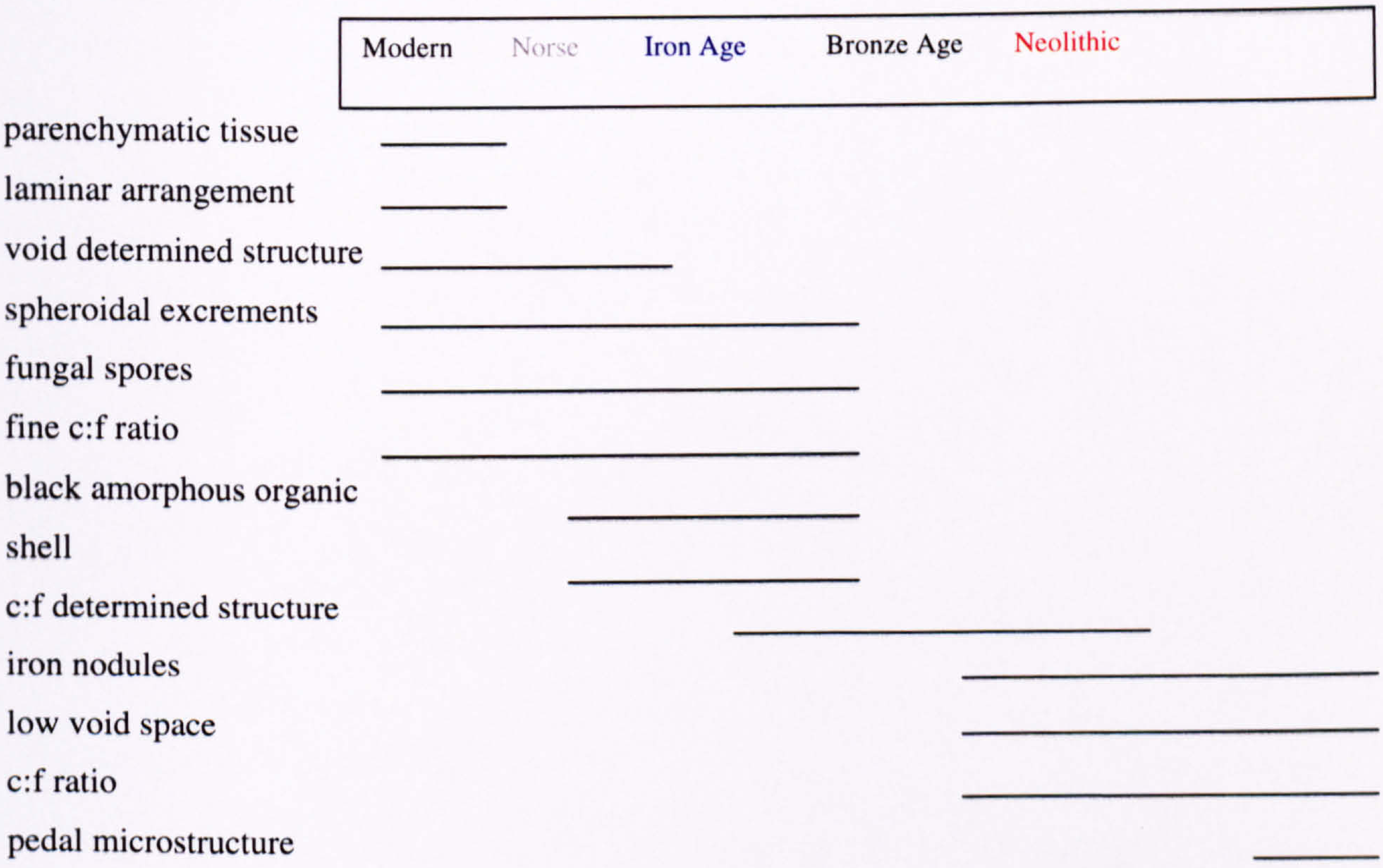
The pedofeatures identified in thin section are of interest in determining the processes of post-burial change, as discussed in chapters 1 and 6. Table 7.4 highlights the characteristic pedofeatures associated with each age class as determined by chi-square analysis. The iron pedofeatures of matrix nodules, rock impregnations, iron pans and matrix mottling are differentially present throughout the age classes. The modern buried soils include characteristically high incidences of iron coatings and rock impregnations, the Bronze Age soils include both iron nodules and iron coatings and the Neolithic soils include nodules and rock impregnations. Void coatings result from the translocation of clay and silt. In neither Modern, Norse, Iron Age, or Neolithic buried soils are these features characteristically common. Only in Bronze Age soils are they more commonly present than expected; this includes both pre- and post-burial clay void coatings with both silty and dusty textures. Excremental features are indicative of the level of activity of soil fauna; the spheroidal excrements of enchytraeids are commonest in the Modern, Norse and Iron Age soils, whilst the mammilated excrements associated with earthworms are more common in the Iron Age and Neolithic soils.

Void space tends to be high in the Iron Age soil materials, moderate in the most recently buried soils and low in the Bronze Age and Neolithic soils; no significant correlation was determined between the occurrence of any particular void type and site age. Microstructure in the modern and Norse soils tends to be dominated by void type, i.e. channel, vughy and spongy. In the Iron Age and Bronze Age soils, microstructures tend to be pellicular, bridged grain and inter-grain microaggregate, these arrangements are related to the c:f related distribution and usually occur in soils dominated by the coarse grain fraction. The Neolithic soils and sediments are characterised by the more frequent occurrence of pedal microstructures. Coarse to fine ratios, drawn at a diameter of 10μm, tend to be lower (finer) in the Modern, Norse and Iron Age soils and the coarse in the Bronze Age and Neolithic soils and sediments. A higher than expected occurrence of laminarly arranged coarse material is also represented in the modern buried soils.

Trends in the relative occurrence of all these soil features over time, however, are less clear. If there is a general increase or decrease in the observed occurrence of a particular feature over time so that a feature is associated with only relatively young or conversely relatively old buried soils, it suggests that time as a continuum is affecting the occurrence of the feature. In this scenario, the process leading to formation or destruction of a feature is operating over time, and so the occurrence of the feature will be a function of the rate of that process. These rates may be modified by environmental changes over the period of time being considered. Alternatively, however, the occurrence or absence of a particular soil feature may be strongly related to a particular age period or set of ages, which cannot logically be explained by a process rate function. The implication in such a case, is that the soil feature is either the occurrence of that feature is being explained by other factors not excluded by the research design. The latter possibility is evaluated in section 7.2 when the relative influence of region / parent material upon the relationships identified in this section is analysed.

Of the micromorphological features for which a significant chi-square relationship with age has been established, those which show an apparently logical age related pattern are spheroidal excrements, iron nodules, parenchymatic tissue, fungal spores, black amorphous organics, shell, low void space, microstructure, c:f ratios and coarse material arrangement. Figure 7.2 illustrates the nature of this relationship for each feature.

Figure 7.2: Diagram showing relative presence of soil micromorphological characteristics over time following burial.



The occurrence of parenchymatic tissues and the laminar arrangement of coarse material are related to the most recently buried soils only. Void determined microstructures (channel, vughy, and spongy) are related to modern and Norse age buried soils; spheroidal excrements, fungal spores and fine c:f ratios are found in modern, Norse and Iron Age sites. Black amorphous organics and c:f determined microstructure (single grain, bridged grain, intergrain micro-aggregate) are characteristic of Norse and Iron Age buried soils. The occurrence of iron nodules is related to Iron Age and Bronze Age sites; low void spaces and coarse c:f ratios are related to the oldest buried soils only, namely those of Bronze Age and Neolithic dates. These results, therefore, begin to indicate a particular sequence of change in the nature of buried soils over time. The inclusion of c:f ratios within this diagram, however, provides a warning that time since burial may not be the only factor important in this apparent sequence of change. The coarse to fine ratio is chiefly determined by the textural characteristics of parent and overburden materials. Although weathering of soil particulates may have an effect upon relative grain size over time, this would be envisaged as a negligible effect over the time scales involved in this study; the overall effect would also be one of fining rather than the coarsening suggested by figure 7.2. The interrelationship between soil features, time since burial and parent material are considered in section 7.2.

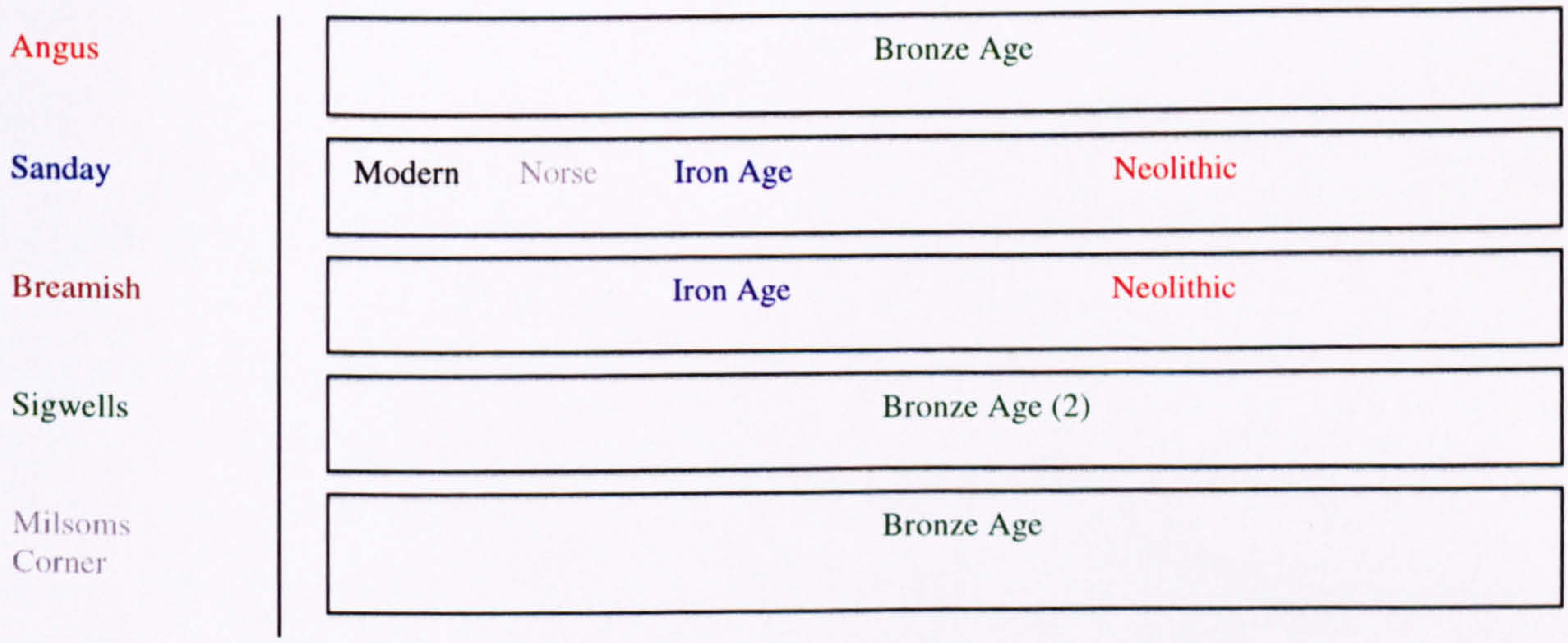
The remaining age correlated features show no relationship with the continuum of time, but are related to the buried soils and sediments of particular archaeological periods. This class of soil features includes all the clay void coatings that are related to the Bronze Age soil materials, and also the yellow and red amorphous organics that are relatively absent from the Bronze Age soils. Depletion features and impregnation of rock clasts with iron are characteristic of the modern and Neolithic soils, the relative presence of iron coatings characterised the modern and Bronze Age soils, and mammilate excrements are most commonly found within the Iron Age and Neolithic buried soils. As has been suggested these correlations may be explained either by environmental conditions particular to each age class, or they may be due to the effects of the other study variables. Section 7.2 explores the latter possibility further.

7.2 The interrelationship between the burial factors of site age and parent material.

7.2.1 Potential problems of age / parent material interdependence.

The nature of any age and parent material interrelationships and their effects upon the processes of post-burial change in archaeologically buried soils will reflect not only real interactions between these two burial factors, but also nesting effects resulting from the research design. Sites of different ages were studied within each of the study regions that were based upon contrasting parent materials. This approach allowed the widest possible range of ages, parent materials and depths of burial to be studied and so makes the results more widely applicable to other buried soil sites. However, because site choice was constrained by availability, overlap between site ages within the different regions was not always possible and this makes disentanglement of the parent material effects from those of time problematical. Figure 7.3 illustrates the spread of site ages between regions. The lack of overlap between regions of site ages and in other cases the lack of within region, age variability pose particular problems for the interpretation of sites.

Figure 7.3: Regional differences in the site ages studied.



In the former situation there is a problem with the lack of comparison for sites of certain ages, within regions of different parent material. The deficit means that the results for certain age classes are absolute site values rather than being a mean of values taken from sites across a range of contrasting parent materials. This problem affects the Modern and Norse aged sites most acutely as only a single site belongs in each category, in both cases the sites were from the island study region of Sanday. A second potential difficulty affects the Bronze Age time since burial category. This category includes four archaeologically buried soils which cover three different parent material types, however the regions in which these sites are situated, Angus and Somerset, only contain Bronze Age sites. In this case, therefore, the category is a mean of different parent materials, but within each parent material type no direct comparison between soils of different age can be drawn.

7.2.2 The relative importance of parent material and age factors in determining the nature of post-burial change in archaeologically buried soils.

The interrelationships between parent material and site ages have been examined using log-linear analysis to examine 2-way, 3-way and more complex relationships in the same manner as was used in chapter 6. General linear model ANOVAs have also been used to assess the between factor importance of age and parent material variables upon the physical and chemical properties of the soils.

7.2.2.1 The relative effects of parent material and age factors upon bulked soil physical and chemical properties.

Section 7.1.1 outlined the main correlations between age and the physical and chemical properties of the buried soils and archaeological sites. The use of GLM repeated measures not only assessed the differences between the mean soil properties of each age class, but also allowed the identification of significant trends with depth from the buried soil / overburden interface within each of the age classes. Significant between age differences were identified for soil moisture, and within region effects for soil moisture and soil pH. However, the effects of region upon the age*moisture, age*moisture*depth, and age*pH*depth are more difficult to quantify. Table 7.5 shows the GLM repeated measures ANOVA results of age / region interactions upon the properties of soil moisture and soil pH when both study variables are treated categorically as between factor subjects. This table shows how the interaction between age and region is significant between subjects for soil moisture and within subjects for soil pH. Both age and region have significant between factor effects for soil moisture as shown in tables 6.1 and 7.2, the regional effect, however, appears to have been smaller in this case than the age effects as illustrated by the relative significance levels given in these two tables. The within factor effects of the age*region interaction upon soil pH suggests that these two factors influence the pH differentially according to the depth from the buried soil surface. Individually age was shown to have a significant within region effect upon soil pH, however, no significant effect was determined for regional differences (table 6.1).

Table 7.5: Within and between region effects of Age / Region interactions upon the soil properties of pH and moisture as determined by GLM repeated measures ANOVA.

Soil property	Interaction	Mean square	F value	df	Sig.
Soil pH	Between factor Age * Region	2.482	.971	1	.397
	Within factor pH with depth * Age * Region	.223	2.645	20	.002*
Soil moisture	Between factor Age * Region	502.387	28.800	1	.000*
	Within factor Moisture with depth * Age * Region	6.770	.334	5.6	.907

7.2.2.2 The relative effects of parent material and age factors upon soil micromorphology.

So far the effect of age upon the micromorphology of buried soils has been considered by bulking together all sites of a certain age irrespective of the region in which the sites belong. Log-linear analysis allows regional influences, and the effects of parent material implied in this categorisation, to be considered alongside the age factor. The micromorphological soil features and properties that will be considered here, are those identified in section 7.1.2 as being significantly correlated with age. The aim of this section is to try and show whether these effects are likely to be due to real effects of time since burial upon the processes of post-burial change, or whether they are an artefact of the nested sampling scheme and are merely reflecting regional variation. The features that are most likely to reflect this regional effect are those which, although correlated with age, included no logical time sequence in the correlation. Not all such correlations are regional effects, however; as has been discussed environmental conditions specific to an archaeological period or periods may also result in a similar pattern. There have also been suggestions that even when an apparent time sequence exists between age and soil feature, regional influences or other environmental variables may also be implicated.

Table 7.6 presents the log-linear results for date and region relationship upon different soil organic fractions. The results presented in this table show how in all cases the distribution of organic materials is best explained by the combination of the factors of date (time since burial) and region. However, the differential importance of these two factors, as indicated by their individual contribution, varies according to the organic fraction being considered. The parenchymatic tissues, black amorphous organics and fungal spores are those organics, which upon the basis of their age correlations, fitted into the cyclical model of change. Parenchymatic tissues are present most commonly within the modern soils, fungal spores in modern, Norse and Iron Age soils and black amorphous organics within the Norse and Iron Age soils and sediments. The relative importance of date and region upon the occurrence of black amorphous organic material is equitable, with both factors contributing relatively evenly to the overall observed distribution.

Table 7.6: General log-linear analysis results comparing variation in the presence of different soil organic fractions against factors of age and region.

Model	**Chi-square**	**df**	**Sig.**
Parenchymatic tissue * age	17.17	4	.0018
Parenchymatic tissue * region	46.88	4	2. E-09
Parenchymatic * age * region	402.73	40	.0000
Black organic * age	19.94	4	.0005
Black organic * region	19.38	4	.0007
Black organic * age * region	313.95	40	.0000
Yellow organic * age	67.01	4	1. E-13
Yellow organic * region	70.27	4	2. E-14
Yellow organic * age * region	405.02	40	.0000
Red organic * age	24.89	4	5. E-05
Red organic * region	24.76	4	6. E-05
Red organic * age * region	323.13	40	.0000
Fungal spores * age	69.33	4	3. E-14
Fungal spores * region	80.05	4	2. E-16
Fungal spores * age * region	469.82	40	.0000

The distribution of parenchymatic tissues and fungal spores between the soil thin sections studied, however, is considerably more affected by regional factors than site age. The distribution of parenchymatic tissue is found to be commonest in the region of Sanday and the modern buried soils respectively. These two variables are highly inter-related because the recently buried soil studied was located upon Sanday. A predilection towards the thin walled parenchymatic tissues within relatively 'young' buried soils may be expected if they are easily decomposed, however, in this instance the age factor appears to be less important than the regional effect. The apparent cycle in soil organic fractions over time, therefore, appears to relate more to the regional influence than to site age and the rates at which post-burial processes of organic decomposition operate.

The red and yellow amorphous organic residues identified in some thin sections are commonest in sites of Modern, Norse and Neolithic, and Modern, Norse, Iron Age and Neolithic age respectively. Bronze Age soils, therefore, are relatively poor in both amorphous forms. In both cases the chi-square value for the two study factors was very similar suggesting both age and region are important in determining the occurrence of these organic fractions. Neither the Sanday or Breamish regions, with which these features are correlated, include the Bronze Age sites from which they tend to be absent. The importance of region is further suggested by the values of final relative difference, for both of the organic fractions the regional model more closely mimics the combined model than does that of age.

Table 7.7 outlines the log-linear results for the occurrence of soil pedofeatures in response to the study factors of age and region. As was discussed in chapter 6, these features are of interest to this thesis as many are the direct result of clay translocation and iron redistribution processes that have operated after burial of the original soil profile. Of these pedofeatures only the spheroidal excrements produced through the activity of enchytraeid worms, and the nodules of amorphous iron were included in the cyclical model of change given in figure 7.2. For the spheroidal excrements this is a preferred distribution within soils and sediments of Modern, Norse and Iron Age date, whilst the iron nodules tend to be present in the thin sections taken from Bronze Age and Neolithic sites. All the other features analysed were related to specific time periods only.

Again the combination of date and region produces the most significant results for all pedofeatures. In the case of both the spheroidal excrements and iron nodules, region is the more significant individual factor especially in the case of the relative distribution of the iron nodule features, the relative influence upon the excremental features is more equitable. The situation with the mammilated earthworm excrements is the reverse of that for the spheroidal units, as although both study factors are strongly related to their occurrence, it is the time since burial factor that appears to be exerting the greatest influence. The remaining iron pedofeatures include iron coatings and the impregnation of rock clasts with iron. In both cases, the regional influence is more important than that of age, perhaps helping to explain their erratic relationship with site age. The relative regional influence upon these iron features appears to be greater than upon the iron nodules. Depletion pedofeatures include both iron and clay, and again the results suggest that it is the regional influence that is most significant.

Table 7.7: General log-linear analysis results comparing variation in the presence of different soil pedofeatures against factors of age and region.

Model	**Chi-square**	**df**	**Sig.**
Pre-burial cutan * age	46.36	4	2. E-09
Pre-burial cutan * region	50.16	4	3. E-10
Pre-burial cutan * age * region	369.16	40	.0000
Post-burial cutan * age	161.93	4	.0000
Post-burial cutan * region	159.75	4	.0000
Post-burial cutan * age * region	603.57	40	.0000
Mammilate excrement * age	100.99	4	.0000
Mammilate excrement * region	91.55	4	.0000
Mammilate * age * region	465.08	40	.0000
Spheroidal excrement * age	49.56	4	4. E-10
Spheroidal excrement * region	69.82	4	2. E-14
Spheroidal * age * region	464.32	40	.0000
Iron nodule * age	22.27	4	.0002
Iron nodule * region	25.47	4	4. E-05
Iron nodule * age * region	309.46	40	.0000
Iron coating * age	13.84	4	.0095
Iron coating * region	56.05	4	2. E-11
Iron coating * age * region	380.56	40	.0000
Fe rock impregnation * age	14.92	4	.0049
Fe rock impregnation * region	34.01	4	7. E-07
Rock impregnation * age * region	349.07	40	.0000
Depletion * age	12.41	4	.0146
Depletion * region	67.05	4	1. E-13
Depletion * age * region	423.13	40	.0000

The void coatings are related to periods of clay translocation prior to and following site construction and the burial of the old land surface. Both the pre- and post-burial cutans correlate strongly with the Bronze Age sites, as well as with the regions of Angus and Somerset. It is the relative influence of age that correlates most strongly with the post-burial cutans suggesting that within the Bronze Age the environmental, anthropogenic, and / or constructional activities were at their most conducive to the formation of clay coatings around voids. The secondary importance of region upon post-burial cutans, however, is illustrated by the relatively equitable results. The distribution of the pre-burial cutans, however, is apparently more heavily influenced by regional factors. Post-burial cutans are found within all the sites from Angus and Somerset and also from the single Norse site of Seater, Sanday. All sites within the Angus and Somerset regions are Bronze Age in date, suggesting that this is the dominant factor especially as post-burial cutans were found throughout the Somerset region irrespective of parent material differences. However, two distinctly different types of post-burial cutan have been identified. Those in Seater and the heavy clay site in Somerset are brown, silty cutans, rich in organics and are interpreted here as the result of post-constructional agriculture, whereas those in Angus and the sandier Somerset sites are mostly mineral and vary between limpid and silty textures. Both the Angus and Somerset sites have lighter sandier textures suggesting that regional differences in parent material in combination with site age, specifically Bronze Age, appear to be determining cutan distribution. These textural differences may account for the regional predilection in the distribution of pre-burial cutans, along with other natural factors of soil development and anthropogenic activities of agriculture and clearance that are in some way specific to the Bronze Age and earlier soils.

The regional and temporal influences upon soil structure and organisation are given in table 7.8. Void space, coarse to fine ratios and the arrangement of coarse materials are all found to significantly correlate with age (table 7.4). Lower void spaces tend to be associated with the older Bronze Age and Neolithic sites as are coarser soil textures, indicated by c:f ratios. Within the modern recently buried soil there is also a tendency for laminar soil arrangements. In some cases this laminar arrangement is associated with peri-glacial activity within the sub-soil (section 5.2.1), however, within the surface horizons of the buried soil a weak laminar arrangement was also observed in association with a reduction in horizon thickness. Log-linear analysis of the coarse

Table 7.8: General log-linear analysis results comparing variations in soil structure and organisation against factors of age and region.

Model	**Chi-square**	**Df**	**Sig.**
Void space * age	17.93	8	.0217
Void space * region	35.44	8	2. E-05
Void space * age * region	345.38	64	.0000
C:f ratio * age	32.61	8	7. E-05
C:f ratio * region	70.70	8	4. E-12
C:f ratio * age * region	505.95	64	.0000
Coarse arrangement * age	68.52	4	5. E-14
Coarse arrangement * region	28.26	4	1. E-05
Coarse arrangement * age * region	401.52	40	.0000

Table 7.9: General log-linear analysis results comparing variations in soil mineralogy against factors of age and region.

Model	**Chi-square**	**Df**	**Sig.**
Shell * age	113.19	4	.0000
Shell * region	67.18	4	9. E-14
Shell * age * region	557.56	40	.0000
Biotite * age	43.08	4	1. E-08
Biotite * region	99.13	4	.0000
Biotite * age * region	508.27	40	.0000
Siltstone * age	52.37	4	1. E-10
Siltstone * region	88.28	4	.0000
Siltstone * age * region	545.05	40	.0000

material arrangement suggests that site age is a more important factor in the nature of arrangements than is region. The results given in table 7.8 suggest that in all other cases of structural * age correlation, the regional influence is more important to the occurrence of these soil properties than is the time factor. This is supported by the inclusion of the coarse to fine ratio, which is more readily explained by parent material type than site age.

The results in table 7.9 explain the relative effects of date and region upon soil mineralogy. Age correlations are identified for shell, biotite and siltstone, with the shell fragments apparently most frequent within the Norse, and Iron Age sites. Shell is readily degradable and may be related to the age of site, however, the differential presence of siltstone and to a lesser extent the more easily weathered biotite could only be related to differences in parent material. This is borne out by the results of the loglinear analysis which show how region has the strongest influence upon the occurrence of biotite and siltstone, whilst the distribution of shell, although entirely restricted to the Sanday sampling region is more strongly affected by the effects of time. Within the region of Sanday, shell is absent from the modern and Neolithic buried soils. The modern buried soil is the only non-midden Sanday site and this explains the lack of shell at this site. Its absence from the Neolithic site (Pool) however, is more likely to result from degradation processes as rare decalcified fragments were identified.

7.2.3 The relative importance of parent material and age in determining processes of post-burial change.

The previous section (section 7.2.2) described and assessed the relative effects of the age / parent material interaction upon the physical, chemical and micromorphological properties of the buried soils and their archaeological overburdens. Comparison of these effects with those recorded between the soil properties and the study factors of age and parent material taken in isolation, have been used to elucidate the relative importance of the two variables upon features associated with processes of post-burial change in these archaeologically buried soils.

In all cases it was the combination of date and region that best accounted for the distribution of the micromorphological soil features between the thin sections. However, the relative effect of the component factors of age and region (parent material) varied according to the feature being considered (table 7.10). Those features and soil properties for which age (time since burial) was the more significant factor were shell, post-burial void coatings, mammilate excrements and amorphous black organics; in all cases region was also a significant factor. For the red and yellow amorphous organic fractions, region and date appear to carry almost equal significance, whilst for all of the other age related micromorphological features region was in fact the more important factor, again the age factor was still a significant factor in most cases.

The relative influence of age and region upon soil moisture and pH was shown to differ between these two properties. Soil moisture and soil pH were found to be significantly correlated with site age using GLM repeated measures, for soil moisture both significant between factor (age class) and within factor (depth from buried soil surface) effects were determined; for soil pH only within factor effects were identified. The inclusion of region in the model, in which age and region were taken as equal factors, suggested that for soil pH the within region effects were little affected. Age therefore appears to have been the dominant within factor influence upon soil pH. The between factor effects upon soil moisture were still significant upon inclusion of region, therefore both region and age appear to have significant between factor effects. The within factor effects were insignificant once region was included suggesting that age alone determines the within factor trends in soil moisture. Between factor effects for soil pH are determined by region, but within factor age is more important.

Table 7.10: The relative importance of region and age factors upon the soil micromorphology of archaeologically buried soils.

Region dominated	**Age dominated**
Pre-burial clay void coatings	Post-burial clay void coatings
Iron nodules	Amorphous black organic material
Iron coatings	Mammilate excrements
Iron rock impregnations	Shell
Spheroidal excrements	Coarse material arrangement
Parenchymatic tissue	
Biotite	
Siltstone	
Void space	
Coarse : fine ratio (μm)	
Microstructure	

Overall, region appears to be the main determinant factor in determining the micromorphology, and chemical and physical properties of soils buried beneath archaeological sites. Site age, however, is in almost all cases an important secondary factor, whilst the occurrence of post-burial cutans, black amorphous organics, mammilate excrements, shell and the arrangement of coarse materials are more strongly influenced by age than region. The physical and chemical soil properties are all correlated with region, and with the exception of soil moisture no significant age effects were determined between the age classes. However, within each age class, age appears to have been significantly affecting the trends in soil pH and soil moisture with depth from the buried soil surface.

7.3 A discussion of the effect of site 'age' upon processes of post-burial change in archaeologically buried soils.

Site age was hypothesised in chapter 2 to be a key variable in the burial environment that influences the nature and effects of processes of post-burial change operating in archaeologically buried soils. The sampling framework was designed to include the study of buried soils of different ages so that the importance of the age variable could be assessed (chapter 2). In section 7.1 significant differences and trends in the physical, chemical and micromorphological properties of the buried soils and archaeological overburdens were identified. Section 7.2 has attempted to apply general log-linear analysis to determine which of the two study variables (region / parent material and time since burial) account for the greatest influence upon the differences in the micromorphology of buried soils of different age. The regional soil differences identified in chapter 6, have also been reassessed in the light of the age variable. This section will consider these trends through time in regard to the physical, chemical and biological processes of change that have been identified in these buried soils. Particular attention will be paid to the post-burial processes of clay translocation and iron redistribution and the clay coatings and amorphous iron features they produce.

7.3.1 The effect of time since burial upon physical processes of change.

The physical processes of post-burial change identified in chapter 6 (section 6.2.1) included the processes of clay translocation, soil compression and alterations to the structure and microstructure of the buried soil. Of particular interest were the processes and features involved in the post-burial translocation of clays and fine silts. In chapter 6 the post-burial cutans around channel, vugh and packing voids were found to be strongly associated with archaeological sites and buried soils within the study regions of Angus and Somerset. All sites studied in these regions include cutans interpreted as post-dating site construction. Small numbers of post-burial cutans were also recorded from the Norse site of Seater in Sanday. Further analysis of these features has revealed a second correlation between their occurrence and soils and sediments dated to the Bronze Age. A similar pattern was found for the clay void coatings interpreted as being inherited, pre-burial features. Log-linear analysis confirmed the importance of age, in conjunction with region, as major influencing factors upon the distribution of both pre- and post-burial void cutan features.

Soil features and properties that may indicate the effects of compression are bulk density, void space, structure and microstructure and the arrangement of coarse materials. No correlation between bulk density and site age was found. Void space and microstructure do correlate with age, but log-linear analysis has shown that regional factors are far more important to these structural characteristics. However, the arrangement of coarse materials in thin section does appear to correlate strongly with age, an effect seemingly confirmed by log-linear analysis. Laminar arrangements are commoner than expected within the very modern buried soil. Whilst some of these arrangements were interpreted as the result of peri-glacial processes that had affected the drift parent material, laminations are also present within the top of the buried soil and these appeared to be the result of compressive forces. The 'modern' age category contained only a single site, which was from the Sanday study region. A laminar arrangement of the coarse organic fractions in the base of the middens from the older sites within the Sanday region was also identified. However, each of the older age categories include a second site from the other study regions. The bias of laminar arrangements within the youngest sites, therefore, may still be an artefact of the sampling scheme and the importance of region upon the occurrence of laminar arrangements may be more important than otherwise indicated.

In chapter 6 correlations were identified between clay cutans and moderate-high c:f ratios, iron nodules, and low incidences of excremental features, organic fractions and fungal spores. This suggests that clay translocation was tending to occur in soils with relatively sandy textures, low organic contents, low levels of fungal and earthworm activity and in which processes of iron redistribution have also been occurring. The source, transportation and deposition of clay appeared in these soils not to be limiting factors, and it was suggested that the release of clay from the soil structure following site construction was the main determinant in the onset of clay translocation. The low organic levels (indicated in thin section and loss-on-ignition), the relative absence of fungal spores, and the moderate to coarse textures of the soils in which clay cutans were found were all identified as possible causes of low ped strength. Weak soil structures could be more easily degraded with the result that clay micelles would be released into suspension in the soil water. This chapter has suggested that besides structural strength as determined by parent material type, clay translocation is also mediated by conditions specific to the Bronze Age sites. This Bronze Age factor would have to influence the formation of both the yellow mineral, and the brown organic type post-burial cutans.

Factors that may influence clay translocation, other than localised soil properties, are climate and humans. It is for this reason that the presence of clay cutans in buried soils is so important to archaeological and environmental reconstruction. Humans may initiate processes of clay translocation through disturbance of the soil surface, for example through tillage or clearance (table 1.1). The brown organic-rich clay void coatings from the Bronze Age site of Milsoms Corner, and also the Norse site of Seater, are interpreted here as the result of post-constructional tillage at the raised ground surface. Dating these disturbance episodes is not possible as tillage may have occurred any time between construction / deposition of the archaeological site and excavation in 1997. Hence, relating the formation of these disturbance features with specific agricultural changes associated with the period of construction is not possible.

Climate and in particular rainfall, however, also affect clay translocation under both disturbed and non-disturbed surface conditions. Rain splash upon the surface of the soil causes the break down of soil aggregates (slaking), releasing clay and resulting in the formation of clay coatings around the void walls. Lessivage is the process of clay translocation under wooded vegetation that resulted in the formation of limpid clay cutans (Fisher, 1982) within the lower soil horizons that have been identified at Fordhouse Barrow, all three Somerset sites, Roo's Loch, Turf Knowe and Wether Hill. These cutans formed under 'natural' undisturbed conditions and are thought to have developed during the Atlantic 'climatic optimum', a period of warm, wet conditions dating from ca. 7500 – 4500 BP (Macphail, 1986). Figure 7.7 illustrates the classic Holocene climatic sequence. This shows how following the Atlantic optimum and the period of lessivage, there was a period of warm, dry weather (sub-Boreal) lasting until the Late Bronze Age (ca. 2500BP). During most of the Bronze Age, therefore, rainfall was relatively low. During the Late Bronze Age, however, there was a climatic

Figure 7.4: Diagram of the classic scheme of Holocene climatic trends across north-west Europe

Period	Climate	Pedogenesis	Archaeology
Sub-Atlantic	Cool, wet oceanic	Hydromorphism	Medieval Saxon Romano-British Iron Age
2500			
Sub-Boreal	Warm, dry	Podzolisation	Bronze Age Neolithic
4500			
Atlantic	Warm, wet 'climatic optimium'	Lessivage	Mesolithic
7500			
Boreal	Relatively warm, dry	Decalcification	
9000			
Pre-Boreal	Sub-Arctic	Raw soils	Upper Paleolithic

Taken from Macphail (1986) p. 265.

deterioration that heralded the start of the cool, wet, oceanic conditions that characterise the Sub-Atlantic period. This increased wetness could be related to the increased formation of post-burial cutans in sites constructed during the Bronze Age. If these sites remained relatively sparsely vegetated for any length of time, the increased rainfall would have acted directly upon the exposed surface of the monument. Similarly, if the surface had later been disturbed by agricultural activity, the higher level of rainfall would increase the likelihood of surface slaking when the soil is exposed. However, no such increase in the incidence of post-burial cutans has been observed within the soils and sediments of the Iron Age sites that should also have been subjected to the effects of an oceanic climate. A second climatic down turn was associated with the onset of the Little Ice Age. This wetter period also corresponds with the date of the only non-Bronze Age site (Norse) within which post-burial cutans were identified. Increased wetness, therefore, may be a factor in the onset of clay translocation processes, but the lack of evidence of clay movement from the Iron Age sites suggests that this is not the only influencing factor. Other possible factors that may influence clay translocation and other post-burial processes are constructional, i.e. the way in which the sites are built, the nature of the material that they are built of, and the depth to which burial occurs. These factors of burial may also vary according to site age. Are the Bronze Age sites constructed in a manner different to that of the sites from the other archaeological periods, and if so could this explain the tendency for post-burial clay cutans to form around the voids in Bronze Age sites. Chapter 8 will evaluate the effects of burial depth and overburden type upon processes of post-burial change.

7.3.2 The effect of time since burial upon chemical processes of post-burial change.

The chemical processes of post-burial change that were identified in chapter 6 (section 6.2.2) included the redistribution of iron, the calcification and / or decalcification of the soil materials, and processes of ongoing mineral weathering. The soil property of pH, and micromorphology features of bone, calcium iron phosphates and biotite weathering have been found not to be significantly related to site age. These properties have been discussed in chapter 6 as evidence of calcification / decalcification and mineral weathering. Iron pedofeatures and shell, however, are correlated with site age, and so processes of iron redistribution and decalcification may still be considered. Site age appears not to be significantly related to the severity of mineral weathering in the soils and sediments analysed in this thesis.

In chapter 6 processes of iron redistribution were discussed in relation to regional parent material characteristics and burial. The presence of iron pans, nodules and matrix mottling all appear to relate to region, namely parent material type. Iron pans and the mottling that results from gleyic processes have been found not to relate to site age in this study. The presence of iron nodules and iron coatings, however, are correlated with site age (table 7.4), although log-linear analysis has shown that these correlations are heavily influenced by regional factors. Iron coatings tend to be found in the modern and the Iron Age sites, iron nodule features correlate most strongly with the Bronze Age and Neolithic sites. The preferential distribution of iron coatings in the very youngest and oldest buried soils suggest that time is not the key factor in this relationship and this was supported by log-linear analysis (table 7.12), which shows that region was a much more significant factor in determining this distribution pattern. Region is also an important factor in the iron nodule distribution, but age has also been shown to be a significant factor. The Bronze Age and Neolithic buried soils in which iron nodules tend to occur have lower soil moisture values, relatively coarse textures, and a greater incidence of low percentage void space. There may also be a relationship between iron nodules and low levels of pyrophosphate extractable iron. Iron nodules themselves correlate with low void space and an absence of organic materials (table 6.20), and so the nature of the overburden material and the site construction may also be important factors in determining their formation. These factors are discussed in chapter 8.

Calcification and decalcification of buried soils were also examined in chapter 6. A general rise in pH with burial was recognised within each region and particularly within the region of Sanday and this apparent calcification was interpreted as the influence of the calcareous rich midden materials that form the overburdens on the archaeological sites studied from this region. Additional salt spray effects are also suggested to explain the raised pH. Calcification and decalcification post-burial processes have been identified by analysis of the experimental site at Overton Down.

Calcification of the buried soil at Overton Down had occurred within a relatively short time period, the 32 years of the experimental study. Over a longer period of time, decalcification of the buried soil was expected to occur (Crowther *et al.*, 1996). Calcification and decalcification of the archaeological overburden material and the buried soil, therefore, would be expected to correlate with time since burial. The only calcareous material that is correlated with age in this study is the relative presence or absence of shell fragments. Shell is a consistent component of the midden type overburden materials, and is found with greater than expected frequency in the Norse and Iron Age sites on the island study region of Sanday. The modern buried site on the island has a non-midden, mineral-based overburden of which shell forms no part. The oldest Neolithic site from this region includes only very rare shell fragments, and these show evidence of intense decalcification. The time scale of decalcification here is much slower than that indicated by the work at Overton Down. Mean pH within the midden overburdens of Sanday is between 6.8 and 8.1. At these alkaline pHs decalcification would be slow and the shell component itself would be capable of buffering the sediments against increasing acidity. Decalcification of the overburden at these sites, therefore, does appear to be progressing, but at a relatively slow rate and the general decline in mean pH over time (table 7.3) seems to confirm this.

The alteration of feldspar minerals over time has been the subject of many studies (Boubaid *et al.* 1995; Ferrari and Magaldi, 1975; Read 1998; Read *et a*l. 1996). The degree of micropitting has been used as a means of visually estimating the severity of alteration and a similar system was applied to the feldspar and mica mineral components in this thesis. In this study, however, no relationship between the degree of weathering and time since burial has been established for either feldspar or mica. The rates of weathering of these minerals may be affected by soil conditions, but generally rates have been established in the order of thousands of years (Hodson *et al.*, 1998). At these rates, particularly in a buried soil isolated, or semi-isolated, from surface processes, the effects of chemical weathering processes may not be identifiable over the time scales involved in this study.

7.3.3 The effect of time since burial upon biological processes of post-burial change.

The biological processes of post-burial change identified in chapter 6 (section 6.2.3) included faunal reworking, the decomposition of organic matter and root penetration. None of these processes were specifically focused upon in this study, however, the basic micromorphological descriptions and the supporting chemical data of loss-on-ignition and pyrophosphate extractable iron allow these biological processes to be briefly considered. The nature of the soil biota and their level of activity following burial may also be important in understanding the nature of the burial environment and add to the understanding of the chemical and physical processes that have already been considered.

The chemical soil properties of loss-on-ignition and pyrophosphate extractable iron have no significant relationship with site age (table 7.2 and 7.3). Excremental pedofeatures (spheroidal and mammilate), parenchymatic tissues, fungal spores and black, yellow and red amorphous organic residues are all, however, correlated with the site age variable.

In the youngest soils are parenchymatic tissues, fungal spores, spheroidal excrements and red and yellow amorphous organics. Parenchymatic tissues then tend to disappear from the older soils and black amorphous organics also appear with greater frequency in the Norse and Iron Age sites. The Bronze Age sites tend not to contain these degradable organic fractions or excremental features, whilst in the Neolithic soils the red and yellow amorphous organic fractions are again present with greater frequency. The mammilated excrements of earthworms tend to be found in the Iron Age and Neolithic sites. The validity of this apparent cycle of change in organic materials was considered in section 7.2. The relative influence of the study variables of region and time since burial was investigated using log-linear analysis and showed how region is the main influence upon the relative distribution of spheroidal excrements and parenchymatic tissue, with age taking a secondary role. The distribution of black amorphous organic material and mammilate excrement is more strongly related to factors of site age than region whilst red and yellow amorphous organics and fungal spores appear to be affected relatively equally by site age and region. The apparent cycle of organic decomposition and alteration appears to largely be a factor of differences in the ages of study sites contained within the study regions. Some processes, however, do appear to be related to factors of site age; these are those of earthworm activity, the formation and decomposition of black amorphous organics, and to a lesser extent the remaining yellow and red amorphous organic fractions, and the level of fungal activity.

This study has found that the excrements of earthworms tend to be present in the older Iron Age and Neolithic sites. This suggests that following burial earthworm numbers decrease and that the population takes a long time to recover. Earthworm numbers are known to be adversely affected by soil compaction (Pizl, 1992; Rushton, 1986), but no real trend of increasing bulk density with age was identified in this study (table 7.2), although the Neolithic soils were relatively high (0.87 g/cm^3). The highest bulk densities were recorded from the Bronze Age soils (1.17 g/cm^3) which also have very low levels of earthworm excrement suggesting that bulk density may affect the re-establishment of the earthworm population. The Bronze Age sites also include only very low organic levels (LOI 2.3%) and the relatively rare presence of any coarse organic fraction; this may also make these sites less attractive to the soil fauna. Conversely fungal spores tend to be found in the youngest sites (modern – Iron Age). Fungal numbers are also known to be adversely affected by mound construction (Harris *et al.*, 1989) and so might have been expected to be absent from the youngest soils at least. Whether the fungal spores relate to fungal organisms that have either survived burial or rapidly recolonised the soils, or whether they are inherited features from pre-burial fungal activity and are degraded over time is not clear. Fungi are known to be involved in the processes of humification that lead to the formation of amorphous black organic material. The black organic materials are correlated with Norse and Iron Age soils and with an apparent lag period in the youngest soils are found in soils of the same ages as the fungal spores.

7.3.4 A brief discussion of the nature of the time since burial variable and its effects upon processes of post-burial change.

The time since burial variable was originally included within the study design to allow analysis of the rates over which different processes of post-burial change proceed. Section 7.1 has revealed certain trends in these processes of change over and between sites of increasing age. These trends may be the result of process rates and duration, and the resistance of certain soil features to change as suggested by Yaalon (1971). Other processes, however, appear to have been related to particular periods in time over the last 5000 years. Most interesting of these are the processes of post-burial clay translocation. The void cutans that result from the translocation of clay and silt have been shown to strongly correlate with archaeological sites dating to the Bronze Age. The time since burial variable, therefore, appears to be identifying two separate effects.

The first of these effects results from the operation of different post-burial processes at different rates. In this scenario, time is a continuum against which these processes are operating and which allows their rates to be measured. Those post-burial processes whose resultant soil features have been identified as related to time since burial are earthworm activity, bringing with it the possibility of biological reworking of buried soils, decomposition of organic materials, and decalcification of shell fragments. The formation of black amorphous organic materials appears to occur over time scales of tens to hundreds of years and these persist with greater than expected frequencies for up to a few thousand years. The relative presence of fungal spores appears to be similar, with a tendency to be found in soils dating from the most recent to the Iron Age. Shell fragments have been found to persist at high frequencies in middens dating to the Iron Age, but have been largely decalcified within the older Neolithic sediments. In the Sanday midden environment, therefore, shell degradation upon the basis of this study, appears to take between 3000 and 5000 years. Similarly, the significant appearance of earthworm excrements in the buried sites included in this study seems to have taken some 1000-2000 years. Does this figure relate to the rate of recolonisation or are depth of burial factors also important in this relationship?

The second effect of the time since burial variable is the specific 'age' correlation between a soil feature or process, and buried soils of a specific age. The features and processes included in this classification are the presence of post-burial cutans, and possibly iron nodules. Not all of these processes are post-burial as the formation of pre-burial clay void coatings also appears to be related to soils dating to the Bronze Age. These specific age relationships cannot be explained by the differential rates at which these processes act and instead are most likely to result from specific environmental and / or anthropogenic conditions that persist within, and are specific to, each age period. Bronze Age soils correlate significantly both with the presence of post-burial clay cutans and also iron nodules. It has been suggested (section 7.3.1) that the correlation between post-burial cutans and Bronze Age sites may be related to the climatic deterioration experienced in the Late Bronze Age although all four Bronze Age sites studied in this thesis are Early Bronze Age in date. The possibility of constructional differences in the Bronze Age that may also explain this relationship is discussed in chapter 8.

7.4 Summary of the effect of time since burial upon the processes of post-burial change upon archaeologically buried soils.

The inclusion of time since burial within the sampling framework was designed to allow the identification of as wide a range as possible of post-burial processes that may be operating in archaeologically buried soils. Correlations between soil features and the processes that formed them, and buried soils of a specific age were made using chi-square and log-linear analysis. In this way, soil features and processes that had a strong tendency to occur only in buried soils and monuments of a particular age were identified.

It has long been recognised that different processes operate over different time scales, and that certain soil features adjust more slowly than others to change as a result of these differential rate factors (Yaalon, 1971). The features that correlated with a logical sequence of site ages were assumed to be affected, at least in part, by rate factors of change. The results presented in this chapter suggest that over time certain soil properties alter in a cyclical manner. The exact nature of this change will be related to local soil properties such as its chemical and physical characteristics determined by parent material characteristics. The results that have been presented suggest that some of these changes may be predictable given a stable environment. In the soils studied in this thesis fungal activity appears to be high following burial and persists for 1000-2000 years. Black amorphous organic material formed within tens to hundreds of years and then persisted for a similar period to the fungal spores. Shell survived in the soils for a period of thousands of years, but had been decalcified after a period of some 4000 years. Earthworms appear to take between 2000 and 3000 years to significantly recolonise the soils studied in this thesis, but this is almost certainly an effect of depth or environment rather than age. Rates of recolonisation by earthworms in quarry soil stores are much more rapid except at depth (Harris, pers. comm.).

The second conclusion that can be made concerns change in the environmental and anthropogenic factors that cause deviation from the assumption of a stable environment over time. Soil features that were found to correlate only with single, or non-consecutive age periods were assumed to fall into this category or to have been affected by sampling, nesting effects. The Bronze Age appears to have included factors that actively encourage the formation of clay void coatings and iron nodules after burial. These factors may be climatic as has been discussed, or they may be anthropogenic. For example, if constructional practices affect the processes of post-burial change that may operate in these archaeologically buried soils, then the features and processes associated with the Bronze Age sites may be related to the constructional practices of that time. The relative importance of overburden type and depth of burial upon processes of post-burial change is considered in chapter 8.

8. Depth of burial as a factor in determining processes of post-burial change in archaeologically buried soils.

In chapters 6 and 7, the relationship between features associated with processes of post-burial change and factors of parent material and age have been explored. In this chapter the effects of depth of burial upon the post-burial change of archaeologically buried soils will be examined. Following the scheme employed in these two preceding chapters, profiles have been categorised for analysis according to their depth of burial. In this chapter the results of the image analysis investigation of the Fordhouse Barrow site and particle size distributions from the Angus and Somerset based sites are also presented as these were carried out at the profile level with depth of burial the main contrasting factor. The nature of the overburden material and its possible effects upon processes of post-burial change are also briefly discussed, and the relative influence of the three key burial factors upon processes of post-burial change is assessed using best-fit log-linear models and multi-factorial cross tabulations.

8.1 Effects of burial depth upon processes of post-burial change.

Depth classifications for chi-square and GLM analyses are made at the 'profile' level. The category boundaries were determined by chi-square analysis, and the requirement for 85% or more of expected cell values to be >5. Burial depths are grouped so as to achieve this and validate the chi-square tests; the optimum groupings were found through iterative trial and error. The chosen categories and their profile membership are given in table 8.1. The division of sites and profiles between the depth of burial categories results in differential clustering of region and age factors in each depth category. The soils of the Breamish region are clustered within the 0 and 50cm depth of burial categories. Sigwells soils cluster within the 0 and 125cm categories, and Milsoms Corner soils cluster within the 0 and 50cm groups. The soils of Sanday and Fordhouse Barrow are included within a wider range of burial depths and provide a more even span of parent material types across the depth categories. Norse soils are limited to the 50cm depth group, Iron Age soils are found in the 50 and 125cm groups and Neolithic soils are found within the 50 and 250 depth of burial groupings.

Table 8.1: Depth of burial categories and their profile membership.

Depth categories	**Range of burial depths (cm)**	**Category membership**
0	0-5	Fordhouse reference, Gallows Hill, Plantation Camp, Slait farm, Little Weston Farm, Roo's Loch profile 3.
50	6-85	Roo's Loch Profile 2, Seater Profile 1, Seater Profile 3, Wether Hill Profile 1, Wether Hill Profile 2, Wether Hill Profile 3, Turf Knowe, Profile 1, Turf Knowe Profile 2, Milsoms Corner, Profile 1, Milsoms Corner Profile 2.
125	86-180	Fordhouse Barrow Profile 3, Roo's Loch Profile 1, Woo Profile 1, Woo Profile 2, Sigwells, CHB2 Profile 1, CHB2 Profile 2.
250	181-400	Pool profile 1, Pool profile 2, Fordhouse Barrow Profile 1, Fordhouse Barrow Profile 2.

Whilst the distribution of parent materials and site ages between the depth categories is not ideal, category boundaries were constrained by the necessity to maintain the validity of the chi-square tests. The resultant groupings represent the best possible compromise. The work of Abdul-Kareem and McRae (1984) on the depth of burial required for an anaerobic zone to develop in modern soil stores concluded that soil texture was a crucial determinant. In clay soils anaerobism is encountered at depths of ca. 0.3m, in loamy soils at depths of 1.3m, and in light sandy textured soils anaerobism does not establish until depths below 2m. The depth of burial categories outlined in table 8.1 should separate between the depths at which anaerobism has been shown to form in contrasting textured soils.

8.1.1 Mean chemical and physical properties of soils buried beneath different depths of material.

GLM repeated measures for chemical and physical soil properties with depth of burial produces no significant between factor results at the 95% confidence interval; moisture is significant at the 90% level. Significant within factor effects are present for soil pH (table 8.2). Within the buried profiles soil pH changes in a linear manner (figure 8.1) with a tendency for pH to increase down profile in shallowly buried profiles (50cm) and decrease with depth in deeper buried profiles (125cm and 250cm). Mean soil property values and 95% confidence intervals for each depth class are given in figure 8.1.

The trends illustrated in figure 8.2 show a decrease in mean soil moisture and pyrophosphate extractable iron with increasing depth of burial; excluding the shallowest profiles organic material (loss-on-ignition) also decreases within the profiles as depth of burial increases. Conversely, bulk density increases as depth of burial increases, which suggests that soil compression may be an important factor of post-burial change in these archaeologically buried soils. Mean pH and dithionite extractable iron levels show no trends with depth of burial.

Table 8.2: Between and within factor (depth of burial) effects upon physical and chemical soil properties determined using GLM repeated measures.

Soil property	**Sum of Squares**	**df**	**Mean Square**	**F value**	**Sig.**
Between factor effects					
Soil Moisture	462.009	1	462.009	4.362	.059
Within factor effects					
pH	10.123	6.3	1.607	4.404	.002*
pH within subjects contrast – linear	8.606	1	8.606	10.715	.017*

Figure 8.1: Mean pH trends for burial category, with depth from buried soil surface.

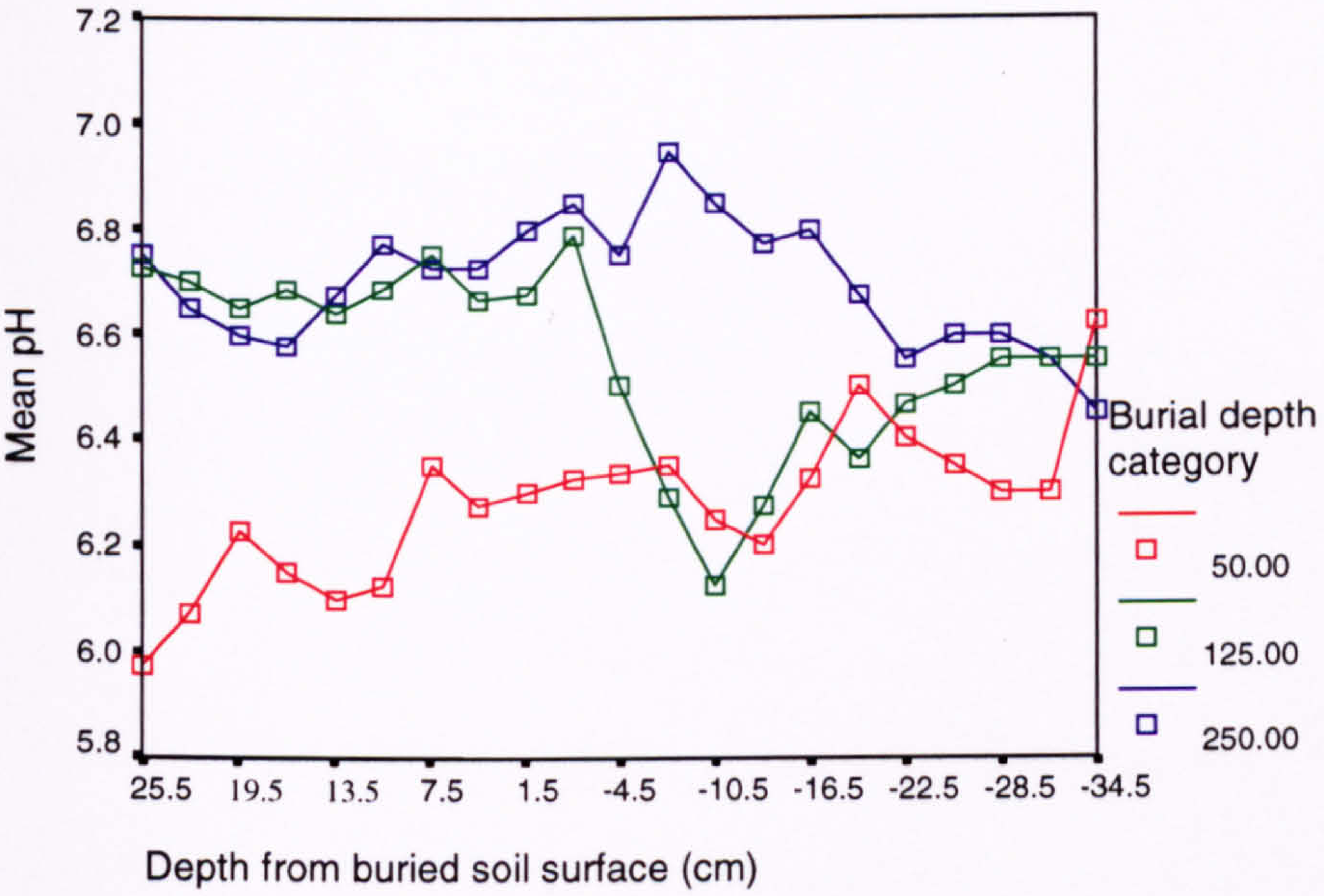
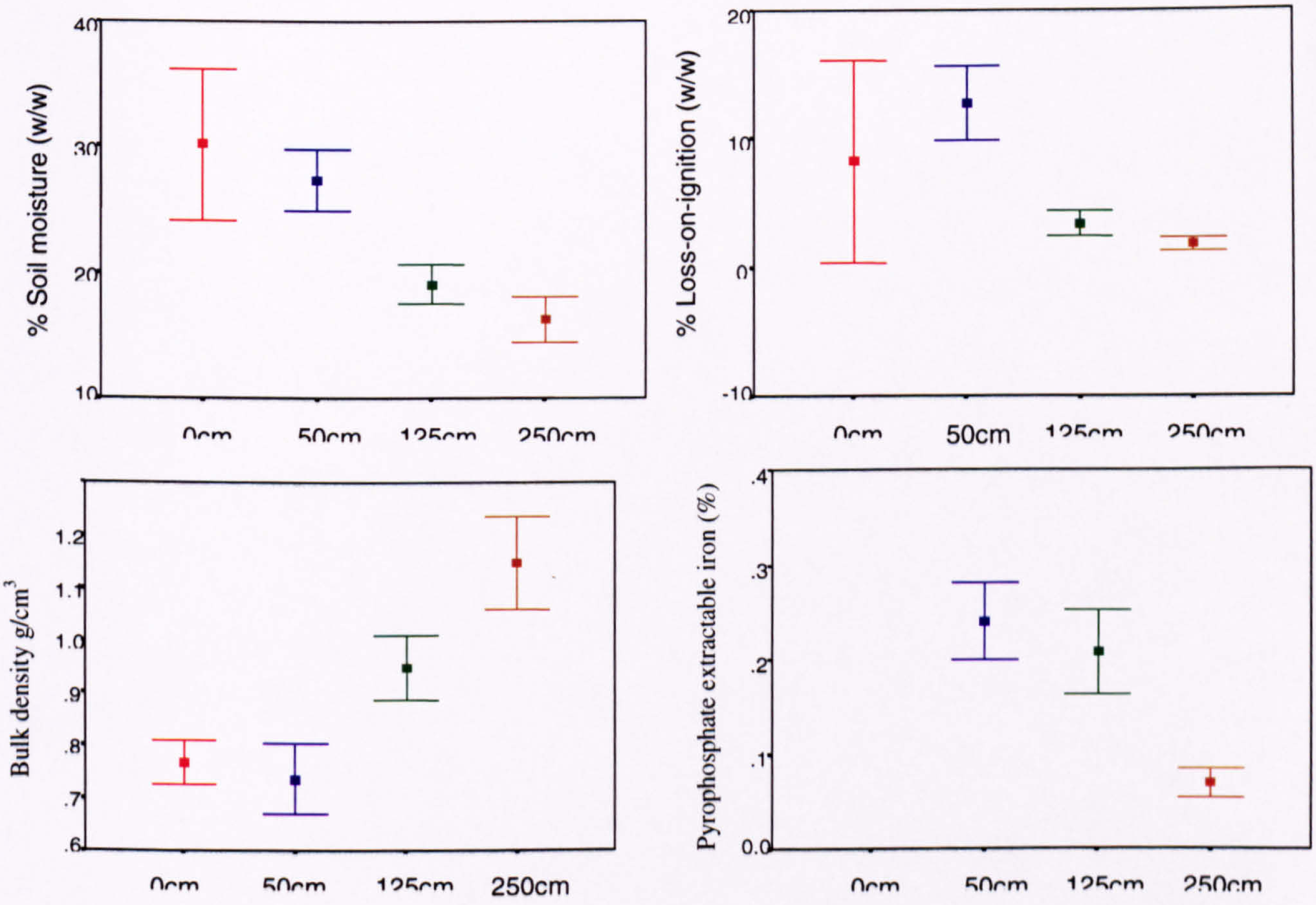


Figure 8.2: Error bar plots at the 95% confidence interval of soil bulk physical and chemical properties against depth of burial.



8.1.2 Characterising the micromorphological properties of soils buried beneath different depths of overburden.

The characteristic micromorphological soil properties of mineralogy, organic material, pedofeatures and soil organisation and structure within each depth of burial category are given in table 8.3.

The results illustrate characteristic differences in the soils and sediments buried within profiles of differing depth. Mineralogical differences involve the relative dominance of quartz, and the presence / absence of biotite, horneblende, feldspar, shell and charcoal. The relative distribution of shell and charcoal within the more deeply buried soils is probably a reflection of site type; these deeper buried soils tend to be barrow and midden structures rather than field banks. There is a brief discussion of the effects of overburden type in section 8.4. Other mineralogical differences probably relate to regional contrasts in parent material.

Organic materials are significantly correlated with the shallowly buried soils (0 and 50cm). These include yellow and red amorphous materials, lignified and parenchymatic tissues, fungal spores and pollen grains. In deeper buried soils all these fractions are less frequent than expected, even within the midden sediments. The high levels of organics within the shallow buried soils may be indicative of surface effects and suggest biological welding of buried and overburden profiles. Discussion of the depth within the profiles at which the organic material occurs may help to support this assumption (section 8.1.3).

The presence of excremental pedofeatures is correlated with the shallowly buried soils in the same manner as organic materials. There is a tendency for both textural and iron pedofeatures to be found within the more deeply buried soils (125 and 250cm). Post-burial clay coatings, including the silty and dusty types, are all correlated with these deep profiles. Limpid coatings are also found in the 50cm depth class reflecting the presence of natural limpid, pre-burial clay cutans identified in many soils. Post-burial clay coatings, iron nodules, iron pans and depletion pedofeatures all tend to form in the deepest buried soils and overburden materials suggesting that depth

Table 8.3: Characteristic soil micromorphological properties (mineralogy, organic matter, pedofeatures and soil structure) for different depths of burial.

Depth of burial category	**Soil features significantly related to depth of burial at 95% confidence level.**			
	Mineralogy	**Organic matter**	**Pedofeatures**	**Soil structure and organisation**
0cm	Biotite.	Lignified tissue, Parenchymatic tissue, Fungal spores, Yellow and red amorphous, Pollen.	Mammilate excrement, Spheroidal excrement.	Packing voids, Planar voids, Organic fine matter, Low c:f ratio, Pedal structures.
50cm	Low Quartz, Feldpar, Andesite.	Lignified tissue, Parenchymatic tissue, Fungal spores, Yellow and red amorphous, Pollen.	Fe coatings, Limpid clay coatings, Mammilate and spheroidal excrement.	Organic fine matter, Low c:f ratio, Pedal structures.
125cm	Shell, Charcoal, Sandstone.		Silty clay, limpid and dusty clay coatings, Post-burial clay coatings, Fe pans.	Packing voids, Mineral fine matter, High c:f ratio, C:f determined microstructure.
250cm	Biotite, Charcoal, High Quartz, Horneblende, Siltstone.		Depletions, Silty clay and dusty clay coatings, Post-burial clay coatings, Fe rock impregnations, nodules, pans.	Vughs, Planar voids, Mineral fine matter, Moderate c:f ratio, C:f determined microstructure.

factors may be having a direct effect upon the processes of clay and iron translocation after burial.

The distribution of organic rich fine fabrics also correlates with shallowly buried soil profiles. Deeper profiles tend to have mineral fine fabrics, high to moderate c:f ratios, and c:f determined microstructures compared with shallower profiles with pedal structures and low c:f ratios. There is no clear trend in the occurrence of void type with depth. Many structural characteristics may be related to the parent material. The significant correlation between depth of burial and the presence or absence of particular micromorphological soil features suggests a causal relationship between the two.

In chapter 2 it was hypothesised that depth of burial affects the micromorphology of buried soils through the differential activity of processes of post-burial change. Log-linear analysis has been applied to test the relative influence of the burial factors upon the occurrence of some of the features identified in table 8.3.

8.1.3 The relative influence of the depth of burial, time since burial and parent material factors upon processes of post-burial.

As was discussed at the start of section 8.1, an artefact of the nested sampling scheme is the uneven distribution of parent material types and site ages between the depth of burial categories. The relative effects of these study factors upon the features found to correlate with depth of burial is discussed and analysed in this section. General log-linear analysis has been used to do this, as in chapters 6 and 7. All features whose distribution was found to significantly correlate with depth of burial were analysed using general log-linear analysis, however, the results for only certain features are presented in this section for reasons of space.

The presence of post-burial cutans is strongly correlated with the deepest buried sites. These features are evidence of post-burial processes of clay translocation within the archaeological overburdens and buried soils. The results of log-linear analyses for post-burial cutans against burial depth, region, age and depth from the buried soil surface are given in table 8.4. The chi-square and significance values given in table 8.4, show that although depth of burial strongly correlates with the presence of post-burial cutan features, it is the other burial factors, particularly site age, that account individually for most of the variation. However, the inclusion of the c:f ratio together with burial depth does improve the significance level, but still not to those described by age and regional factors.

Table 8.4: General log-linear analysis for post-burial cutans comparing combinations of burial factors and soil texture (depth of burial, region, age, c:f ratio).

Model	**Chi-square**	**df**	**Sig.**
Cutans * burial depth	40.7	3	8. E-09
Cutans * region	159.7	4	.0000
Cutans * age	161.9	4	.0000
Cutans * burial depth * region * age	2551.8	187	.0000
Cutans * burial depth * c:f ratio	129.4	17	2. E-19

Table 8.5 presents the same sequential relationships as table 8.4, but for the presence of amorphous iron nodule features in thin sections. The significance of the relationship is greatest when all three burial factors are included, however, individually it is region or parent material factors that are most important followed by site age. The inclusion of c:f ratio along with burial depth again improves the relationship.

Table 8.6 shows the results of analyses that illustrate the relative effects of the burial factors upon the presence of iron pan features within thin sections. Using log-linear analysis to cross-tabulate the factors, burial depth has no significant relationship with the occurrence of iron pans until the c:f ratio is also included, the latter apparently having a significant effect. Individually it is the factor of region / parent material, and also site age that are the more important.

Table 8.5: General log-linear analysis for iron nodules comparing combinations of burial factors and soil texture (burial depth, region, age, c:f ratio).

Model	**Chi-square**	**df**	**Sig.**
Nodules * burial depth	14.0	3	.0028
Nodules * region	25.5	4	4. E-05
Nodules * age	22.3	4	.0002
Nodules * burial depth * region * age	1697.1	226	2. E-223
Nodules * burial depth * c:f ratio	93.1	17	2. E-12

Table 8.6: General log-linear analysis for iron pans comparing combinations of burial factors and soil texture (burial depth, region, age, c:f ratio).

Model	**Chi-square**	**df**	**Sig.**
Pan * burial depth	6.4	3	.0925
Pan * region	13.3	4	.0098
Pan * age	11.1	4	.0257
Pan * burial depth * region * age	1327.1	187	7. E-171
Pan * burial depth * c:f ratio	78.0	17	9. E-10

Table 8.7: General log-linear analysis for iron coatings comparing combinations of burial factors and soil texture (burial depth, region, age, c:f ratio).

Model	**Chi-square**	**df**	**Sig.**
Coatings * burial depth	13.8	3	.0032
Coatings * region	56.0	4	2. E-11
Coatings * age	13.8	4	.0095
Coatings * burial depth * region * age	1795.1	226	5. E-242
Coatings * burial depth * c:f ratio	94.9	17	9. E-14

Table 8.7 contains the significance values of cross-tabulations between the burial factors and the presence of iron coatings in thin sections. In this case also, region / parent material appear to be the dominant factors, with site age and burial depth also important, particularly in combination. Again the c:f ratio has a major effect upon the significance of burial depth as a determinant of iron coating occurrence.

Table 8.8 presents the results of the same relationships, for the presence of the mammilated excrements of earthworms in thin sections. In this case, although depth of burial has a highly significant relationship with the occurrence of mammilated excrements, factors of site age and parent material individually account for most of the variation. Again soil texture appears to be important in conjunction with burial depth.

Table 8.8: General log-linear analysis for mammilate excrement comparing combinations of burial factors (burial depth, region, age, depth from buried soil).

Model	**Chi-square**	**df**	**Sig.**
Mammilate * burial depth	23.9	3	3. E-05
Mammilate * region	91.6	4	.0000
Mammilate * age	101.0	4	.0000
Mammilate * burial depth * region * age	1974.9	187	1. E-295
Mammilate * burial depth * c:f ratio	121.5	17	8. E-18

Table 8.9 presents the relationships between key burial factors and the presence of the spheroidal excrements of enchytraeids in thin section. All three burial factors have highly significant relationships with the excremental features, however, region again appears to the more important with age and burial depth producing relatively similar effects. Soil texture is again important in relation to the occurrence of spheroidal excrements in combination with burial depth.

Table 8.9: General log-linear analysis for spheroidal excrement comparing combinations of burial factors and soil texture (burial depth, region, age, c:f ratio).

Model	**Chi-square**	**df**	**Sig.**
Spheroidal * burial depth	40.8	3	7. E-09
Spheroidal * region	69.8	4	2. E-14
Spheroidal * age	49.6	4	4. E-10
Spheroidal * burial depth * region * age	2061.0	187	.0000
Spheroidal * burial depth * c:f ratio	146.6	17	1. E-22

Table 8.10 gives data on the relationships between these key burial factors and the occurrence of fungal spores. All three burial factors have very similar, highly significant relationships with fungal spores; region or parent material are the slightly more significant, followed by burial depth and age. The inclusion of c:f ratios in the burial depth equation increases the significance of the relationship, but perhaps not by as much as for the other soil features so far examined.

Table 8.10: General log-linear analysis for fungal spores comparing combinations of burial factors and soil texture (burial depth, region, age, c:f ratio).

Model	**Chi-square**	**df**	**Sig.**
Spores * burial depth	70.7	3	3. E-15
Spores * region	80.0	4	2. E-16
Spores * age	69.3	4	3. E-14
Spores * burial depth * region * age	2009.4	187	2. E-302
Spores * burial depth * c:f ratio	179.9	17	3. E-29

Table 8.11 presents the results for relationships between parenchymatic tissues and the key burial factors. Parenchymatic tissue is chosen as an analogue of the other organic materials, all of which are also found most frequently in the shallowest buried profiles. Region / parent material and burial depth can be seen to be far more influential in the distribution of parenchymatic tissues than is site age. As for fungal

spores, soil texture is having a relatively minor effect upon parenchymatic tissue distribution.

Table 8.11: General log-linear analysis of parenchymatic tissue comparing combinations of burial factors and soil texture (burial depth, region, age, c:f ratio).

Model	**Chi-square**	**df**	**Sig.**
Parenchy. * burial depth	68.9	3	7. E-15
Parenchy. * region	46.9	4	2. E-18
Parenchy. * age	17.2	4	.0018
Parenchy. * burial depth * region * age	1994.3	187	2. E-299
Parenchy. * burial depth * c:f ratio	168.0	17	7. E-27

The relative influence of burial depth, site age and parent material upon the occurrence of features associated with processes of post-burial change differs according to the micromorphological features in question. Region is having a major effect upon the distribution of all features analysed, site age appears to be more important in determining the occurrence of post-burial clay coatings, and also mammilate excrements. Burial depth appears to be influential in the relative occurrence of parenchymatic tissues and fungal spores, i.e. the organic components of the buried profiles.

8.2 The effects of burial depth upon processes of post-burial change examined using image analysis and particle size determination.

The identification of depth of burial effects upon processes of post-burial change in archaeologically buried soils can also be made by considering individual study profiles and sites in which factors of parent material and age are constant. The image analysis of thin sections for void space, textural pedofeatures and amorphous iron features was undertaken upon the soils and sediments from Fordhouse Barrow and its reference soil. The results of that study are presented in this section, as too are the laser-determined particle size results for the Fordhouse Barrow and Somerset sites.

8.2.1 Image analysis results from Fordhouse Barrow.

Image analysis was used to quantify elements within the thin sections taken from the three buried profiles and one unburied reference profile from Fordhouse Barrow. The morphological characteristics of the features were identified following the procedures described in chapter 3 and appendix 3 and recorded at 2 cm intervals down each soil slide; the results are given in appendix 5. The features chosen for analysis are those that reflect the processes central to this investigation, namely clay translocation and iron redistribution. The presence of clay cutan types and amorphous iron pedofeatures were identified using image analysis techniques. Void characteristics were measured to characterise local drainage characteristics in areas of clay and iron deposition, and to investigate possible compressive effects directly within the soil. As only thin sections from the profiles of Fordhouse barrow were analysed, variation is assumed to result from the depth of burial factor. Thin sections from the reference profile were analysed to provide a base line against which to compare results. The distribution of clay cutans and amorphous iron pedofeatures within each profile is highly localised so mean area measurements for each of the four profiles have been calculated. These mean values were compared using independent-samples t-tests and the results are given in tables 8.12, 8.13 and 8.14. ANOVA analysis of the data was not possible because of the high number of zero values.

The data in table 8.12 shows how the mean area of orange clay decreases with depth of burial between the three archaeological profiles. Mean area of orange clay cutans in the field of view is significantly higher in the two profiles where depths of burial exceed 2m than in the third profile buried to a depth of 1.6m. There is no significant difference between the mean area of orange clay in the third buried profile and its mean area in the reference soil. The orange cutans identified include the silty clay coatings found within the till type parent materials as well as those features interpreted as post-burial (i.e. the orange type I and II features, chapter 5, section 5.1). The area of pre-burial brown clay cutans in thin section (table 8.13) decreases with increasing depth of burial. The area of brown clay in profile 3 is significantly higher than that in profiles 1 and 2. No significant differences exist between the buried and reference profiles in mean area of brown clay cutans.

Iron nodules and pans (table 8.14) have a less clear pattern with burial depth. Profile 3 has a significantly higher mean area of iron features than profile 2, and both profile 1 and 3 have higher mean values than the reference profile. A burial effect is, therefore, suggested, but the relationship between this and depth of burial is not clear. One problem was the difficulty in distinguishing between iron features and the black amorphous organic matter, and this may be masking a depth effect. The profile distribution of iron nodules and pyrophosphate extractable iron were also compared (figure 8.4). No correlation between pyrophosphate extractable iron and the incidence of the iron pan at the base of the mound was found, supporting the hypothesis that redox processes are involved as opposed to podzolisation.

Table 8.12: Independent-samples t-test significance for mean area values of orange clay in profiles of different depths.

	FHB1 (245cm)	FHB2 (205cm)	FHB3 (160cm)	FHR (0cm)
Mean area (μm^2)	2544.0	1796.4	367.0	710.4
FHB1	*/*	*.079*	*.000**	*.001**
FHB2		*/*	*.005**	*.072*
FHB3			*/*	*.464*
FHR				*/*

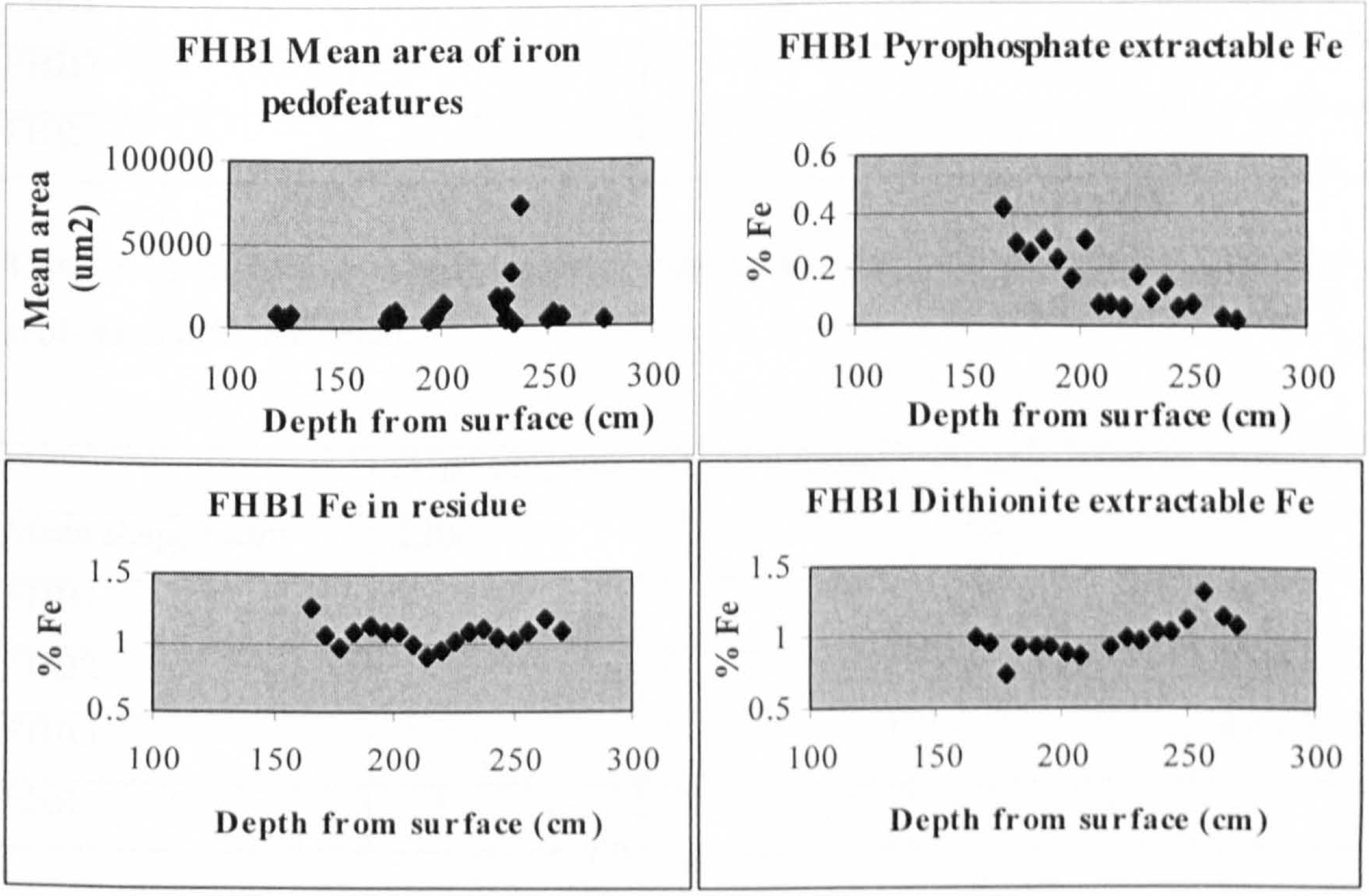
Table 8.13: Independent-samples t-test significance for mean area values of brown clay in profiles of different depths.

	FHB1 (245cm)	FHB2 (205cm)	FHB3 (160cm)	FHR (0cm)
Mean area (μm^2)	366.13	802.76	2698.06	1275.74
FHB1	*/*	*.545*	*.000**	*.315*
FHB2		*/*	*.029**	*.668*
FHB3			*/*	*.160*
FHR				*/*

Table 8.14: Independent-samples t-test significance for mean areas of iron aggregations in profiles of different depths.

	FHB1 (245cm)	FHB2 (205cm)	FHB3 (160cm)	FHR (0cm)
Mean area (μm^2)	11141.7	7458.7	14571.4	5448.5
FHB1	/	*.192*	*.443*	*.048**
FHB2		/	*.043**	*.139*
FHB3			/	*.022**
FHR				/

Figure 8.3: Depth profiles of iron nodules, pyrophosphate and dithionite extractable iron.



Tables 8.15 and 8.16 show the mean area and shape factors for total void space in thin section. Mean total void space is lowest within the reference soils and profile 3 between which there is no significant difference. These are significantly lower than mean void space in the more deeply buried profiles 1 and 2, the reverse of what would be expected if significant compression has occurred at this site. Shape factor (table

8.16) shows a general trend toward increasing roundness with decreasing depth of burial. Between the different buried profiles, however, these differences are significant. Each buried profile, however, does have a significantly less round mean void shape than that of the unburied reference profile. This is the expected result of compression. The two void factors, therefore, are at odds with one another with respect to the effect of compression on the soils and sediments.

Table 8.15: Independent-samples t-test significance for total void space mean areas in profiles of different depth.

	FHB1 (245cm)	FHB2 (205cm)	FHB3 (160cm)	FHR (0cm)
Mean void area (μm^2)	8150.1	10473.6	5926.6	5800.8
FHB1	/	*.232*	*.018**	*.025**
FHB2		/	*.037**	*.044**
FHB3			/	*.889*
FHR				/

Table 8.16: Independent-samples t-test significance for mean void shape factor in profiles of different depth.

	FHB1 (245cm)	FHB2 (205cm)	FHB3 (160cm)	FHR (0cm)
Mean shape factor	.2200	.2372	.2287	.3019
FHB1	/	*.071*	*.337*	*.000**
FHB2		/	*.449*	*.002**
FHB3			/	*.001**
FHR				/

The data presented in tables 8.12 and 8.13 suggest that as the mean area of orange clay cutans increases the corresponding area of brown clay cutans decreases. Correlation between the occurrence of the orange clay and brown clay was determined using SPSS curve estimation. Best-fit is a linear model with a significant negative relationship i.e. when the mean area of orange clay is high, the mean area of brown clay is low (table 8.17).

Table 8.17: Linear regression statistics for the mean area of brown clay against orange clay.

Pearson's Correlation (r)	Sig. (p)	One way ANOVA (F)	Sig. of F (p)
-.268	.005*	6.81	.000*

At the 90% confidence level, there is a linear relationship between pre-burial brown clay and the abundance of iron features, but when the data was plotted the linear relationship was clearly nonsensical. High mean areas of brown clay are found in slides with only small areas of iron, however, this relationship is skewed by a single slide with high mean areas of brown clay found together with large areas of iron. No relationship was found when the outlier was removed.

Overall, the burial depth relationship between post-burial cutans and burial depth is supported. The orange, mineral type post-burial cutans are found over greater areas in the deepest central areas of the mound than at the more shallowly buried edges. It must be remembered, however, that some of this orange clay in all profiles is inherited from the till type parent materials, particularly towards the top of the archaeological profiles. The lower levels of orange cutans in the shallow third profile may also be influenced by the presence of the stone layer sealing the buried soil biasing the results. However, if large amounts of clay were translocated within this section of the mound, the stone obstruction would be expected to cause the formation of large quantities of cutans immediately above this layer and should help to standardise the results. The mean level of brown clay cutans in the buried soil should not have been affected by the relative depth of overburden above, as these features have been interpreted as pre-burial in origin. However, as burial depth decreases the level of brown clay cutans increases. There is also a negative, linear correlation between the mean area of brown clay cutans and orange cutans. It is suggested, therefore, that the decrease in the area of brown clay coatings is not a real effect of burial, but an indirect effect of the mobilisation of orange clay after the barrow has been constructed. Two effects may be operating to produce this effect, the processes that are mobilising clay from within the micro-fabric of the overburden may also cause the mobilisation, and hence the destruction, of any inherited brown clay cutans. The second, and probably more important process is that of obscuration of the brown clay coatings by the later deposition of orange clay. This assumes that water movement and clay deposition occurred within similar void structures for both phases of movements. No significant correlation between the void size categories and clay cutans was found using the results from image analysis. However, in the micromorphological descriptions of these buried soil and archaeological sediments, the modal distribution of the two types of cutans did appear to occur within voids of the same mean area, although the orange clay was also found in voids of much greater diameter (chapter 5, section 5.1). Taking the mean area for 5 fields of view at each 2cm depth also helps to account for spatial differences in the occurrence of the orange and brown cutans. In rare instances orange cutans directly overlying brown ones were also noted. Surprisingly, no such relationship was identified between the occurrence of brown clay cutans and amorphous iron features, possibly because of the more localised distribution of post-burial iron features, and the inclusion of pre-burial iron features in the mean area values.

The lack of any significant differences in clay coatings and void space characteristics between the shallowly buried third profile and the unburied reference profile, suggests that burial at this depth is having only minimal effects upon these properties of the buried soil micro-fabric. A general decrease in the roundness of voids suggests that this characteristic is affected by burial, even at the shallowest depth examined. A general increase in mean area of amorphous iron pedofeatures with burial may also occur, but problems with distinguishing between these and black amorphous organic materials makes interpretation of the data difficult.

8.2.2 Particle size profiles from Fordhouse Barrow and Somerset.

Laser grain size determination of the <500μm fine earth fraction from all profiles within the study regions of Angus and Somerset was performed. The results are given in appendix 6. The analysis was undertaken to provide fine resolution data concerning the translocation of fine particulate matter in the soils and sediments.

The coulter counter percentage volume results were grouped into particle size classes (Appendix 6). Down profile, significant differences in particle size distribution were only noticed at the Milsom's Corner and Weston Farm sites where linear increases in the proportion of clay with depth were identified. Both sites have developed upon clay parent materials and it is this that probably accounts for these patterns. The statistical descriptions of each particle size distribution were also examined. These statistics were analysed using hierarchical cluster analysis upon each regional group (Angus, Sigwells, and Milsoms Corner). The final number of clusters analysed was determined using the agglomeration matrix and also by reference to the cluster membership tables when each of between 2 and 10 clusters were produced. The most appropriate level for analysis was then chosen.

The Angus samples were best described in six clusters; the sample membership of each cluster is given in table 8.10. Samples from the reference profile are included in clusters 1-5. Surface samples from the Ah horizon fall into cluster 1, samples from the A horizon and one spurious B-horizon sample fall into cluster 2, depths 9-12 cm (AB) are included in cluster 3, and clusters 4 and 5 are dominated by samples from the B and C horizons respectively. All samples from the deepest buried profile (profile 1) fall into clusters 4 and 5. Buried profile 2 samples are included in clusters 3, 4 and 5. The shallowest buried profile (profile 3) includes samples contained in clusters 2, 3 and 4. The buried soil samples themselves are all included in cluster 4. The particle size statistics of the archaeological profiles, therefore, mirrors most closely those of the B and C horizon reference materials. This is a particularly strong relationship in the samples from the deepest buried soils and the buried soils from the relatively shallowly buried profiles.

Table 8.18: Cluster membership for Angus samples by depth from surface (cm) as determined by their particle size statistics.

	Sample depths from surface (cm). N.B. barrow surface lowered during excavation			
Cluster	Reference	Profile 1	Profile 2	Profile 3
1	0			
2	3, 6, 42			0-18, 36
3	9, 12		54, 84-90	24
4	15-39, 48	0-66, 78-102	12-48, 60-66, 78	42, 48-78
5	45, 51	72	72	
6			6	

The typical particle size distribution curves that characterise each of the Angus clusters are shown in figure 8.3. Clusters 1-5 have a modal distribution in the medium sand size range, whilst cluster 6 peaks within the medium – fine silt range. Cluster 1, which consists of the reference sample from the Ah horizon, is a smooth curve with a highly dominant sand fraction; the proportion of silt and clay particles is relatively low. Clusters 2 - 4 show an increasing trend towards lower and finer sand content and an increasing proportion of silt and clay. These clusters are characterised by the A, AB and B reference horizons, respectively and suggest an overall fining down profile. Cluster 5 consists of till parent materials from the reference profile and samples from the archaeological profiles 1 and 2. On the whole these contain higher medium sand contents of between 4 and 6% by volume, and very little silt and clay. Cluster 6 is an isolated sample from within the barrow overburden of profile 2, and consists predominantly of silt sized particles.

Table 8.19 shows cluster memberships determined using hierarchical cluster analysis for the soil and archaeological samples collected from the sandy textured sites in Somerset (Sigwells). Three clusters only are required to provide adequate definition of sample size statistics. The reference soil materials from Slait Farm fall into all three clusters. Those from the surface A / Ah horizon form cluster 1, the A horizon materials form cluster 2, and the B and BC materials are included in cluster 3. All samples from both archaeological sites and their buried soils fall into cluster 3, i.e. their particle size statistics most closely resemble those of the lower reference soil horizons, including the samples taken from the plough soil developed at the barrow surface.

Table 8.19: Cluster membership for Sigwells samples with depth from surface (cm) as determined by their particle size statistics.

	Sample depths from surface (cm)		
Cluster	Slait farm reference	CHB2	Sigwells
1	0		
2	3-9		
3	12-48	0-130	90-162

The particle size curves that typify each of the three Sigwells clusters are given in figure 8.4. These suggest fine sand dominated soil textures with relatively low levels of silt and very low levels of clay. Cluster 1 contains the sample from the Ah horizon of the reference profile. The modal size class is fine to very fine sands with a peak percentage volume value of around 5. Cluster 2 consists of samples from the A horizon of the reference profile, these curves also peak in the fine-very fine sand classes at levels of between 5.5 and 6.5 % volume. The third cluster consists of the B and B/C horizons of the reference profile and all the archaeological and buried soil materials. Again the modal size classes are fine and very fine sands with peak values of between 7 and 9% by volume. The overall trend, therefore, is one of increasing sand content.

Figure 8.4: Particle size distribution curves for each of the Angus clusters.

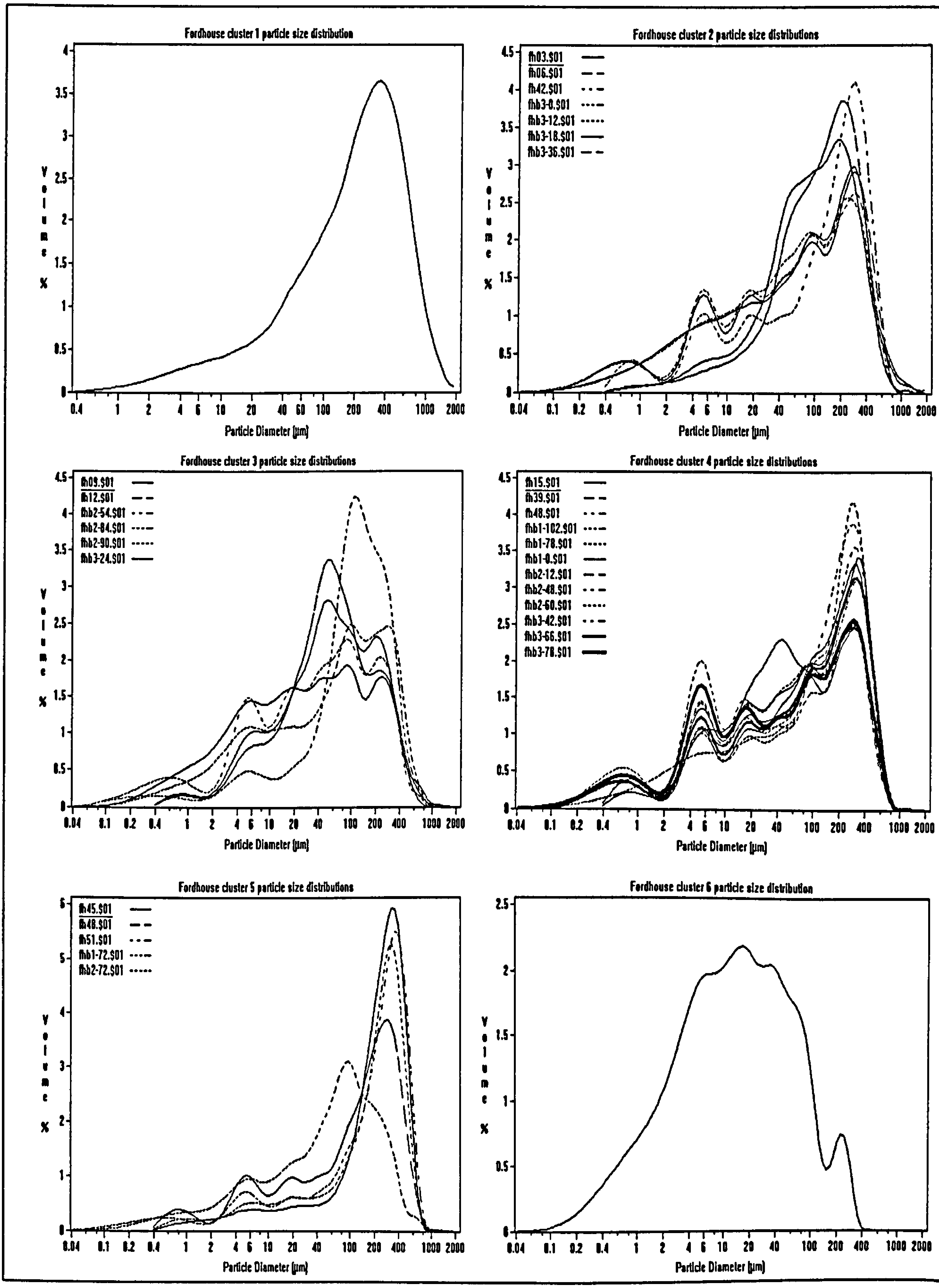
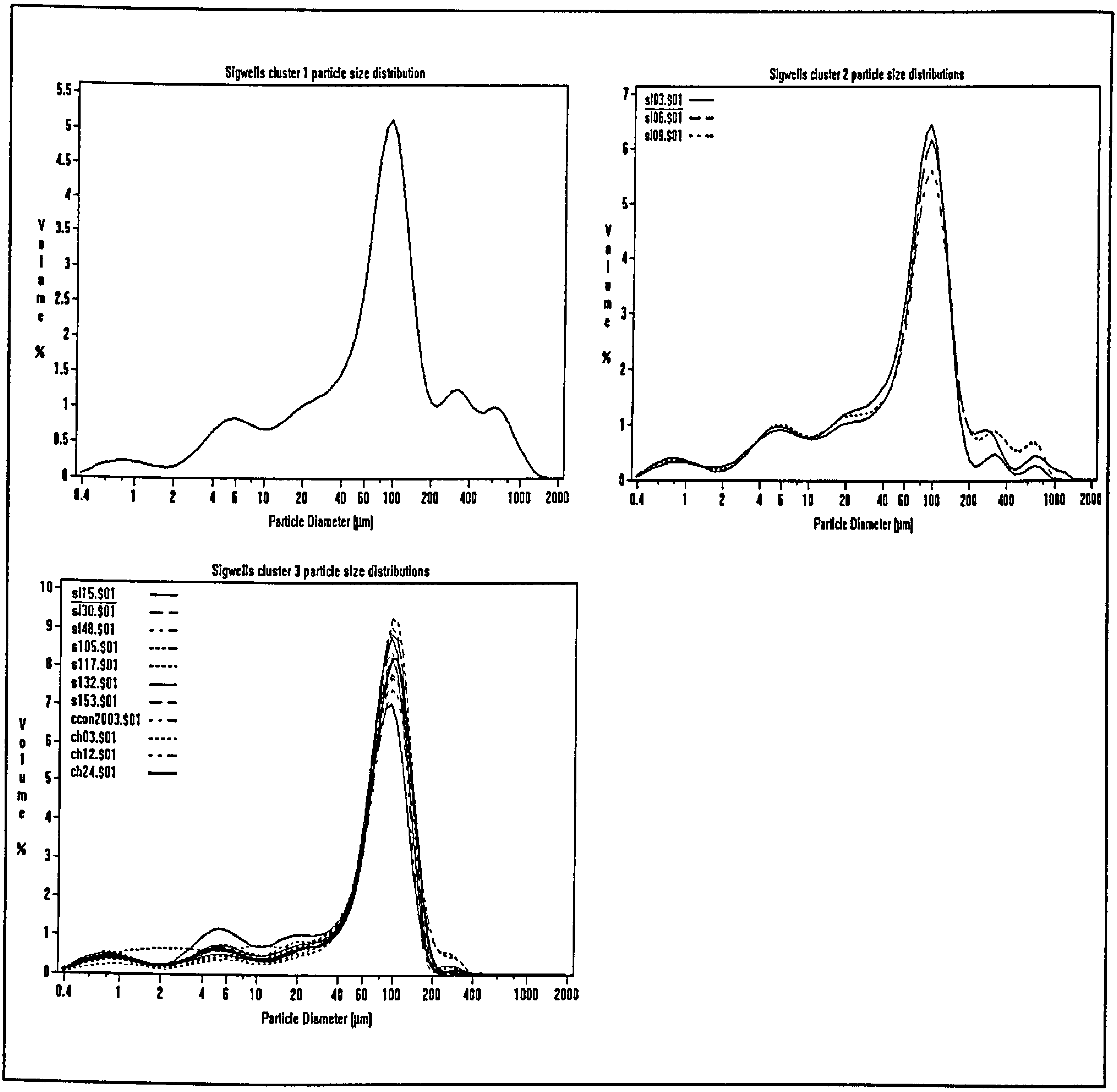


Figure 8.5: Particle size curves for the Sigwells clusters.



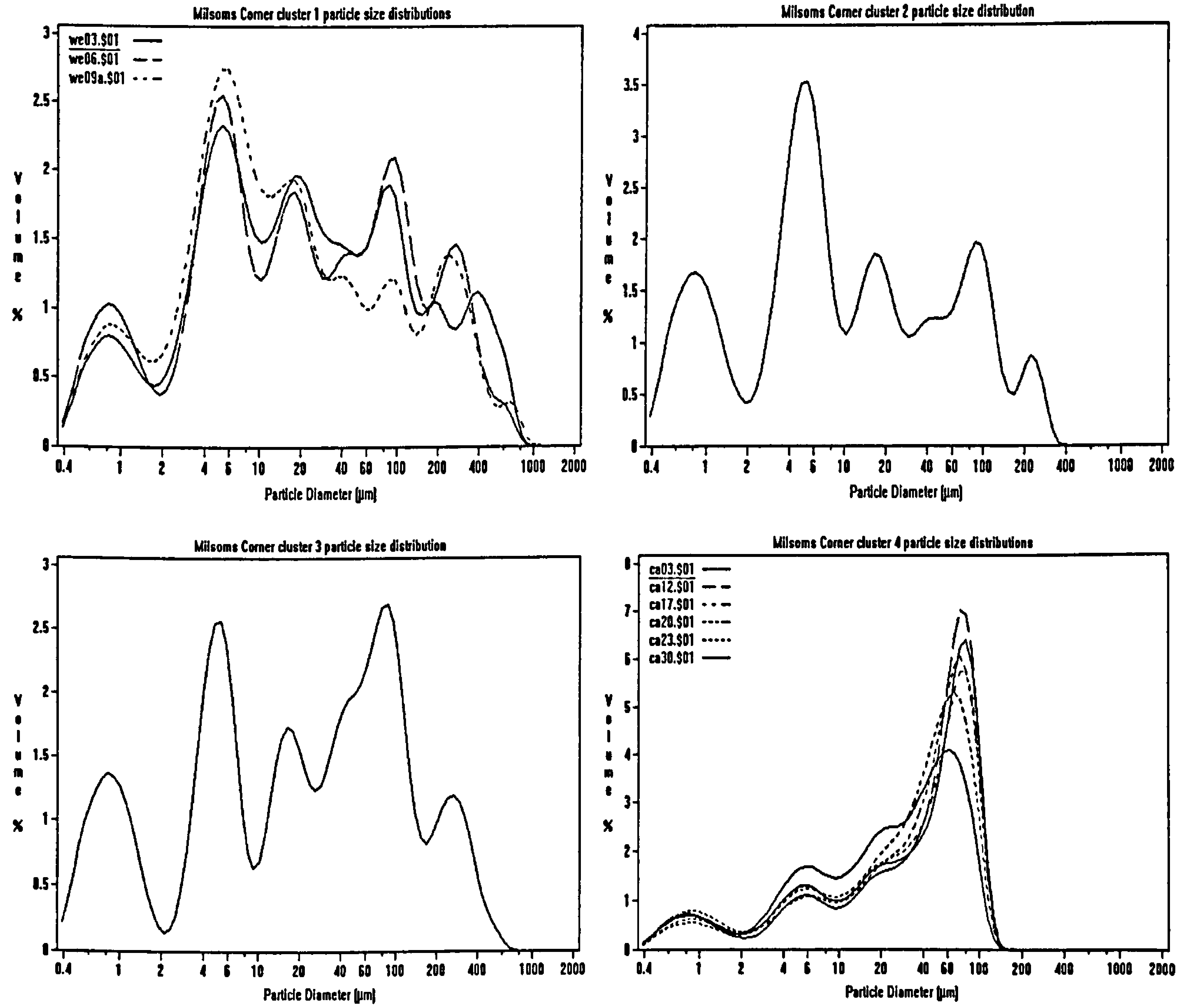
Four clusters were identified to account for the particle size statistical characteristics of the heavier clayey soils and sediments of Milsoms Corner (table 8.20). Following the pattern established in the reference soils of Fordhouse and Sigwells, samples from the A and A/B horizons from the reference profile at Little Weston Farm comprise cluster 1. Cluster 2 includes a single sample from the lower B(g) horizon, and cluster 3 consists of the lowest sample taken from the gleyed Lias clay parent material. All samples from the buried, archaeological profile of Milsoms Corner formed the fourth cluster and suggest a particle size distribution distinctive from the reference soil. The inclusion of more clusters failed to significantly divide the sediments and soils belonging to the archaeological profile.

Table 8.20: Cluster membership for Milsoms Corner samples with depth from the surface (cm) determined on the basis of their particle size statistics.

	Sample depths from surface (cm)	
Cluster	Weston farm Reference	Milsoms Corner
1	3-9	
2	12	
3	15	
4		0-33

The particle size curves for these four Milsoms Corner clusters are shown in figure 8.5. These highlight the nature of the differences between the Milsoms Corner (cluster 4) and Little Weston Farm (clusters 1-3) samples. The archaeological and buried soil samples from Milsoms Corner differ markedly from those of the reference profile of Little Weston farm with the former dominated by fine sands and coarse silts and the latter by silts and clays. Both sites are formed upon Lias clays and although the sub-soil materials from Milsoms Corner are still sandier than their counterparts from the reference profile, this is a less marked difference. The increased sandiness at Milsoms Corner may be the result of sandy hill wash materials known to affect this site which originate from the steep face of the hill fort above. Within the Milsoms Corner profile, sandiness decreases with depth and medium and fine silts increase. This increase in the finer fraction is more likely to reflect isolation from hill wash effects and proximity to the clay dominated parent materials than the effect of translocation processes.

Figure 8.6: Particle size curves for the Milsoms Corner clusters.



Cluster analysis, therefore, suggests that the particle size distributions of all the buried and archaeological profiles closely resembles those of the lower and sub-soil horizons of the modern, undisturbed profiles. No archaeological sample has a similar particle size signature to those of A and Ah reference samples. Organic materials were not removed from the samples prior to laser determination, and it may be this fraction that is causing the differentiation between surface and sub-soil materials. Both thin section and loss-on-ignition values from the archaeological materials suggest a significant reduction in levels of organic material following burial. It may be the relative loss of organic material, therefore, that is responsible for the apparent sub-soil characteristics of these materials. Down profile differences in the archaeological profiles are not significant enough to be isolated using cluster analysis. Where the particle size curves indicate down profile trends in particle size distribution, they tend to indicate a fining at Fordhouse Barrow and Milsoms Corner and a coarsening at Sigwells. These trends cannot safely be attributed to translocation effects and instead appear to reflect isolation from surface processes and increasing proximity to the parent material.

8.3 Discussion of the effects of burial depth upon processes of post-burial change.

8.3.1 Effects of burial depth upon physical processes of change

Physical processes of change include clay translocation and compression of buried soils. Image analysis and particle size analyses have provided further information upon the action of these processes in buried profiles. Clay translocation leads to the formation of fine textured coatings lining void walls. Chi-square analysis has suggested that the presence of clay coatings formed after site construction is related to parent material, site age and the depth of burial. In relation to burial depth, these features have a tendency to be found in the deeper profiles with burial depths of ca.125 cm and 250 cm; this relationship is particularly strong with respect to the mineral type post-burial cutans. Finer resolution analysis of the clay coatings in the thin sections from Angus was made using image analysis. The results of this analysis support the relationship between depth and post-burial clay translocation as the mean area of orange clay is shown to decrease as the depth of burial decreases. At the very shallowest burial depth, the area of cutans is not significantly higher than that associated with the till type materials of the reference profile suggesting that the burial effects upon orange clay cutan formation are not significant in this portion of the barrow. Furthermore, with increasing amounts of orange clay there is a correlated linear decrease in the area of pre-burial brown clay coatings. It is suggested that this is the result of obscuration of pre-burial features by the post-burial features, and also possibly by the physical loss of brown clay coatings through mobilisation from within the overburden. This observation has profound implications for the interpretation of pre-burial soil processes and disturbances from soil thin sections.

The sites at Fordhouse and Sigwells in which these cutans occur are both formed of sand and sand loam materials. In soil stores constructed of coarse textured materials, Abdul-Kareem and McRae (1984) found that an anaerobic layer established at depths of below 2m and in loams at ca. 1.3m. This corresponds well with the results of the micromorphology from the sites studied in this thesis since the sandy soils were buried to depths of greater than 2m and the more loamy Fordhouse Barrow includes profiles that fall into both 1.25 and 2.5m burial categories. This may suggest that the establishment of an anerobic layer is important either directly or indirectly in the onset of post-burial clay translocation processes. This cannot be the whole explanation, however, as in more clayey soils, such as those at Milsoms Corner anaerobism may develop at depths of less than 0.3m. Such depths are exceeded by many of the sites studied without any evidence of the formation of these mineral post-burial cutans. Perhaps the combination of depth and soil texture is the crucial element initiating translocation processes. Log-linear analysis for the three-way crosstabulation of these factors does indeed show an increase in significance when the c:f ratio is considered alongside burial depth and cutans (table 8.4). This analysis, however, also suggests that site age, and region or parent material are the more important factors. In section 8.5 the interactive effects between the burial factors and micromorphological features are analysed in an attempt to find a best-fit model. This model helps to explain more of the variability resulting from the nested sampling scheme and provides a better insight into the relative importance of the burial factors.

Besides clay translocation, another physical process that may affect buried soil is that of compression. If so, as depth of burial increases the area of void space should decrease and this may be accompanied by an alteration in void morphology. In thin section no significant relationship between burial depth and void space has been observed. At the greatest depths (c.250cm), planar voids have a greater tendency to occur, a relationship that may be associated with compressive effects. However, planar voids are also found more frequently in the very shallowly buried soils where they are a reflection of the pedological environment. Mean bulk density measures are highest in the deepest buried soils (figure 8.2), but results from the image analysis of thin sections from Fordhouse Barrow have established that void space is highest in the reference and shallowest buried profiles. With increasing depth, void morphology does tend away from roundness. There is, therefore, some evidence of compression in the soils and sediments analysed, but evidence from different sources is often conflicting.

8.3.2 Effects of burial depth upon chemical processes of change.

Features associated with processes of iron redistribution and whose presence correlate significantly with the depth of burial factor are iron coatings, pans, nodules and rock impregnations. No correlation was found between the presence of mottle features and burial depth. This supports the finding in chapter 6 (6.1.2) that mottling, and the gleyic process that form them, have not been accelerated by burial in the buried soils studied. Only within the sub-soil bank material of Wether Hill is mottling clearly post-constructional in date, with the development of a perched water table above the buried soil within the overburden. Amorphous iron nodules have been found to be significantly more common within the buried soils and sediments than within the reference soils. Their occurrence is also correlated with depth of burial, these features being more common than expected within the very deepest profiles. Again this may be related to soil texture, and log-linear crosstabulation suggests that for both iron nodule and pan features, the inclusion of the c:f ratio alongside burial depth produces a great increase in significance (tables 8.5 and 8.6). Levels of pyrophosphate extractable iron decrease as burial depth increases (figure 8.2) and so the rise in nodule and pan features is probably not related to this iron fraction. By implication secondary podzolisation processes are probably not the cause of their formation.

Other chemical changes that have been discussed in relation to factors of parent material and site age are calcification and decalcification and chemical weathering processes. In thin section no correlation with mineral weathering is present, and although shell is correlated with the 125cm burial category, its absence from the more deeply buried site of Pool suggests that its distribution reflects site age and parent material distributions within the burial categories. The bulk samples suggest that with increasing depth, mean soil moisture levels decrease and no effects upon mean soil pH are observed. However, depth of burial does seem to affect the response of pH within the profile as in the shallowly buried sites pH increases with depth in the same way as a surface soil profile. With greater depth of burial the soil pH tends to decrease down profile, in particular within the upper 10cm of the buried soil. The increase with depth within the very shallowly buried soils (ca. 50cm) perhaps reflects welding of the buried soil within the soil profile establishing at the new surface.

8.3.3 Effects of burial depth on biological processes of change

The biological features for which correlation with burial depth has been identified are those of lignified tissues, parenchymatic tissues, fungal spores, pollen, red and yellow amorphous organic residues, mammilate and spheroidal excrements. Neither between or within factor (burial depth) effects are recorded for the organic related soil properties of loss-on-ignition and pyrophosphate extractable iron, although error bar plots illustrate significant decreases in the mean values for each of these properties with increasing depth of burial. In thin section, all of these organic and biologically mediated features are found with greatest frequency in the shallowest buried soils (0cm and 50cm burial categories). Most of these soil features also positively correlate with the 'younger' buried soils and the Breamish and Sanday study regions. Log-linear crosstabulation suggests that it is burial depth that is having the greatest effect upon the occurrence of organic material, especially the lignified and parenchymatic tissues, and fungal spores appear to be more influenced by burial depth than site age. As with soil pH, the elevated levels of organic material and biological activity are most probably the result of soil welding, with additions of organic material through root penetration and the mixing of the soils by soil fauna, penetrating to these relatively shallow depths.

8.3.4 Summary of the influence of depth of burial upon processes of post-burial change in archaeologically buried soils.

Depth of burial was hypothesised in chapter 2 as determining the degree of isolation from surface processes of pedogenesis that a buried soil is exposed to. The surface processes that might impinge upon a buried soil include all pedogenic processes that cause the movements of materials within the soil profile. If the buried soil is not buried to a depth below the influence of these processes, it may become 'welded' within the surface profile. The depth at which isolation occurs appears to vary with soil texture, but in loess deposits isolation may not be complete at depths of over 4.5m (Leigh *et al.*, 1989; Schaetzl, 1987). Certainly within the soils and sediments buried by up to 85cm of material in this study, welding is readily evident in thin section. The evidence for welding takes the form of organic inputs, biological activity seen in thin section and bulk samples and soil pHs that increase with depth down the profile; this is in contrast to the profiles formed in deeper sites. Soil welding includes a suite of post-burial processes that may operate if the old land surface is not buried to a sufficient depth. Welding may still be occurring to some degree in these deeper sites but the techniques employed are not sensitive enough to detect it, and, therefore, the actual depth of isolation has not been ascertained in this study.

Another set of processes results from burial itself rather than the action of surface processes that result in welding. These processes include compression, clay translocation and the formation of amorphous iron nodules and pans. The prevalence of each of these processes increases as depth of burial increases and in the case of clay translocation and iron redistribution this may be in response to isolation from the atmosphere. Other soil factors, however, may also be important. Parent material may affect the response of the buried soil and sediments to burial, and site age determines the period of time over which these processes have to act and the environmental conditions prevalent at the time of burial. The results of log-linear cross tabulations established that site age is an important factor in the formation of clay cutans, whilst regional effects are more important to the formation of the iron features. In both cases the c:f ratio of the materials also appears to be important. All of the processes of post-burial change mentioned here have the ability to alter the fabric of the buried soil and so have important implications for the interpretation of thin sections from archaeologically buried soils. The main differences visible in thin section, therefore, between soils that have been buried shallowly <85cm and those that have been buried more deeply are outlined in table 8.21.

Table 8.21: Main differences between deeply and shallowly buried soils.

Shallowly buried soils (<85cm)	**Deeply buried soils (>85cm)**
High soil moisture.	Low soil moisture.
pH increases with depth.	pH-depth relationship more complex.
High organic matter and fungal spores.	Low organic matter and no fungal spores.
Excremental pedofeatures.	Post-burial clay coatings, iron pans and nodules.
Pedal structure, organic rich fine matter and low c:f ratio.	C: f determined microstructure and high c:f ratio.

8.4 The effects of differences in overburden material upon processes of post-burial change in archaeologically buried soils.

The analysis of the effects of the nature of the overburden material upon processes of post-burial change has not been the main aim of this thesis. However, as at many sites the overburden material is derived from local soil and sub-soil materials, regional parent material (chapter 6) appears to be the main determinant of overburden material. However, this excludes those sites where site materials differ from the local soils and also overlooks the potential importance of differences in site construction. Further analysis of this potentially important burial factor has been undertaken by broadly typing the sites that form the overburdens of the buried soils given in table 8.22. Categories were arrived at using archaeological and on-site knowledge of site differences.

Quarry waste includes large slabs of sandstone, gravel clasts, topsoil materials and sub-soil materials. The quarry waste mound has an open, stone-dominated structure with finer material in the spaces between. The midden materials are predominantly organic with plant remains, charred organic material and charcoal, within which are bone and shell fragments; evidence of dung from herbivorous mammals was also found (Chapter 5, section 5.2.2). The depth of these deposits was varied and these buried sites fell within the 50, 125 and 250cm depth categories. A further constructional difference inherent in these sites is the relatively slow accumulation of material in contrast to 'built' sites. The field boundaries and banks studied are all dominated by local soil and / or sub-soil materials and tend to be relatively low structures of < 70cm height. The barrow structures included in this study are all Bronze Age in date and are constructed of local soil and sub-soil materials with the occasional inclusion of turves, burnt materials and dressed stone slabs. In all cases the barrows studied had relatively sandy textures consisting of sands, sandy loams and sandy clay loams. All barrows were also included in the 125 and 250cm depth categories.

Table 8.22: Overburden categories and site membership.

Overburden categories	**Category membership**
Quarry waste	Roo's Loch.
Midden material	Seater, Woo, Pool.
Field / boundary bank	Wether Hill, Turf Knowe, Milsoms Corner.
Barrow	Ford house Barrow, Sigwells, CHB2.

8.4.1 Characterising the overburden material types.

The significant physical and chemical differences between these categories were determined using general linear model repeated measures and the results are given in table 8.23.

Soil pH is the only soil property to show a significant between overburden effect; the mean values and 95% confidence intervals are given in figure 8.7. Within overburden effects with depth from the buried soil surface, are recorded for loss-on-ignition, soil moisture, soil pH and pyrophosphate extractable iron; for the first two this relationship is quadratic, whilst for soil pH and pyrophosphate extractable iron it is a linear relationship. Figure 8.6 illustrates the mean chemical and physical values for each overburden type with their 95% confidence interval.

Table 8.23: Between and within factor (overburden) effects for soil bulk physical and chemical properties using GLM repeated measures.

Soil Property	**Type III Sum of Squares**	**df**	**Mean Square**	**F-value**	**Sig.**	**Within factor Contrast**
Between factor						
pH	39.740	1	39.740	12.054	.018*	
Within factor						
Loss-on-ignition	760.764	4.3	178.783	19.615	.000*	quadratic
Soil moisture	582.094	4.3	135.181	4.269	.004*	quadratic
pH	6.557	8.5	.775	3.253	.005*	linear
Pyrophosphate extractable iron	1.189	17.0	7. E-02	7.008	.000*	linear

The barrow sites have significantly lower mean values for loss-on-ignition and soil moisture than for the other site types, and relatively low values for soil pH and both of the iron fractions. Bulk density is significantly higher in these barrow sites than in the field banks, quarry wastes, and midden type sites. Mean soil pH was very high in the midden sites, in part probably due to the anthropogenic additions of shell, bone and ash materials. The quarry waste site also has a relatively high pH, and as both this and the midden sites are restricted to the Sanday study region some of the pH effects may be due to the effect of salt spray upon the island. The midden sites also have a relatively low mean loss-on-ignition, possibly indicating a substantial loss of organic matter from these sites since their construction.

Significant differences in the micromorphology of the profiles from the four site types are outlined in table 8.24. Mineralogical differences in andesite, sandstone, siltstone, quartz, biotite, and horneblende reflect regional parent material differences between the overburden types. Shell and charcoal, however, are artefactual and tend to be found within the midden and barrow sites that they characterise. Organic matter fractions are all characteristically low within the profiles of the barrow type sites. The midden sites from Sanday are characterised by the presence of black and yellow

Figure 8.7: Mean and 95% confidence interval plots for soil bulk physical and chemical properties against overburden type.

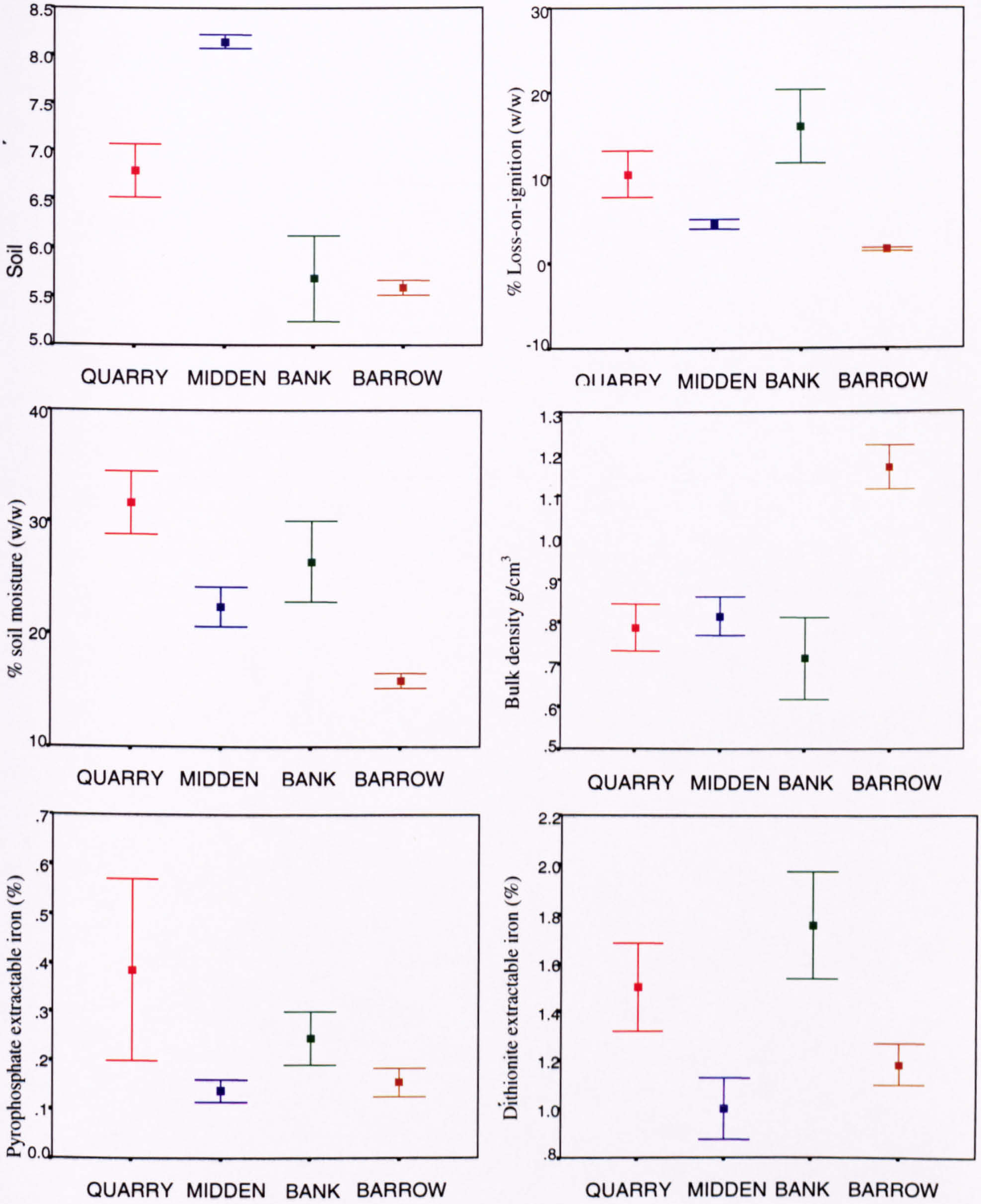


Table 8.24: Characteristic soil micromorphological properties (mineralogy, organic matter, pedofeatures, soil structure and organisation) for each overburden category as determined using the chi-square test.

Overburden type	**Soil features significantly related to overburden type at 95% confidence interval.**			
	Mineralogy	**Organic matter**	**Pedofeatures**	**Soil structure and organisation**
Quarry waste	Sandstone, Siltstone.	Lignified tissue, Parenchymatic tissue, Yellow amorphous, Red amorphous, Fungal spores, Diatoms.	Fe mottles and coatings, Spherical excrement, Depletions.	Vughs, Void determined structure.
Midden material	Sandstone, Shell.	Black amorphous, Yellow amorphous.	Mammilate excrement.	
Field / boundary bank	Low quartz, Feldspar, Andesite.	Lignified tissue, Parenchymatic tissue, Fungal spores, Diatoms.	Fe mottles and coatings, Limpid clay coatings, Mammilate and spherical excrement, Depletions.	Planar voids, Pedal structure.
Barrow	High quartz, Biotite, Horneblende, Siltstone, Quartzite, Charcoal.		Post-burial clay coatings, Pre-burial clay coatings, Limpid, dusty and silty clay coatings, Fe coatings and nodules.	Vughs, High packing voids, C:f determined structure.

amorphous organic residues whilst the bank and quarry waste sites are also relatively rich in lignified and parenchymatic tissues and fungal spores. As was discussed in section 8.3, the presence of these diverse organic fractions within the bank and quarry waste sites may be related to surface processes; these site types included only relatively shallowly buried soils.

Clay coatings, including post-burial, silty, dusty and limpid ones, are all strongly correlated with the barrow type sites. It should be noted that these sites are all relatively deeply buried (125 and 250cm) and all date to the Bronze Age. Iron nodules are also characteristic of the barrow site type whilst excremental features, which are relatively common elsewhere, tend to be absent from these sites. The barrow sites in this study also tend to have high c:f ratios, c:f determined microstructures (inter-grain microaggregate, single grain and bridged grain) and a relative dominance of packing voids. The field bank sites tend to have relatively more frequent planar voids and pedal structures, whilst the quarry waste site is typified by void determined microstructures (channel, vughy, spongy) and has a more frequent than expected occurrence of vugh-type voids.

8.4.2 Effects of overburden material type upon processes of change.

Processes of post-burial clay translocation, therefore, are almost exclusively confined to the barrow type sites. The mineral post-burial clay coatings are only found in these sites, but more organic coatings in bank and midden sites were also identified. These latter textural void coatings were interpreted as the result of later tillage activities upon the new, raised land surface. The barrow sites seem to correlate with this particular form of mineral clay and silt translocation after burial. However, the barrow sites studied in this thesis all date to the Bronze Age and each profile falls into the 125 and 250cm burial depth categories. Therefore, the isolation of overburden or constructional effects, from age and depth considerations is difficult.

The effect of overburden type upon the occurrence of features associated with iron redistribution is less clear. Mottle features and iron coatings are present in the soils and sediments associated with both the quarry waste materials and earth banks; iron coatings and nodules are also found more frequently than expected in the barrow sites. Of all the amorphous iron features only certain iron nodule and pan features from sites in Angus and Somerset can be confidently identified as post-burial in date. At other sites, coatings and depletion rims around stone clasts may also in certain instances relate to post-burial processes of podsolisation operating within the later established soil profile (chapter 5, section 5.3). Pan features were identified too infrequently for a significant relationship with overburden type to be established, however, only the barrow sites have greater than expected frequencies of amorphous iron nodule pedofeatures. In chapter 6 these features were found to be occurring at the top of the archaeological profiles in Angus and within the lower overburden and buried soils elsewhere, and tend to be found in the deepest profiles.

The features associated with biological processes tend to be absent from the barrow sites and this explains the negative correlation between these features and the presence of post-burial clay coatings. Other measures of organic content such as pyrophosphate extractable iron and loss-on-ignition levels are also low within the barrow sites. The midden type overburdens that are formed from a high proportion of organic matter tend to contain amorphous organic materials. However, no elevated occurrence of other organic tissues or excremental features is seen and loss-on-ignition and pyrophosphate extractable iron levels in these sites are also low.

In the case of each overburden type, a particular suite of micromorphological features and soil properties seems to exist. This suggests that overburden is a fourth burial factor whose influence upon processes of post-burial change in archaeologically buried soils ought to be considered alongside parent material, site age, and burial depth. Problems of dependence between each of these burial factors as an indirect consequence of the nested research design, however, still exist and will be briefly considered in the next section.

8.5 Modelling the relative influence of parent material, time and burial depth upon features of the burial environment.

This section uses general log-linear analysis to develop best-fit models to better describe the relationship and interactions between burial factors and features of post-burial change identified in thin section. This process builds upon the analyses presented in sections 7.2, and 8.1. In these sections general log-linear analysis was used to provide multi-dimensional cross-tabulations of burial factors and features to determine through the determination of the chi-square statistic the degree of independence or otherwise between burial factors and the micromorphological features of interest. In this section the analyses so far determined provide a base-line model against which more complex models are compared. These models were built by sequentially introducing 2-way and 3-way interactions until the best-fit model of least complexity was identified. The relative difference in the log likelihood ratio (L^2) with each sequential introduction is used to identify the main effects and develop the models. As the aim is to fit a model a high p-value is required and values in the range of 0.10 and 0.35 were looked for (chapter 4, section 4.4.2).

The fitting of these models has concentrated upon those features of particular interest to this thesis, namely those associated with the post-burial processes of clay translocation and iron redistribution. Of the various clay coating features that have been identified in this thesis, it is the mineral post-burial type identified in the archaeological sites and buried soils from Angus and Somerset that have been the focus of investigation. The formation of pre-burial features are obviously not linked to burial factors, and the more organic post-burial features identified in Sanday and Milsoms Corner are thought to have been the result of later agricultural disturbance. Of the amorphous iron pedofeatures, a significant increase in the frequency of occurrence within the buried relative to the non-buried soils (chapter 6, 6.1.2) was found for nodules only, although pan features are not present in high enough frequencies to determine a statistical significance. These features also tend to be found most often in the buried soils and their overburdens. Mottle features in the archaeological sites and buried soils could usually be linked with gleyic features in the reference soils and, therefore, may at only most have been enhanced by burial. Only the mottling within the earth bank at Wether Hill could be firmly dated as post-burial in origin, here a perched water table had formed above the buried soil. Other soil features found in chapter 6 to correlate with the presence or absence of these translocation and redistribution post-burial features, include soil texture, organic materials, excremental features and fungal spores. The interactions of these features, therefore, are also included in the models to assess their relative importance in the processes of formation of clay coatings, iron nodules and iron pans.

Modelling was first tried incorporating the three burial factors that formed the basis of the research design (parent material, time since burial and depth of burial), the nature of the overburden as discussed in section 8.4, and the relative presence of post-burial clay coatings. The usual way in which the nature of a causal relationship would be obtained, i.e. a relationship in which independent factors are affecting the 'response' of a dependent factor, is to start with a baseline model. In this baseline model all possible interactions between the independent factors are explained (Region*Age *Depth*Overburden), and then interactions with the dependent are gradually added in to obtain the 'best-fit'. The hypothesised causal factors in the models considered here, however, are not independent because of the nested research design and a baseline model that incorporated all possible factors and interactions explains too much of the variation in itself. Base-line models have to be devised, therefore, that include the main interactions between independent factors, but that do not saturate the model unduly. However, the strength of the interaction between overburden type and site age is such that it dominates any attempted model and as a result overburden has been left out of all subsequent models. This interaction, although not included in the analyses, should be borne in mind throughout.

The effects of relationships between the presence of post-burial cutans and different burial factors are outlined in table 8.25. For the baseline model, region and age, and age and depth interactions have the largest effects upon the L^2 value; these are then used as the baseline model. Building up from this base the additional two-way interactions between region and cutans and depth and cutans produce the best-fit model. If the base line model is expanded to include three-way interactions, the fit becomes too large and so the two way interaction model is accepted. This model is illustrated in figure 8.8, and depicts the main interactions in the system that account for the first 30% of variation.

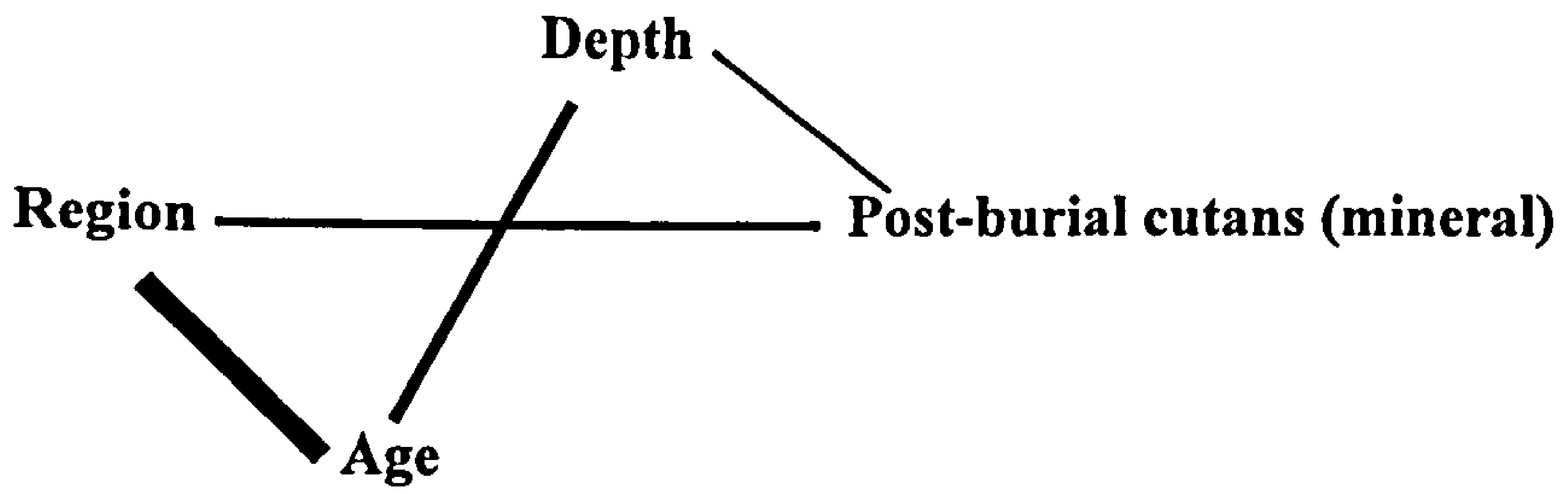
In chapter 7 and section 8.1.2 site age was highlighted for the highly significant correlation between it and the presence of post-burial cutans which tend to occur in the Bronze Age sites and buried soils. The model outlined above whilst, acknowledging that there does appear to be a direct interaction between the presence of these coatings and site age, suggests that the greatest interactions occur between coatings and region or parent material, and coatings and burial depth. Site age is perhaps having a more indirect effect upon the soils and sediments of this study through its strong interaction with region and depth. To a large degree these interactions are a result of the sampling scheme.

Table 8.25: Log-linear hierarchical models for the interaction between burial factors and the presence of post-burial cutans.

MODEL	**L^2**	**DF**	**P (Sig.)**	**ΔL^2**	**ΔDF**
{R}{A}{D}{C}	1039.2346	226	2.E-104		
{R}{A}{D}{C} {RA}	745.0602	206	4.E-62	294.17	20
{R}{A}{D}{C} {RD}	826.7075	214	8.E-73	212.51	12
{R}{A}{D}{C} {AD}	758.9278	211	7.E-73	280.31	15
{RA} {AD} {C}	469.0761	191	2.E-25		
{RA} {AD} {RC}	282.5199	187	8.E-06	186.56	4
{RA} {AD} {AC}	276.5919	186	2.E-05	192.48	5
{RA} {AD} {DC}	379.1909	188	5.E-15	89.89	3
{RA} {AD} {RC} {AC}	236.3575	182	.0041	46.16	5
{RA} {AD} {RC} {DC}	193.6026	184	.2992*	171.41	3
{RA} {AD} {RC} {AC} {DC}	193.6057	179	.2157*	42.75	3
{RA} {AD} {AC} {DC}	215.8359	183	.0066	60.76	3
{RA} {AD} {AC} {RC}	236.3572	182	.0041	40.24	4
{RAD} {C}	242.0531	119	6.E-10		
{RAD} {RC}	80.9610	115	.9932	161.09	4
{RAD} {AC}	49.5658	114	1.0000	192.47	5
{RAD} {DC}	152.1614	116	.0137	89.89	3
{RADC}	.0000	0	1.0000		

R=REGION, A=AGE, D=DEPTH OF BURIAL, C=POST-BURIAL CUTANS

Figure 8.8: Best-fit model illustrating the most significant interactions between burial factors and the presence of post-burial cutans.



{Region*Age} + {Age*Depth} + {Region*Cutans) + {Depth*Cutans}

Line weight indicates relative strength of interaction.

In addition to this simple three factor model, further best-fit models were created that include some of the other micromorphological features that are significantly correlated with the presence of post-burial clay coatings in thin sections. For example in Chapter 6, it was found that these clay coatings are found in soils with a moderate to high c:f ratio, i.e. in soils with a relatively coarse texture. Soil textural characteristics are determined by the parent material, this supposition is supported by the results of particle size analysis (section 8.4.2). The c:f ratio results, therefore were fed into the model in place of the region / parent material factor. Organic materials are also correlated with the absence of post-burial cutans. The model was, therefore, also extended to include these factors. The resultant best-fit models are shown in table 8.26. In each case interactions including the added factor are not required to explain variation in the system. Each factor was found to have some effect, but these effects are minor in comparison to the interactive effects of the three key burial variables hypothesised in chapter 2 to influence post-burial processes. In the case of the c:f ratio the results suggest that although the c:f ratio is important, the net regional effect is more than just a factor of soil texture.

Table 8.26: The best-fit general log-linear models including soil texture (c:f ratio), and organic materials.

Model	**L^2**	**df**	**P (sig.)**
{AD} {AC} {T}	138.4609	112	**.0456**
{RA} {RD} {AC} {F}	462.7484	428	**.1191**
{AD} {RD} {AC} {Y}	429.4217	443	**.5395**
{RA} {RD} {AC} {P}	460.5376	428	**.1340**

R=Region, A=Age, D=Burial depth, C=Post-burial cutans, T=C:f ratio, F=fungal spores, Y=Yellow amorphous organic material, P=Parenchymatic tissue

The presence of elevated levels of iron nodules in thin section has also been shown to correlate with burial and each of the three key burial factors. The interactive influence of these factors has also been modelled (table 8.27). Table 8.27 shows how again it is the interactions between the three burial factors themselves that accounts for almost all variation. Taking the two two-way factorial interactions with the greatest effect, all three two-way interactions including the occurrence of iron nodules are needed and even then the overall fit of the model is relatively poor (figure 8.9).

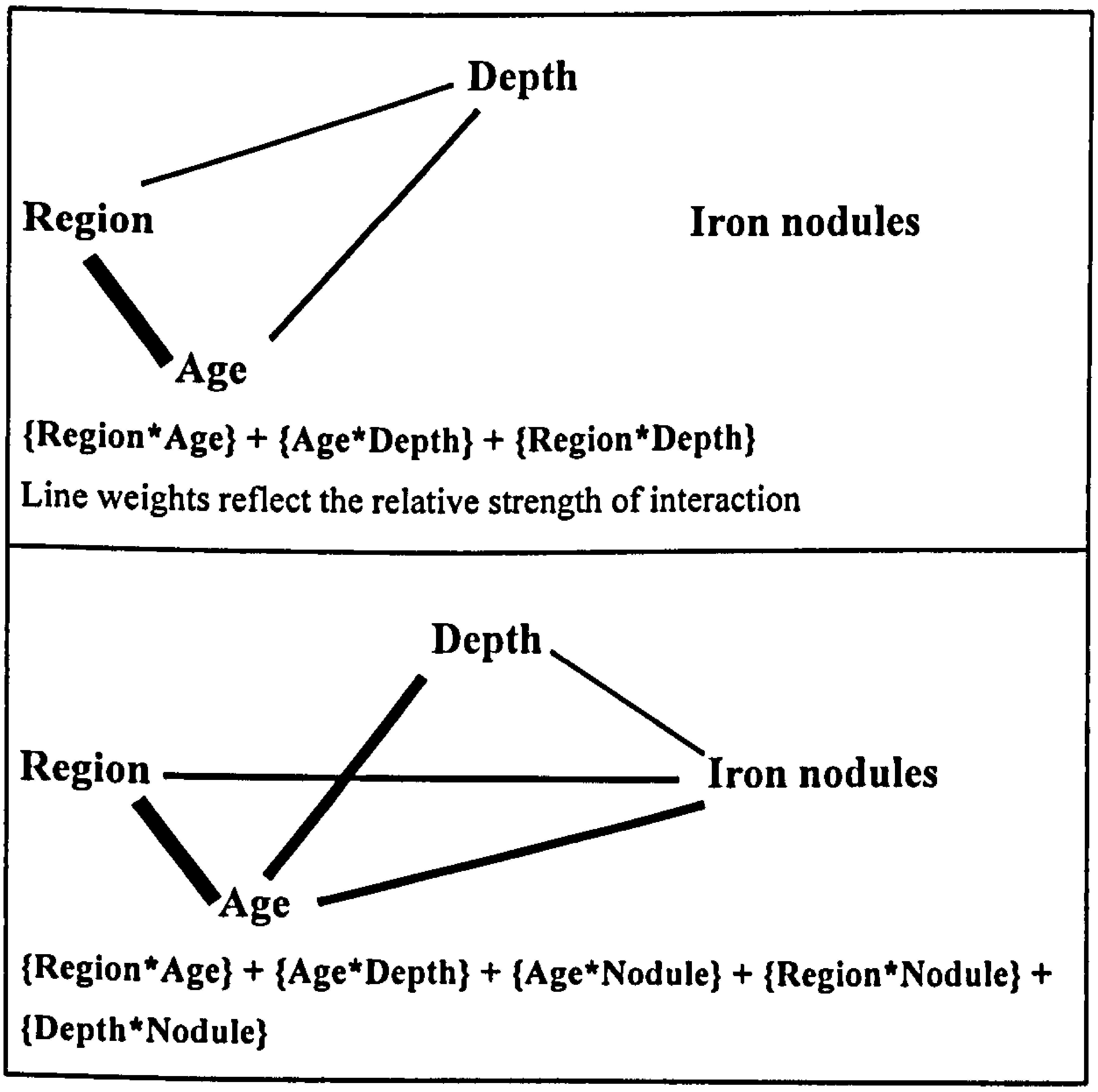
Table 8.27: Log-linear hierarchical models for the interaction between burial factors and the presence of amorphous iron nodules.

MODEL	**L^2**	**DF**	**P (Sig.)**	**ΔL^2**	**ΔDF**
{R}{A}{D}{N}	861.1835	226	7.E-75		
{R}{A}{D}{N} {RA}	567.0098	206	2.E-35	294.17	20
{R}{A}{D}{N} {RD}	648.6563	214	3.E-45	212.53	12
{R}{A}{D}{N} {AD}	580.8777	211	3.E-36	280.31	15
{R}{A}{D}{N} {RN}	829.1184	222	7.E-71	32.07	4
{R}{A}{D}{N} {AN}	828.4942	221	4.E-71	32.69	5
{R}{A}{D}{N} {DN}	845.8696	223	3.E-73	15.31	3
{RA} {AD} {N}	286.6971	191	9.E-06	280.31	15
{RA} {RD} {N}	354.4768	194	2.E-11	212.53	12
{AD} {RD} {N}	368.3441	199	3.E-12	212.53	12
{RA} {AD} {AN}	254.0081	186	.0007	32.69	5
{RA} {AD} {AN} {RN}	242.0854	182	.0019	11.92	4
{RA} {AD} {AN} {RN} {DN}	229.9346	179	.0061	12.15	3
{RA} {AD} {RD} {N}	59.6699	179	**1.0000**		
{RAD} {N}	59.6747	119	1.0000		
{RADN}	.0000	0	1.0000		

R=Region, A=Age, D=Burial depth, N=Iron nodules

As with clay coatings supplementary models were run which included other micromorphological features that have been found to correlate with the presence of these nodules in thin section, namely fungal spores, void space and yellow amorphous organics. Again, however, the strength of interaction is minimal in comparison to those of the burial factors. A final model that incorporates burial factors, post-burial clay coatings and iron nodules has also been constructed. Here too, it is the interactions between the burial factors that are most important, followed by those with the cutan features. The strength of any interactions including iron nodules is low and these, therefore, are never found within the best-fit models (table 8.28). Obtaining a p-value of between 0.1 and 0.35 with the inclusion of either micromorphological feature was not possible.

Figure 8.9: Best-fit model illustrating the most significant interactions between burial factors and the presence of amorphous iron nodule.



{Region*Age} + {Age*Depth} + {Region*Depth}

Line weights reflect the relative strength of interaction

{Region*Age} + {Age*Depth} + {Age*Nodule} + {Region*Nodule} + {Depth*Nodule}

Table 8.28: The best-fitting general log-linear models including burial factors, post-burial clay coatings and iron nodules.

Model	L^2	df	P (Sig.)
{RA} {AD} {N} {C}	527.2359	430	.0009
{RA} {AD} {AC} {N}	303.5206	425	1.000
{RA} {RD} {AC} {N}	371.3003	428	.9777

R=Region, A=Age, D=Burial depth, C=Post-burial cutans, N=Iron nodules

Overall it appears that the nested sampling scheme has produced a high degree of dependence between the burial factors of parent material, site age, depth of burial and also overburden type as these variables in themselves account for much of the variability. Keeping the strength of these interactions to a minimum in the model whilst maintaining overall integrity, it appears that region and depth have the strongest direct interaction with clay coating presence and the effect of site age has a more indirect influence. The relative distribution of iron nodules requires factors of region / parent material, site age and burial depth to best explain the observed variability. The relative interactions between the distribution of other micromorphological features and the coating and nodule features are relatively minor in comparison to the effects of the burial factors, although significant correlations are observed. This perhaps suggests that the nature of the interactions between the burial factors and post-burial processes involve a whole range of soil types, changing soil properties, and other processes. No one feature was found to strongly mimic the influence of any one burial factor upon the system. The relative effects of overburden type, because of the its very strong interaction with site age, was not possible to determine individually. Site age interactions, therefore, may include some element of variability derived from the influence of overburden type.

8.6: Summary of the influence of burial factors upon the processes of post-burial change identified in the study sites.

This chapter and the two preceding ones have concentrated upon identifying processes that have operated after burial and which have significantly affected the micromorphology of these buried soils and sediments. Specifically each chapter has analysed the relative importance of the three key burial variables identified in chapter 2 and hypothesised to affect the nature of post-burial change in archaeologically buried soils. These key variables are the factors of parent material, time since burial and depth of burial. In addition, the nature of the overburden material has also been highlighted as an important variable, and important correlations between the features associated with physical processes of clay translocation, chemical processes of iron redistribution and biological factors of biological activity and nature and concentration of organic material have been identified. The key differences between sites of contrasting parent material, age, and burial depth that form the basis of the conclusions of this thesis are presented in table 8.29.

Parent material has been studied at a regional level and has been found to influence the chemical, physical and biological properties of the soils. These chemical and physical characteristics may then influence the response of the soil to burial. Burial itself has been shown to lead to a reduction in soil organic matter, pyrophosphate extractable iron and moisture content, and a general increase in soil pH and bulk density. In thin section burial has been linked to the formation of clay coatings around voids and an increase in the incidence of iron nodules and iron pans within the buried soils and their overburdens. Whilst the occurrence of organic fractions and excremental pedofeatures are reduced following burial. The regional parent material factors linked with these post-burial changes include soil texture and soil pH. Soils with lighter sand dominated textures as at Sigwells and Fordhouse Barrow correlate with the formation of post-burial clay coatings, iron pans and nodules. High pH either from the parent material (Milsoms Corner), anthropogenic additions (Seater, Woo, Pool) or salt spray due to a coastal location (Sanday) is linked with marked rises in mean pH following burial.

Table 8.29: Summary table of main effects and conclusions.

Parent material		**Site Age**		**Burial depth**	
Angus (Old red sandstone derived till)	Pre and post-burial clay translocation, moderate c:f ratio, acid pH, high bulk density, iron pans and nodules.	**Modern**	High degraded and amorphous organics and fungi, moderate void space and excremental features.	**0cm (0-5cm)**	High soil moisture, pH increases with depth, low bulk density, organic matter and fungal spores, excremental features, pedal structure, organic fine matter.
Sanday (Old red sandstone derived till)	High pH, low c:f ratio, bone and shell, Ca-Fe phosphate, amorphous organic matter, mammilate excrement.	**Norse**	Amorphous organics and fungal spores, excremental pedofeatures.	**50cm (6-85cm)**	High loss-on-ignition, pH increases with depth, low bulk density, organic maater and fungal spores, excremental features, pedal structure, organic fine matter.
Breamish (Andesite derived till)	Low pH, high pyrophosphate extractable iron, organic matter and fungal spores, excremental pedofeatures, low c:f.	**Iron Age**	Amorphous organics and fungal spores, excremental pedofeatures.	**125cm (86-180cm)**	Low soil moisture, low loss-on-ignition, mod. bulk density, pre- and post-burial clay coatings, iron pans, high c:f ratio, c:f determined microstructure and mineral fine matter.
Sigwells, Somerset (Lias sand and limestone)	Pre-and post-burial clay coatings, high c:f, low pH, iron pans and nodules, mineral, low loss-on-ignition.	**Bronze age**	Low soil moisture, Iron nodules and pans, Pre- and post-burial clay coatings, low void space, high c:f ratio.	**250cm (181-400cm)**	Low soil moisture, low loss-on-ignition, high bulk density, pre- and post-burial clay coatings, iron nodules and iron pans, moderate c:f ratio, c:f ratio determined microstructure, mineral fine matter.
Milsoms Corner, Somerset (Lias clay and limestone)	Low c:f ratio high dithionite extracatable iron, pre-burial clay coatings and post-burial silty clay coatings, iron mottles.	**Neolithic**	Low soil moisture, iron nodules and depletions, amorphous organics, low void space, high c:f ratio.		
Summary	High c:f ratio, low organics, iron pans and iron nodules associated with post-burial clay coatings, clay movements associated with structural stability?	**Summary**	Rapid break down of organic material to form amorphous residues and gradual loss of fungal spores. Older buried soils compressed (low void space). Bronze Age site strongly correlated with formation of iron pans and nodules, and post-burial clay coatings maybe effect of construction other.	**Summary**	Soil buried <85 cm have high organic matter, ped development and biological activity reflecting closeness of surface and 'welding' of profiles. Deeper buried soils have very low organic matter and biological activity, more compressed and have iron pans and post-burial clay coatings. Associated with conditions isolated from surface, possibly anaerobism and break down of structure as organic matter and fungi lost.
Parent material and depth of burial important in determining nature of post-burial change, site age may be important as organic matter decomposes over time and soils compress, but generally age effects may be related to changing site and overburden type over time. Coarse textured and deeply buried soils prone to iron and clay translocation. More shallowly buried soils may become welded within surface soil profile with additions of organic matter, sustained biological activity and structural development / preservation.					

Site age seems to affect processes of post-burial change in two ways. Firstly the age determines the time over which processes have to operate; for example shell in the Sanday sites has been weathered out of the midden overburdens of the oldest, Neolithic site, this was matched by a general decrease in mean soil pH with time. The presence and type of organic matter in the buried profiles also appears to relate to time since burial, relatively unaltered parenchymatic and lignified tissues are present in the modern buried soils. Black amorphous organics, fungal spores and enchytraeid excrements tended to be present in buried profiles dated between modern and Iron Age. This decrease in organic material corresponded with general decline in the mean level of pyrophosphate extractable iron over time. The second way in which time relates to processes of post-burial change is the correlation between processes and particular periods of time. The relationship may be mediated by environmental conditions and/or constructional methods specific to this time, or it could be that within sites of this age there are indirect influences of parent material and burial depth. The presence of clay void coatings, iron pans and amorphous iron nodules were all correlated with Bronze Age sites in this manner.

Clay coatings, iron nodules and iron pans also tend to be present within the deeply buried profiles (>85cm). In the shallower profiles organic matter and excremental features are more common. This suggests that two broad groups of processes are operating. The first included clay translocation and iron redistribution and relate to burial and isolation of the soils from surface processes and conditions. In these deeply buried profiles loss-on-ignition, soil moisture, and pyrophosphate extractable iron are low and bulk density is relatively high. In the more shallowly buried soils the processes of change appear to be controlled by the action of pedogenic processes within the surface soil which are impinging upon the buried profile. The soils' textural characteristics may be related to the relative depth at which isolation from the surface occurs.

In the final section of this chapter, all three burial factors have been built into general log-linear models in order to examine interactive effects and develop best-fit models that explain in the simplest way, most of the variability in the distribution of different soil features. By constructing the models hierarchically, the interactions due to nesting effects were identified and the main direct two-way interactions between each of the burial factors and the feature of interest analysed. This has shown how the three burial factors hypothesised in chapter 2 as influencing the nature of post-burial change are important contributors to the variability in the system, but the relative influence of each factor varies according to the feature and process being considered. Log-linear model analysis has also demonstrated that the role of site age in the initiation of clay translocation after burial is largely an indirect effect of the interdependence between site age, parent material and burial depth. The final discussion chapter that follows, draws together these threads, evaluates the findings in relation to previous research and discussion and highlights the wider implications of this work.

9. Overview of findings on the processes of post-burial change in archaeologically buried soils.

In the preceding chapters (5,6,7 & 8), the nature of the soil and burial environments have been reconstructed from the evidence obtained from soil thin sections. The chemical and physical properties that characterise the local soil environment have been determined by bulk analyses of unburied reference profiles, whilst the properties associated with the burial environment have been ascertained using the same bulk analyses upon samples from buried profiles. The combination of these two lines of evidence has allowed the identification of pedogenic and post-burial processes that may be operating in these two contrasting environments. This chapter discusses the processes of change further and builds upon the evidence of differences in buried soil features and properties identified in the preceding chapters. The initiation of these processes of change is considered in relation to the research hypotheses and aims outlined in chapter 2. A discussion of the manner in which these processes may be operating is presented. Suggestions about the reasons for their initiation through investigation of observed changes relative to existing literature upon the subject and the Database of British buried soils are put forward. The wider implications of the results and questions raised by this work are discussed, and the main conclusions are summarised.

9.1 A discussion of observed post burial change in relation to the burial environment and burial factors.

9.1.1 A discussion of post-burial clay translocation.

The presence of clay and silt coatings around voids in thin sections has been indicative of clay translocation at a number of the study sites. The determination of these features as forming either before or after burial has involved a study of their distribution relative to inherited microfabrics, their internal composition, their orientation, and their spatial hierarchy within the soil microfabric. Post-burial clay cutans were identified within the sites of Fordhouse Barrow, Somerset and Seater. Two types of post-burial cutans were identified; at Fordhouse Barrow and Sigwells, orange coloured mineral cutans with dusty to silty textures are present. In Seater and Milsoms Corner brown, organic rich dusty and silty clay cutans have been identified that are thought to result from disturbance of the raised land surface. A mechanism for this second type of cutan, therefore, exists in which their formation is not directly dependent upon factors of burial.

Parent material is likely to affect the formation of these brown silty, textural pedofeatures, as slaking of the soil in response to tillage and other disturbance activities appears to be site specific dependent upon soil resilience (Carter and Davidson, 1998; Usai, 1999). Site age may be less important; brown silty textural pedofeatures are found in both Bronze Age and Medieval/Late Norse sites. Depth of burial may be important in terms of the impact of cutan formation upon the microfabric of the buried soil. Both sites are relatively shallowly buried; at Seater depths of overburden are between 55 and 65 cm, at Milsoms Corner burial is to depths of 40 cm and 28 cm. In both of the Milsoms Corner profiles these brown cutans had formed within both the overburden and the buried soil; at Seater no cutans were found within the buried soil, only within the overburden. It seems that the deeper the depth of burial, the less likely that disturbance at the surface will have had a significant effect upon the fabric of the buried soil. The actual depth to which these cutans may form is probably site specific, dependent upon soil structural development and its resilience to disturbance, the intensity of disturbance, and drainage characteristics.

The formation of the second type of cutan (orange, mineral) is less well understood, but it can be hypothesised that its formation is related to the disturbance of the soil materials used in the construction of the site. The three sites at which these cutans were identified were Bronze Age barrow sites, in which the depth of burial was up to 2.5m and consistently over 1m. Image analysis of thin sections from Fordhouse Barrow suggests that their mean area increases as the depth of burial increases. In these sites the texture of the buried soil and barrow material is sands and sand loams. From the field descriptions, ped strength in the reference profile is weak, in the archaeological sites ped development is weak or non-existent and microstructures tend to be inter-grain microaggregate, bridged grain, single grain and pellicular. The organic content as indicated by loss-on-ignition and as seen within thin section is low and bulk density is high. Soil pH at these sites is both acid and neutral, but soil moisture tends to be low, possibly because of the coarse texture and low organic matter. A model of the sites at which processes responsible for the formation of these cutans may operate, can be proposed. All three sites were dated to the Bronze Age, but log-linear analysis has shown that the main direct influences upon the clay coatings are those of depth and region or parent material. The age factor has influenced the formation of coatings more indirectly through its strong interactions with the other factors of burial depth and region/parent material.

Clay translocation involves three distinct component processes, the release of clay, silts and other fine particulates from the soil matrix, their mobilisation and transport in suspension with the soil water, and their deposition within voids to create the coatings diagnostic of this suite of translocation processes. Transportation of clay requires a flow of water through the soil profile. Within the deep profiles where post-burial clay translocation was identified, soil moisture content was lower than in those where no clay translocation has occurred. The arrangement and continuity of voids determine the flow of water through the soil. Water movement will take place preferentially through continuous macrovoids (Hatano *et al.* 1992) in transmission voids greater than 50μm in diameter (Vinten and Nye, 1985) and through cracks and channels with a vertical orientation (Hallaire and Curmi, 1994). In thin sections from Fordhouse Barrow and Sigwells the cutans were found to be occupying voids greater than 100μm in diameter which corresponds with the theories of preferential flow paths for soil water and clay suspensions. The Fordhouse Barrow site was found to have relatively high void space in thin section and Sigwells sites relatively low void space. A key finding of this study, therefore is that total void space, therefore, appears not to be a determinant in the formation of clay cutans.

The deposition of clay from suspension in the soil water may involve two different processes. The first of these is suspension retention in which down profile water flow is impeded due to changes in soil texture and soil porosity or because of the presence of physical barriers such as an iron pan, stone, fragipan or water table. Clay held in suspension, may, under conditions of stagnancy as experienced in a perched or ground water table, settle out to coat the surrounding void wall (Sullivan, 1994; Vinten and Nye, 1985). Alternatively, the clay may be deposited when the soil water flowing through macro and meso voids, the preferred paths of soil water flow, is absorbed into the surrounding soil matrix through the micro-void system (Mckeague, 1983). This absorption may occur when the conducting voids are saturated relative to the surrounding soil matrix; i.e. the water potential of the voids is greater than that of the soil matrix. Particulates held in suspension will then be deposited upon the void walls as the soil water is filtered through. Soil water retention has been found to decrease rapidly in voids >300μm in diameter (Vogel and Babel, 1994). There is also a suggestion that soil water flow will be impeded more in channel voids rather than in cracks because of void morphology (Hallaire and Curmi, 1994). In the soils and sediments at both Fordhouse Barrow and Sigwells, cutans are found most often in voids between 100 and 300μm in diameter, suggesting that suspension retention may have been a factor in their formation. The cutans are predominantly found coating channel type voids. However, in none of the other sites studied where clay coatings are not present, are channels of less than 300μm diameter absent. Within all the archaeological profiles studied, discontinuities in terms of material type and porosity are common and include the buried soil / overburden interface, junctions between various constructional units, and the presence of iron pans. Again, therefore, the opportunity for clay deposition is not expected to be a limiting factor in the formation of void cutan features. This finding is further supported by the lack of consistency in the void characteristics between the Fordhouse and Sigwells sites where clay cutan formation has occurred after burial.

The remaining stage in the process of clay translocation is the release of clay and silt from the soil groundmass. This assumes that the soils and sediments contain a source of clay for mobilisation and translocation. The buried soils and overburdens of almost all sites studied in this thesis have loam or clay loam textures which include between 5 and 40 % clay (Hodgson, 1976) and are a result of the parent material type. The sites of Sigwells are some of the poorest in clay (very fine sandy loam and sands), but clay translocation is a significant process both prior to and following site construction. A source of clay and silt, therefore, appears not to have been a limiting factor in the formation of clay cutans in the sites studied. Neither is it the determining factor as post-burial clay translocation has not occurred within the more clay rich soils studied.

Clay and silt particulates are normally held within the soil structures, the stability of which depend upon the presence of organic compounds (Fortun *et al.*, 1989), fungal and root structures and exudates (Molope *et al.*, 1987), microbial biomass (Edgerton *et al.*, 1995), and cations, including polyvalent iron (Giovanni and Sequi, 1976; Chisci *et al.*, 1978). The correlation between these soil components and the presence of post-burial clay cutans was explored in chapter 6. It was found that in the deeply buried soils where post-burial cutans are present, there is a strong tendency for organic matter (fresh and decayed, coarse and fine), fungal spores and excremental features to be absent. The stabilising elements of the soil structure, therefore, are relatively rare within the soils in which post-burial translocation of clay has occurred. These sites also have relatively little or no ped development, even within the reference soil profiles ped strength was low. In all of these sites, pre-burial cutans interpreted as resulting from anthropogenic disturbance were also present. These features are known not to form in all soils subjected to disturbance, and the strength of the soil and its resistance to disturbance is one possible reason for this (Carter and Davidson, 1998; Usai, 1999). The strong positive correlation between the presence of pre- and post-burial cutans suggests that the same soil properties that encourage clay translocation in the disturbed soils also encourage clay translocation in response to burial. This is not an exclusive relationship, however, as sites with pre-burial cutans do not all contain post-burial textural pedofeatures, and so the structural stability of the soil materials prior to site construction cannot entirely explain post-burial clay translocation processes. Construction and burial itself, therefore, must be having an effect and burial depth and site age may be amongst the important determining factors.

Besides an inherent instability in the soil, therefore, burial itself must also play a role in the further destabilisation of soil structures causing the release of clay and silt into the soil water. Studies into the structural alterations in modern soil stores may offer some insight into such a set of processes. The structural changes that occur at the base of a soil mound are a reduction in porosity, increased bulk density, the destruction of original soil structure and occasionally the formation of large aggregates (Abdul-

Kareem and McRae, 1984; Harris and Birch, 1989; Hunter and Currie, 1956). The formation of these aggregates and the reduction in soil stability appears not only to be a response to the forces of compression that these materials are subjected to, but is also related to the massive decline in fungal biomass immediately following burial (Harris and Birch 1989; 1990). This decline in fungal biomass is related to constructional disturbance and the development of anaerobic conditions. The fungal biomass bonds soil ped structures and infers a resistance upon them to forces of compression (Harris and Birch, 1989). The depth at which anaerobic conditions develop has been found to vary according to soil texture, in clay soils 0.3m of overburden is sufficient and in sandy soils depths of 2m are required (Abdul-Kareem and McRae, 1984). The reduction and absence of fungal spores in buried soils, particularly those buried to depths greater than 86cm, was noted in the archaeological sites studied. The observed reduction in organic matter within the studied buried profiles over time could also be expected to further destabilise the soil structure (Chaney and Swift, 1984; Fortun *et al.*, 1989).

During site construction the soil materials and the structures they contain are subjected to another form of stress, forces of shear, that act in a way difficult for even structured soils to resist (Kooistra and Tovey, 1994). This constructional disturbance also destroys the fungal hyphae that bind the structures (Harris *et al.*, 1989). Even prior to the deposition of the constructional materials, the structural units they contain would have begun to deteriorate. In regions of the mound where anaerobism develops and soil pH is depressed, the dispersivity of clays may also be enhanced (Chorom *et al.*, 1994; Hunter and Currie, 1956). Mean soil pH in the buried profiles studied tended to be significantly higher than that of the unburied reference profiles. However, the within profile variation in soil pH suggests that in the deeply buried soils soil pH decreases with depth down the profile. It is within these deeply buried soils that post-burial clay translocation occurs. The deeply buried soils also tend to be coarser textured with moderate to high coarse to fine ratios. In loams and sands anaerobic conditions require burial of between 1.3 and 2m to develop (Abdul-Kareem and McRae, 1984). In the same study anaerobism in heavier clay soils was found to develop at depths of only 0.3m. It is surprising then that there is an absence of iron pans, mineral type post-burial cutans, and no increase in amorphous iron nodules, within the shallowly buried, clay rich sediments at Milsoms Corner, particularly as the heavy textured sediments burying the soil profile also have an apparent lack of organic matter, fungal spores and earthworm activity. The suggestion is that the structural strength endowed upon the sediments by the cohesitivity of the clay fraction has prevented the mobilization of the iron and clay fractions despite clear evidence of anaerobism within this profile.

The formation of the organic rich cutans in response to disturbance may form at any point in the history of the buried soil. Courty *et al.* (1989) note that textural features may appear quickly in a soil, within a few hours or days, but that the formation of an argillic horizon is thought to require hundreds of thousands of years. Particle size analysis of the Fordhouse Barrow and Somerset sites, showed no significant increase in total clay content over time, certainly not to the extent required for classification as an argillic horizon. The hypothesised breakdown in aggregate stability within the burial environment, the exposed mound surface and this relatively low level of clay enrichment may suggest that the formation of these features covers a period of tens of years rather than thousands. The initiation of these processes appears to have been in response to the specific set of depth, constructional, climatic and parent material conditions favoured by buried soil sites of the Bronze Age.

9.1.2 A discussion of post-burial iron redistribution.

Amorphous iron nodules, coatings and pans, impregnation of stone clasts by iron, and mottling of the soil matrix were identified in one form or another from all of the reference and buried sites studied. Distinguishing between pre- and post-burial features, however, was not as easy as clay cutans and no consistent means of doing so was found. The determination of post-burial iron features was made by establishing where significant differences in presence between the buried and unburied soils occurred. The presence of iron nodules and pans is found to correlate strongly with buried soils, suggesting that the processes of their formation are enhanced by conditions within the burial environment.

Mottling of the soil matrix and the impregnation of stone clasts by iron compounds are not significantly related to burial. Although mottling within the overburden at

Wether Hill had clearly formed after construction of the earth bank, there is no evidence that burial has significantly encouraged the formation of mottle and impregnated stone features at the sites studied. This is at odds with the evidence that already exists in the archaeological, Quaternary and the modern, quarry soil store literature. In modern soil stores, gleying of the base of the mound has been frequently reported as a perched water table develops at the interface between the buried soil and the overburden (Abdul-Kareem and McRae, 1984). Archaeologically, many buried soils have been noted to contain evidence of mottling that has formed after burial (Allen and Macphail, 1987), and burial gleization is a well-documented phenomenon in Quaternary palaeosol literature (Pipujol and Buurman 1994). Many of the buried soils in this study include mottle features, but when compared with the reference profile, groundwater gleying is usually also a feature of these non-buried sites. The presence/absence criteria adopted in this study may not have been sensitive enough to detect any promotion of gleying processes within the buried soils, although any mottling of horizons not previously affected should have been recorded.

The formation of nodule and pan features is positively correlated with the presence of post-burial clay coatings, and as with those features discussed in section 9.1.1, are negatively correlated with organic matter, fungal spores and excremental features. Nodule and pan features have been noted within archaeologically buried soils. Increased numbers of amorphous iron nodules were noted in the experimental earthwork at Overton Down after only 32 years (Crowther *et al.*, 1996). In Denmark iron pans surrounding the core of Bronze Age barrows must have formed very rapidly after construction judging by the preservation of organic materials (Breunig-Madsen and Holst, 1996; 1998). The way in which iron behaves within the burial environment, however, has been the subject of discussion. Two main theories have been proposed for the movement of iron within and beneath archaeological sites.

The first of these, podzolisation, is the mobilisation of iron within organic chelates and aluminium hydroxide sols. The possibility of podzolisation beneath Bronze Age barrows in Holland was first raised by Waterbolk (1964, cited from Runia and Buurman, 1987). Runia and Buurman's work (1987) has disputed this possibility, but has shown that some enhancement of podzols may occur as material leaches through sods in the barrow core. Iron rich lamellae can form in the sods through the immobilisation of organo-metallic chelates percolating through the profile (Runia, 1988; Runia and Buurman 1987). They also believe that during the Bronze Age, podzolisation processes were initiated at pHs higher (pH 4) than those required in similar soils today (pH 3). Dormaar and Lutwick (1983) have also examined iron fractions within buried soils, and they conclude that following burial, decomposition of the humic fraction leads to a decrease in the level of pyrophosphate extractable iron as organic carbon levels drop, masking previous podzolisation processes.

Another set of processes involved in the redistribution of iron, and that have been shown to operate in buried soils are those associated with redox processes deep within the overburden and buried soil. The mobility of iron and manganese is a function of environmental pH and Eh (Collins and Buol, 1970). In soils of low pH and/or negative Eh, as occurs in an anaerobic environment, iron exists principally in the more mobile ferrous form (Fe^{2+}). Under aerobic conditions, the less mobile, ferric iron (Fe^{3+}) is dominant. In the reconstruction of a barrow in Denmark, conditions conducive to nodule and pan formation had developed within only 7 days and after 1 month the presence of ferrous iron was detected (Breunig-Madsen and Holst, 1996; 1998). Although mottling features are not found to be greatly enhanced by burial of the soils in this study, mottling of the buried soil and overburden were noted within many sites including Fordhouse Barrow. Fordhouse Barrow also contained distinctive post-burial iron pans in association with the buried soil / overburden interface and turves used in mound construction. The correlation between organic material and iron pan formation is consistent with the theory of oxidation-reduction processes as organic materials in modern soil stores create localised pockets of intense anaerobism enhanced by the anaerobic decomposition of the organic matter (Abdul-Kareem and McRae, 1984). Similar processes were concluded to be responsible for the formation of iron pans rich in iron and manganese, but relatively poor in aluminium in the upper layers of podzols buried beneath peat (Conry *et al.*, 1996). The lack of correlation between nodule and pan presence and levels of pyrophosphate extractable iron in the sites studied also supports the suggestion that redox conditions are the cause.

Iron nodule and iron pan formation are found to correlate with the deeply buried soils in which the development of anaerobic conditions is most likely, and also in the sites dating to the Bronze Age. The sites also tend to have sandy and sandy loam textures.

The strong correlation established in this study between the occurrence of these iron features and of post-burial clay coatings suggests that the burial conditions required to initiate the processes of their formation are similar (section 9.1.1). The best-fit log-linear model suggests that site age, along with parent material and burial depth, is more important in the formation of iron nodules than post-burial clay coatings, although no good fitting model could be determined. Certainly iron pans at sites previously excavated have tended to date to the Bronze Age although their presence in Neolithic and Medieval sites has also been noted (Holst pers. comm.). Likewise, although iron pan formation in the buried soils and sites discussed in this section have tended to be on sandy sites, their presence in heavier clayey soils has also been noted. The rapid formation of iron nodules and pans in modern experimental sites suggests that climatic conditions within the Bronze Age are not the only factors associated with site age that are important. Indirect age effects and their influence upon burial depth, parent material and site construction methods may be more important than climate, as was concluded for clay translocation. Finally, the coating of iron features by clay pedofeatures indicates that iron features form more rapidly than the textural features. It may be, therefore, that the redoximorphic redistribution of iron is a further factor in the destabilisation of soil structure and the onset of clay translocation.

9.1.3 A brief discussion of biological and other physical and chemical processes of post-burial change.

Through the study of processes of clay translocation and iron redistribution in the buried soils, a number of other features associated with post-burial change have also been identified. Many of these features, and the processes that led to their formation, are inter-linked so that the properties that initiate one process may also initiate another, and the action of one set of processes may have implications for a second. In this way, by studying the wider burial environment, a better understanding of the processes of interest may be gained. Other features that have been identified in the course of this study and which are associated with processes of post-burial change in archaeologically buried soils are the weathering of shell and bone and calcification and decalcification of the soil and sediment micro-fabrics. Earthworms and enchytraeids have reworked the soils and sediments, and organic matter has been decomposed and /or added to the profiles. The mean bulk density of the soils and sediments has increased after burial, whilst the voids present in thin section tend to be less spherical in the buried soils than in the unburied soils.

Many of these processes have been indirectly discussed within the previous two sections. The increase in bulk density following burial is an expected response to compressive forces and the relationship between burial depth and bulk density is also no surprise (figure 8.2). If anaerobism and structural instability are developing in the deeply buried soils they may act to further increase the bulk density of the buried soil. The reduction in excremental features in the deeply buried soils can also be predicted as increased bulk density has been shown in many studies to adversely affect earthworm numbers (Pizl, 1992; Rushton, 1986; Sochtig and Larin, 1992). The depressed numbers in the Bronze Age sites are probably related to the relatively inorganic nature of the soils and sediments within the sites studied from this period.

The occurrence and nature in soil organics were found to reflect not only regional variation, but also site age and burial depth. In shallowly buried soils organic materials of all types were more frequent suggesting the biological welding of shallowly buried soils with the developing surface soil through the action of soil fauna, flora and plant roots. Over time a sequence in organic fractions present was also identified. Parenchymatic tissues tended to be found in the youngest buried sites, fungal spores in soils dating from modern to the Iron Age, and black amorphous organics in the buried soils and archaeological sediments from Norse and Iron Age sites. Yellow and red amorphous organics were frequently present in all sites except those of the Bronze Age. A sequence of decay and alteration of the organic matter, therefore, is suggested.

Decalcification of shell over time was identified in the sites of Sanday where this material was found within the midden overburdens. Shell disappears from these sites between the Iron Age and the Neolithic. Its original presence within the Neolithic site is indicated by the presence of decalcified shell remains. Decalcification over these long time scales, however, is specific to the alkaline deposits rich in shell, bone and ash and subject to additions of salt spray, that were studied. A second weathering process recorded was that affecting bone, the formation of calcium iron phosphates and their translocation to form isotropic coatings around nearby voids. This process has been described by Jenkins (1994), and again the processes and rates involved are likely to be site specific. Calcification of the buried soil, through the leaching of base cations down profile out of the overburden was also evident in the Sanday sites; the modern and Norse sites showed clear evidence of this. The continued addition of salt spray to the soils and archaeological sediments, however, masks potential effects of time and burial depth upon this process.

With the exception of the decomposition of organic matter and increasing bulk density, each of these processes is in some way related to pedogenic processes operating within the developing surface profile. Calcification, the addition of organic matter, and biological reworking of the soils and sediments can all be viewed as processes of welding in which the buried soil is not sufficiently isolated from the new land surface.

9.1.4 A comparison of study results with the database of British buried sites.

In chapter 1 a database of archaeologically buried soils in the British Isles was presented. This database incorporated information about soil type, location, micromorphology, and anthropogenic and post-burial interpretations. Can the data contained within the database be used to validate the findings from this study?

A number of prospective problems in this approach exist. The first is a potential circularity of argument. The database was constructed at the start of this study in order to collect information and to guide the research, so using the same data set to validate the results is obviously unsound. The data set, however, was used initially only to identify the types of post-burial processes that may affect archaeologically buried soils. No correlations were made between the occurrence of these processes of change and regional, age and depth characteristics. The sampling design used in this research was deliberately wide, aiming to cover soils with a range of textures and base status, with ages covering the extent of deliberately constructed upstanding archaeology in Britain, and as wide a range of depths as possible.

A second problem is the nature of the data set itself. The references used for many of the sites contained only scant information upon many of the issues and the drawback of the database is that the absence of information is not evidence of the absence of a feature or process. Therefore, there is a strong bias towards positive information; this is particularly important as the distribution of sites is strongly correlated with the research areas of particular researchers, creating the potential for a double bias in the results. In practice it was found that the large number of sites at which information concerning observed effects of post-burial change were absent dominated the data set. The size of the data subsets and the proportion of sites for which information is present, determine percentages based upon sites of specific age and parent material. Ratios between sites with an observed absence or observed presence of a particular feature were also flawed because of the positive recording bias. Tables of parent material/post-burial change and site age/post-burial change queries are included in the query window of the full database provided on floppy disk in Appendix 1. The results show no corroboration with the results of this study, but because of the problems outlined above, neither do they invalidate it.

What the database does show is the small number of sites from which evidence of post-burial change has been specifically recorded in the site report / publication. Of the 209 soils included in the database, 53 record evidence of nodule, pan or mottle formation after burial. Post-burial clay translocation and the possible formation of clay cutans is recorded for 13 sites; structural changes, usually the result of compression are documented for 12 sites, and biological alterations at 13 sites. In comparison to the results of this study the recorded incidence of biological reworking and alteration of the soil appear to be low. In all sites except for those in the Somerset region, some degree of biological reworking was recorded (table 5.28). Of the 13 sites at which biological reworking was recorded, 2 also contained evidence of clay translocation and 5 included evidence of iron redistribution. Considering the very low numbers of sites at which either biological or translocation processes were noted, these correlations suggest that the action of these processes is in some way connected. However, the results of this study do not support this; processes of both clay translocation and iron redistribution tend to occur in sites at which levels of biological activity are low. The pattern suggested by the database may suggest that the results of this study are only valid for the sites studied. A second possibility is that a site report in which one process of change has been noted is more likely to also note a second or third process as evidence of post-burial change is being actively looked for and recorded. In the light of logical process explanations (sections 9.1.1 and 9.1.2) for the negative correlation between iron redistribution or clay translocation and biological activity, it is the latter explanation that is most likely.

Of the processes identified in this database most have been identified in the course of this study; only vivianite, gypsum, pyrite and sodium carbonate formation were not found. A wide and representative range of processes of post-burial change, therefore, has been covered within this study. The results of this study, therefore, have revealed the activity of post-burial processes of change, and identified the soils and sediments in which these processes are expected to occur. The results have also highlighted the need for a systematic approach to the recognition and recording of evidence of post-burial change.

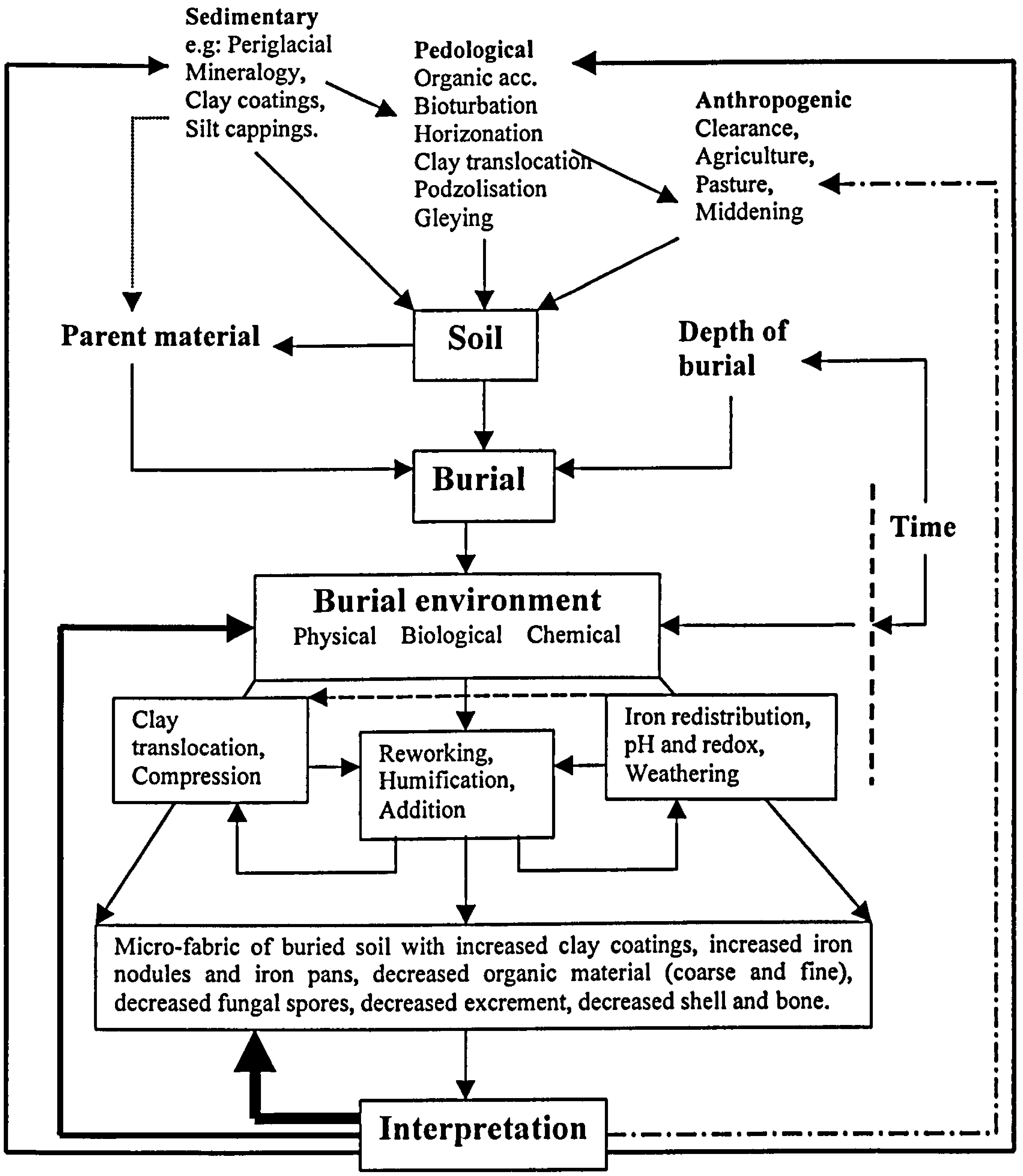
9.1.5 A discussion on the nature of the burial environment and processes of change.

The research model provides a broad overview that encompasses the development, burial, sampling and interpretation of buried soils. The model was first presented in figure 2.1. At the top of the model are the pre-burial pedological and anthopogenic disturbance processes that determine the nature and development of the soil prior to burial. At a certain point in time the soil is buried and the precise nature of burial is site specific. The previous three chapters have sought to categorise and quantify the effects of three of these burial factors, namely the local parent material and depth to which burial occurs and the nature of the overburden material has also been considered. These burial factors elicit a response in the buried soil through the development of conditions specific to the burial environment. The nature of the burial environment has been addressed through the analysis of bulk and thin section samples. Processes of post-burial change, including phases of clay translocation and iron redistribution operate, in response to the changing physical and chemical properties of the burial environment. These processes operate over time and as a result site age becomes the third burial factor. The result of these post-burial processes is the alteration of the buried soil fabric as seen in thin section. Analysis of the data has explored the link between burial factors, the development of conditions in the burial environment and the alteration of the soil microfabric. The final link in this theoretical model of post-burial change is the effect of change upon the microfabric of the original soil profile and the consequences of change for thin section interpretation.

Each section of the original model has, therefore, been evaluated in the last four chapters and more specific models of the formation of individual types of features have been developed. The main interactions and feed backs identified within the context of the research model are presented in figure 9.1. The initial model of post-burial change and its effects upon the fabric of buried soils appears to be supported by the results of this study.

The inherited sedimentary features from the earliest phases of soil development in the profiles studied identified glacial tills with silty clay coatings and silt cappings providing evidence of periglacial disturbance of the sediments prior to pedognenesis. The nature of the buried soil included well developed brown earths, acid brown earths and podzols as well as more skeletal soils developed upon shell sand and clay deposits. Pedogenic processes that were discerned from the buried soils included the accumulation of organic matter, bioturbation and the development of distinct soil horizons, besides the more specific pedogenic processes of clay translocation, podzolisation and gleying. Within the microfabric of the soils, episodes of clearance, agricultural and pastoral activity were identified, although at some sites with a known agricultural history, no micromorphological evidence was found. After burial, the depth of burial and the soils' textural and drainage characteristics largely determine the response of the buried soil to burial and the processes of post-burial change that operate within the burial environment. The nature of these processes, the feed-backs between them, and their relationship with burial factors of parent material, depth of burial and site age and type have been covered comprehensively within chapters 6, 7, and 8.

Figure 9.1: Research model with processes, features, feed backs and interactions identified from the results of this study.



Arrows show direction of influence.
Dashed timeline illustrates the influence of time as a continuum of change.
Thickness of interpretation feed-back lines is a subjective measure of how well features associated with different phases in soil history survive and the level of interpretation that can be made concerning them.

Interpretation of thin sections from archaeologically buried sites depends upon the survival and alteration of the pre-burial features of interest. The micro-fabric of the buried soil is a direct reflection of the conditions within the burial environment. The effect of the burial environment upon the soil micro-fabric has been the focus of this study and is a function of the pre-burial soil properties and the factors of burial. It is difficult to quantify the survival of the original soil fabric as the pre-burial situation is an unknown. However, in each case the pedogenic features identified within the unburied reference soil were also evident within thin sections from the buried soil. Those sedimentological features present within the pedogenically altered reference soils were also visible in the buried soils. Burial, therefore, appears to have only limited implications for the survival of these structures that have already been subjected to pedogenic alteration. The survival of anthropogenic features is more difficult still to assess as there is no reference for the effects of these processes within the local soils. The identification of features interpreted as relating to anthropogenic disturbance episodes within the buried soils, suggests that they are, in many cases at least, surviving. Section 9.2 deals more fully with the question of the survival of the pre-burial micro-fabric.

9.2 The wider implications of the results to thin section interpretation and sampling of archaeologically buried soils.

Although the research hypotheses concerned the effects of three specific factors, one of the wider aims of this study was to assess the implications of post-burial change of buried soil microfabrics upon thin section analysis and interpretation. This study has involved the detailed study and documentation of specific processes, but it is the wider implications of their effects upon the fabric of buried soils for archaeologists and other researchers that are of particular interest. Two main implications for micromorphologists and archaeologists arise from this investigation.

The first is an indirect result of the work into processes of post-burial change and the formation of clay coatings. This concerns the formation of pre-burial dusty coatings in response to soil disturbance processes such as clearance and agriculture. The formation of these features is not an assured product of such disturbance processes as many soils from contexts with a known disturbance history do not contain these dusty coatings; the site of Turf Knowe, Northumberland is one such example. Macphail (1992) has suggested that the formation of textural features is a function of structural stability of the soil, findings echoed by Davidson and Carter (1998), Carter and Davidson (1998), Usai (1999) and the results of this study. If the formation of both pre- and post-burial clay coatings is related to structural stability, the presence of clear post-burial features in thin section may suggest that the absence of pre-burial features reflects a real absence of disturbance? More work needs to be done to establish a relationship. A second possibility is that in those buried soils where disturbance features are now absent, pre-existing features have been destroyed by post-burial change. However, the survival of features in other sites, even where extensive alteration of the micro-fabric has occurred would suggest that this is not the case.

The second and more direct implication is that by altering the microfabric of buried soils, processes of post-burial change are affecting the nature, quantity and quality of information that the buried soil contains. This has important implications for site preservation and the 'worth' of the site to different concerned parties. For example, the alteration of the soil and sediment micro-fabric is of little concern to the casual site visitor who is more interested in the surface expression of the site. However, to micromorphologists who are interested in reconstructing past pedological, anthropogenic and environmental site histories, the formation of clay void coatings and amorphous iron nodules and pans after burial is important. Other potential problems are the inclusion of organic matter and biological activity and the secondary formation of brown organic cutans from surface disturbance, that are found within more shallowly buried soils. To overcome these problems, as undisturbed a soil as possible, or a soil in which the post-burial alteration is well understood is desirable. The results of this study have shown that both deeply and shallowly buried soils are affected by processes of post-burial change; the nature of the processes differs according to burial depth. Soils of all textural types and chemical status will be affected in some way, and even very recently buried sites (3-5 years) are affected although some processes of change require more time before their effects become evident in the soil fabric. Perfect preservation of these buried soils, therefore, will never be achieved.

The discussion of site preservation and the worth of that site as a source of pedological, environmental and archaeological information have implications for the sampling of buried sites to obtain thin sections. The aim of any sampling exercise is to retrieve a representative sample that will allow particular hypotheses to be tested. The nature of the sample that is required, therefore, is determined by the research hypotheses that are to be tested. In turn, it is the research hypothesis that will determine which kinds of post-burial alterations are likely to be important and which can be tolerated or are even sought. In studies such as this, where it is the post-burial processes themselves that are the focus of interest, a range of alterations are sought. In most cases, however, it is the information that the soil contains about conditions prior to burial that is important. The results of this study have shown that the microfabric of all buried soils will be altered to some extent by processes of post-burial change. In shallowly buried soils the changes are likely to involve its reworking by soil fauna and the intrusion of plant roots as was first suggested by Atkinson (1957); such processes may destroy pre-burial structures and pedofeatures. A further source of confusion may be the misidentification of features formed by processes operating at the new surface, particularly the possible intrusion of organic silty cutans formed by agriculture. In all these shallowly buried soils pedological and sedimentological information were still evident, although at the Turf Knowe site, anthropogenic disturbance features were absent from this cultivated soil. However, as has been discussed, their absence immediately prior to burial is a more likely explanation than the subsequent loss of disturbance pedofeatures from Turf Knowe. If the soil is heavily turbated, this can be envisaged to have profound implications for the survival of the original soil and in particular for the spatial and hierarchical characteristics of the features in these soils.

In deeper soils new pedofeatures may be formed in response to the changing properties of the burial environment. These features, as has been shown, may result in the obscuration of pedofeatures relating to earlier phases in the soils' evolution. In the soils studied as part of this study, the extent of the post-burial alteration was never so advanced that no information about the original soil could be gained. The sedimentological history of the soils was as clear within the buried soils as the unburied reference soils, suggesting that the influence of burial processes upon these features found at depth in the soil profile is negligible.

All of these post-burial changes are more easily identified if appropriate samples are taken. In all cases the processes affecting the buried soil have also been operating within the overburden. The systematic inclusion of samples from the overlying sediments, therefore, should be standard as this often helps with the identification of specific processes that have resulted in the feature of interest. The taking of undisturbed reference profiles was also found to be very useful in this study as a comparison for the buried profile. In the deeper Bronze Age profiles of Fordhouse Barrow where post-burial processes of clay translocation had occurred, the buried soil least visibly affected was the shallowest profile that had been sealed beneath a layer of stonework. Where possible, therefore, in soils that upon the basis of this study are prone to clay translocation (coarse textured, deeply buried Bronze Age sites) the sampling of such 'sealed' contexts may be advisable. In all descriptions and interpretations of thin sections from buried contexts, the possible effects of post-burial change must be considered.

9.3 Outcomes of the research hypotheses and aims.

Three central research hypotheses were presented in chapter 2 and it is these that this research has attempted to test. These were:

1. The parent material from which a soil is formed influences the response of that soil to burial and the subsequent development of the buried soil micro-fabric.
2. The time for which a soil has been buried influences the nature of the post-burial processes affecting it and the severity of their effects in thin section.
3. The depth of material burying a soil affects the nature of processes of post-burial change and the development of the buried soil micro-fabric.

The following three sections address each of these hypotheses in turn in order to assess their validity.

9.3.1 Assessing the hypothesis that parent material affects processes of post-burial change in archaeologically buried soils.

Parent material type was hypothesised to affect the nature of post-burial change in archaeologically buried soils. It was suggested that parent material as a determinant of the soils' physical and chemical properties, would in turn influence the response of that soil to burial, i.e. it affects the resistance of soil properties to change. To test this hypothesis, the micromorphology, physical and chemical properties of buried soils within five study regions each of which contained a different parent material type were examined. Significant differences in soil development and post-burial change between these regions were identified.

Regional environmental differences were present besides that of parent material, for example the localised actions of salt spray in Sanday, and the differential anthropogenic disturbance of the soils prior to site construction. However, parent material does seem to have been a critical factor in regional differences. In particular, the soils' textural characteristics and those of the overlying material appear to be important in determining the processes of post-burial change that may operate. In the coarser textured sand and sand loam soils, post-burial translocation of clay and iron were noted, whilst in the finer textured clay loam soils, biological activity and weathering processes appear to have been more dominant.

Soil pH was originally thought likely to be important in determining the nature of post-burial change. Soil pH has been found to be a key factor in determining the iron fractions present within the soil, and their mobility (Collins and Buol, 1970); the more mobile ferrous ion (Fe^{2+}) is favoured in environments with a low pH. The dispersion of clay has also been linked with low soil pH (Chorom *et al.*, 1994), although Aguilar *et al.*, (1983) have shown that clay cutans can also form in calcareous soils. It was expected, therefore, that the soils from the Somerset region, which have inputs of Oolitic limestone, would not show evidence of either of these potential post-burial processes, and the soils would be more resistant to compression as their structural stability should be relatively high. In the field the freely-draining, sandy soils of Sigwells were weakly acidic to neutral and it was these decalcified sediments that showed evidence of post-burial clay translocation and iron redistribution; the heavier clay soils of Milsoms Corner were still alkaline. However, the pH relationship has not been supported by this study as acid, neutral, and alkaline soils have all been affected in some way by post-burial change. In the soils of Somerset both clay translocation and iron redistribution had operated after burial, in contrast to the more acid soils of Breamish where no clay translocation and more modest levels of iron redistribution were present. In the alkaline sediments of Milsoms Corner, the clay translocation was in response to surface disturbance rather than the constructional disturbance suggested as an explanation for the more acid Sigwells sites. In the high pH of the Milsoms Corner sediments, the identified iron redistribution could only have occurred in conditions of low negative Eh.

Parent material types, therefore, are important in determining the processes of post-burial change that may operate within archaeologically buried soils as was initially hypothesised. This study has shown that contrary to the author's expectations that soil pH would be a crucial factor, it is the soils' textural and structural characteristics that are most important in determining the nature of alteration processes acting in the burial environment. Soil pH was found only to be important locally in initiating or retarding processes of bone and shell weathering.

9.3.2 Assessing the hypothesis that time since burial affects processes of post-burial change in archaeologically buried soils.

Time since burial was hypothesised as a factor in post-burial change, not because it would affect the nature of the processes operating, but because it would determine the length of time that any one process has to operate. As different processes operate over widely different time scales, it was hypothesised that time since burial would affect the expression of the results of any process within the microfabric of the buried soil. Analysis of the results from this study has shown that buried soils of certain ages have a strong relationship with the particular features of post-burial change that they tend to contain. It has also been suggested from the results that time acts in two ways. The first of these is that time is acting as a continuum against which processes of post-burial change are operating. The longer the period of time a soil has been buried, the greater the accumulated effects of that process will be within the micro-fabric of the buried soil. This action of time has been illustrated by the weathering of shell and bone over time and by the possible recolonisation by soil fauna and flora after burial. The work of Bockheim (1980) suggests that soil processes operate as a logarithmic function of time, so that although there is a decline in rates of change over time, a 'steady state' is never actually achieved. The same rates can be envisaged for the processes of post-burial change in archaeologically buried soils. This system also assumes a steady environment and any disturbance to the system such as changes in hydrological or climatic conditions, may kick-start a new series of processes in response, as has been identified by Kemp and Faulkner (1998).

The second way in which time has been seen to be operating is the correlation between presence and absence of certain post-burial features with particular periods of time. Of particular interest here is the occurrence of post-burial clay coatings, iron nodules and iron pans within buried soils and their overlying sites dating to the Bronze Age. Many of these correlations may be an artefact of the sampling design, and log-linear analysis has shown that in the formation of post-burial clay coatings, the age effect is largely indirect through its interaction with the factors of parent material and burial depth. The 'Bronze-Age effect', however, has been noted in other studies of post-burial change, particularly in association with processes of iron redistribution. In Denmark, Bronze Age barrows are known for the frequent presence of iron pans encapsulating the mound core (Breunig-Madsen and Holst, 1996; 1998). In Holland, Bronze Age barrows have been the focus of studies into the formation of amorphous iron lamellae and possible secondary podzolisation (Runia, 1988; Runia and Buurman, 1987). Meanwhile in Britain, the presence of iron pans at the base of Bronze Age barrows have been frequently identified (for example, French, 1994) and include the Bronze Age barrow sites of this study. Translocation of mineral clay and silt in this study has also been shown to correlate with sites constructed in the Bronze Age. The real differences separating this period from the others studied appear to be constructional and/or textural rather than climatic.

Time since burial, therefore, has been shown to be a significant factor in the determination of processes of post-burial change, and the effects of these processes upon the micro-fabric of archaeologically buried soils. The manner by which time exerts its influence, however, is subtler than at first assumed. Time does appear to be acting as a continuum of change for certain weathering and organic decomposition processes. However, for many other processes it is the specific suite of climatic, anthropogenic and regional factors that are indirectly associated with site age and which are important in initiating processes of post-burial change. In chapter 7 the importance of climate upon clay translocation and iron redistribution was assessed, as the Late Bronze Age is marked by a deterioration in climatic conditions. The lack of such features from sites dating to the Iron Age, which was also affected by the cooler, wetter climate of the Sub-Atlantic period, suggests that the deteriorating climate cannot be the whole answer. The similar lack of features from Neolithic sites dating to the warmer, drier Sub-Boreal period that continued throughout the Early Bronze Age when the affected sites were constructed, also refutes a correlation between these processes and the prevailing climate at the time. The Bronze Age effects, from the results presented and the log-linear models produced, appear to be having an indirect influence, stemming from the constructional and spatial factors of site type, depth and parent material.

The specificity of the conditions required to initiate these processes essentially masks the rate functions of these processes, as only soils of a certain age exhibit the characteristics. The results from experimental earthworks at Overton Down, Wareham and in Denmark, however, suggest that many of these processes are initiated very soon after burial and their effects in thin section may be visible within a relatively short period of time (Bell *et al.*, 1996; Breunig-Madsen and Holst, 1998; Crowther *et al.*, 1996). Redox iron redistribution appears to be rapidly initiated within the anaerobic portions of the overburden and buried soil. Clay illuviation may occur somewhat later as the clay coatings, where found in combination with iron pans, were always found coating the latter.

9.3.3 Assessing the hypothesis that depth of burial affects processes of post-burial change in archaeologically buried soils.

Depth of burial was hypothesised to affect buried soils in two ways. Burial may isolate a soil from the atmosphere and from pedogenic or other disturbance processes that are operating at the new surface. The depth of burial will also affect the physical load of material beneath which the soil is buried and so will determine the forces of compression to which it is exposed. Significant relationships between burial depth and the nature of processes of change were identified in the sites studied. In the shallowest buried soils (0-85cm), soil biota and the inclusion of organic material appear to be the main processes of change. In the deeper buried soils (86-400cm), processes of clay translocation and iron redistribution forming clay coatings, iron nodules and iron pans were the dominant processes.

The processes of post-burial change that are associated with the surface processes of pedogenesis and disturbance are those that mainly affect the shallowly buried soils. In these cases the buried profile is 'welded' chemically, physically and biologically within the soil profile developing at the new land surface. Biological activity and the addition of organic matter, principally through root penetration and their *in-situ* decomposition, fall into this category. The calcification and decalcification of the buried soils and sediments of Sanday are also included in this category as it is the surface addition of salt spray, or the leaching of the base rich midden materials that results in these post-burial alterations. Disturbance of the new land surface may cause the formation of silty clay coatings. The actions of soil fauna and root penetration are probably limited in their extent. Evidence of biological activity was minimal or absent within the deepest soils studied in this thesis. The depth to which disturbance related clay cutans may form also appears to be low, at Seater no penetration into the buried soil was recorded at a depth of 65cm. The leaching of bases from the overburden into the buried soil and the chemical welding of the two profiles, however, may be affecting soils buried even to very great depths, but which this research was not sensitive enough to detect.

The second set of processes that operate in the deeper buried soils as a direct result of burial itself include the redoximorphic redistribution of iron and the translocation of clay and sometimes iron, possibly in response to the structural degradation of the soil materials that form the overburden. This results if the depth of burial is great enough for the complete isolation of the lower overburden and buried soil from the surface atmosphere to occur. The depth of burial necessary for this form of isolation may be a factor of the soils textural characteristics.

The hypothesis that depth of burial affects processes of post-burial change in archaeologically buried soils has been supported by the results of this study. Whether the soils are deeply or shallowly buried, processes of change will always act. The depth to which the soil is buried determines the nature of change. If they are shallowly buried, alteration of the micro-fabric occurs through the physical, biological and chemical welding of the buried soil within the developing soil profile at the surface. If the soil is more deeply buried, a different set of processes may occur in response to the changing chemistry of the burial environment. The parent material and site age characteristics may be important in determining the relative depth at which isolation from surface pedogenesis and the surface atmosphere occurs.

9.3.4 An assessment of the initial research aims and the extent to which they have been achieved.

The central aims this research attempted to address were as follows:

(1) To study the effect that the burial environment has upon the micro-fabric of archaeologically buried soils as expressed in thin section.
(2) To understand and elucidate the processes of change that may produce the features observed in thin section.
(3) To assess the implications of the visible macro- and microscopic burial alterations for future interpretations of the micromorphology of archaeologically buried soils.
(4) To investigate the prevalence and, cause of post-burial translocation of fine particulates within the buried soil, and between the buried soil and the overburden.
(5) To investigate the prevalence, and cause of iron redistribution within the buried soil, and between the buried soil and the overburden.

The first of these aims to study the effect of the burial environment upon the micro-fabric of archaeologically buried soils has been achieved. A very wide range of features and structural patterns have been observed in thin sections taken from buried soils that have formed after the overlying archaeological site was constructed. Not all features and alterations were found at all sites, the nature of post-burial change is quite site specific. The nature of the processes that have resulted in post-burial alteration of the soil micro-fabric have also been considered. By identifying characteristic regional, temporal and depth patterns of distribution for each of soil features related to burial, the processes that have formed them can be better understood. Understanding the physical and chemical properties of the burial environment also helps in the formulation of hypotheses and the drawing of conclusions concerning the exact nature of the processes operating. Further research, however is needed in this area. The implications of post-burial change have also been considered. The reworking, destruction, obscuration and secondary formation of those features of interest to pedological, archaeological and environmental research have all been noted during this study.

The final two aims of this thesis were to assess the prevalence and cause of iron redistribution and clay translocation within and between the buried soil and its overburden. Both processes have been identified in the archaeologically buried soils studied, but in each case more than one type of process has been responsible for their formation. Post-burial clay translocation was identified within 5 of the 10 buried soils, and two different processes appear to have been responsible for their formation. The distribution of these features both within and between sites reflects the nature of the processes that have been operating. The features formed by iron redistribution were more diverse and also more prevalent, present in some form at 8 of the 10 buried sites than those resulting from clay translocation. As the features that have been formed are varied (nodules, pans, coatings, mottles, impregnation of stone clasts), so too are the processes that may have formed them and the sites in which they may form. Two distinct types of iron redistribution processes may be operating, podzolisation and redoximorphic, the first in response to surface processes and the second in response to the conditions that develop in the burial environment of deeply buried or fine textured soils.

All five of the research aims have, therefore, been addressed by this study. There has been a comprehensive description of many types of post-burial alteration and as was discussed in section 9.1.4, the features covered in this study include the majority of those that have been identified in archaeologically buried soils in Britain over the last 50 years. The consideration of all these features together in one study, therefore, represents an advance in the understanding of their formation. The processes involved in these alterations have been discussed, especially for those features associated with iron redistribution and clay translocation and through this greater understanding of the processes involved, it is hoped that the prediction of potential micro-fabric alterations can be made prior to sampling.

9.3.5 Suggestions of further research to expand upon the results of this study.

The models that have been presented in this work, both the specific feature / burial factor interaction models presented in chapter 8 and the overall research model discussed in section 9.2.4 of this chapter, need to be tested to validate their conclusions. The discussion of the research results against the database of previously excavated buried sites in the British Isles goes some way towards this, but suffers from the non-specificity of these reports towards the questions that need to be addressed. Issues of circularity also arise as it was this database that was first used to inform the research design. An independent validation exercise should, therefore, be carried out. Such an exercise may involve either or both, a field or desktop survey, specifically targeted to testing the conclusions of this research and addressing the questions raised. Specifically the interpretation of the results of this study suggest that changes in structural stability, redox conditions and soil biota, broadly governed by burial depth and parent material, are important factors in determining the onset of processes of post-burial change such as iron redistribution and clay translocation. More research is needed to investigate the response of these soil properties to burial and to assess their impacts directly upon post-burial processes of change in buried soils and their overburdens. There is also scope for research to tie the features of clay translocation and iron redistribution identified in thin section with the situation in the field. This would help to ascertain their potential effects at the field level and their implications for excavation, dating and other scientific analyses.

More widely, the adoption of a procedure for the systematic description of post-burial effects and their documentation by a wider circle of researchers would quickly begin to build a useful database. Not withstanding the regionality of much of the work as outlined in chapter 1, this might help to confirm or refute the spatial and temporal trends in the occurrence of features associated with post-burial change suggested in this study. The widespread and systematic recording of the standard of preservation and evidence of post-burial alterations from thin sections, and the establishment of a standard scheme for doing this in the light of results from this and experimental studies into post-burial change within archaeological sites and buried soils is, therefore, required. Such an approach would begin to bridge the gap between the very useful work of Breunig-Madsen and Holst (1996; 1998) and the experimental earthwork project (Bell *et al.*, 1996) in documenting relatively rapid changes in soils in response to burial, and the processes operating over the longer time scales which are of interest to archaeologists.

There is also a need to re-examine thin section from previously studied sites to see what the implications of the findings of this research are for previous micromorphological methods, descriptions and interpretations. The re-examination of a large number of slides from varied sites, and in which varied processes of post-burial change have operated, and would help to fill in the gaps in this research and to verify or modify the findings. A number of issues, therefore, could be addressed in this way.

The first issue that could be addressed by a re-examination of thin sections from other sites would be an assessment of the interpretations made of clay coatings in the light of the findings of this study. Those sites from which clay coatings have been identified include Strathallan, which also possessed a thin basal iron pan, both of these features were interpreted as the result of human disturbance. The clay coatings within the barrow were thought to be the result of agriculture upon the mound surface, and the iron pan was thought to have resulted from grazing activities before the construction of the mound. On paper Strathallan, based upon fluvio-glacial deposits on which have developed acid brown forest soils, would appear upon the basis of the findings of this research to be likely to be affected by post-burial clay and iron movements. A re-examination of this site, therefore, would be a useful exercise, particularly as Macphail (1986 pp. 270) quotes a communication from Romans and Robertson that 'when unconsolidated materials bury a soil, soil water may slake and carry soil material into the buried soil, producing a last phase of coatings and infills in the micro-fabric'. Likewise, re-examination of slides from Wroxeter Baths and Deeping St. Nicholas, which also with a basal iron pan, where post-burial clay movement have also been identified may be a useful re-interpretation and validation exercise. A second phase would include the re-examination of a sample of those sites in which no post-burial clay has been identified, but in which pre-burial disturbance processes have been interpreted upon the basis of textural pedofeatures within the buried soil. This study has suggested that where you get pre-burial disturbance cutans (brown silty type in this research) there is a tendency to also to have post-burial movements of clay. Are their specific reasons why there has not been such a movement of clay at these numerous sites or has there been a systematic misidentification of post-burial textural pedofeatures in the past?

Upon the basis of the findings of this study there would seem to be a variety of pre- and post-burial processes that may lead to the mobilisation of clay and iron. For the clay coatings there seem to be distinct characteristics typical of coatings produced by different processes. For example, at Seater (Sanday) and Milsoms Corner (Somerset) clay coatings were thick, poorly oriented, and impure with a high silt, charcoal, phytolith and organic matter content. These were interpreted as resulting from surface agriculture of disturbance following burial. By contrast, the Bronze Age sites of Sigwells and CHB2 (Somerset), and Fordhouse Barrow (Angus) tended to be strongly oriented, thinner, and mineral in nature with reddish, orange or yellow colours. These are interpreted here as a process initiated by mound construction and isolation from surface conditions by burial. The question has to be asked, therefore, are they real differences that could be developed and used to aid interpretation, or are they simply the result of variability?

To help answer this, the re-examination of thin section from sites where processes of clay translocation can be confidently ascribed to different processes would be a useful exercise. The thin sections from the Flixborough and Hullbridge estuarine sites where the inundation of saline waters has stripped the soils of their clay (Canti, 1992a) would be a good example of how this approach could be applied. There are also numerous examples of sites where colluviation and clay translocation have both been identified a correlation between these two processes, therefore, might be suggested. The thin sections from South Lodge Camp (cf. Macphail, 1986) and from Credenhill Camp (Burnham, 1964), therefore, may point to differences in coating texture, colour and composition as a result of this. A further example of post-depositional clay translocation was identified by Anne Gebhardt who identified clay laminae that appeared to have formed in response to ground water fluctuations within a Medieval Motte (Gebhardt and Langhor, 1996). This interpretation was based upon the relative preservation of wood within the motte and the relative location of these clay laminae. These slides would be compared with those from, for example, Strathallan (Romans and Robertson, 1983) and Seater where the silty brown cutans have been interpreted as the result of clay translocation, and Fordhouse Barrow, Somerset and Deeping St. Nicholas (French, 1994) where 'barrow' type coatings have been identified. By examining such a geographically wide spread of soils from very different sites where known post-burial clay translocation is known to have occurred, natural variability may be accounted for.

Re-examination of these slides would allow a reassessment of whether, and how widely these clay and iron pedofeatures have been misinterpreted in past. Such a study could also prove to be a useful verification and development exercise to build and expand upon the findings of this research.

9.4 Overview of findings

In summary, the processes of post-burial change that affect soils buried beneath archaeological monuments have been studied and their effects upon the microfabric of buried soils have been assessed. A number of different processes have been identified which have equally varied effects upon the soil microfabric. Some of the key findings are outlined here.

(1) All of the soils studied exhibited some evidence of post-burial change. Alteration was mediated either through pedogenic processes acting upon the developing surface profile, or through processes initiated by the physical, chemical and biological properties specific to the burial environment.

(2) The latter group of processes (operating in response to burial itself) includes processes of iron redistribution and clay translocation.

(3) Processes of iron redistribution appear to have been mediated through oxidation-reduction processes within the basal sections of the overburden and the buried soil. The effect of the nodules and pans formed by these processes is that of obscuration of the original microfabric.

(4) Post-burial clay translocation has also been identified and again the large numbers of clay coatings that have been observed to coat previous pedofeatures, especially pre-existing clay coatings. The formation of clay void coatings following burial is thought to be a function of the breakdown of soil structure associated with site construction and the development of anaerobic conditions. There may be a feedback between the processes of iron redistribution and clay translocation as those sites in which iron pans have formed also contain post-burial clay coatings post dating the former. The effect of clay translocation is the accumulation of illuvial clay around the iron pan (usually at the base of the overburden / top of the buried soil, or in turves within the overburden) and the obscuration of the soil microfabric. Besides the formation of nodules and pans, mottling of the buried soil and overburden in response to anaerobic conditions may also develop in some sites.

(5) Pedogenic processes affect soils buried beneath relatively shallow depths of material that are insufficient to isolate the buried soil from the influence of these surface processes. The actual depth of isolation is dependent upon the processes involved and the texture of the overlying material. Physical, chemical and biological pedogenic processes may all be involved and 'weld' the buried soil within the developing surface profile. The effects of this type of alteration are usually evident if the entire profile is examined rather than treating the buried soil in isolation. Chemical processes include podzolisation, clay translocation in response to surface disturbance,

the leaching of bases and the addition of organic matter through root penetration and biological activity. At many of the sites studied, earthworm and enchytraeid activity has continued after burial of the site, particularly in those soils with a silt or sandy clay loam texture and which have been only shallowly buried. Both faunal types present problems in thin section as they rework the soil fabric, destroying original structure and the spatial relationships of the different soil components. Earthworms offer a second problem in that many species traverse horizon boundaries to a greater extent than enchytraeids. The result of this movement of materials is the mixing of materials between horizons.

(6) Parent material, burial depth and time since burial are important factors in determining the nature of the processes affecting buried soils. The movement of materials from the overburden into the buried soil, the reworking of the buried soil fabric and the degradation of particular components may all occur after burial resulting in an altered micro-fabric and changed chemical and physical properties.

In conclusion all buried soils beneath archaeological sites, no matter the site type, site age or burial depth, have been subject to some form of alteration. This may be a direct effect of the changing physical and chemical properties associated with the burial environment, or the result of ongoing processes of pedogenesis at the new land surface. Parent material, site age and depth of burial do affect the processes of post-burial change in archaeologically buried soils, but their influence is specific to the processes of change being investigated and the combination of burial factors being studied.

In coarse textured, deeply buried Bronze Age soils processes of post-burial change are likely to include redoximorphic redistribution of iron to form amorphous iron nodules and pans, and the translocation of clay and silt to form clay void coatings. In shallowly buried, finer textured soils beneath sites of lesser age biological activity and the addition of organic matter to the system are more dominant processes. However, surface disturbance (agriculture) and pedogenesis (leaching and eluviation) may also impact upon the buried soil with the potential for confusion in interpretation of thin sections.

Finally, there is a relative paucity of information concerning evidence of post-burial change and the preservation of the buried soil in many site reports and publications. This limitation of the archaeological literature needs to be addressed if the burial environment is to be better described, and the continuing development of buried soils understood. Further research into structural stability, soil biota and redox conditions within buried soils would also help to confirm the findings of this study and to better understand the processes of change that may occur. If the processes of change that are likely to be affecting a buried soil can be predicted in advance, sampling can be undertaken in such a way as to obtain as 'unaltered' a sample as possible for the purposes of the investigation. However, despite the observed alteration of all the buried soils, in each case, evidence of the pedological, anthropogenic and sedimentary development phases of the soils had survived. Despite their alteration, therefore, these buried soils are still valuable sources of palaeoenvironmental, archaeological and pedological information. If consideration of the processes of post-burial change is given more emphasis during interpretation of buried soil thin sections, the functioning of the burial environment and its effects within the micro-fabrics of the soil and sediments will be better understood. With this knowledge, the basis for future investigation and interpretation of buried soils will be placed on a firmer foundation.

References

Abdul-Kareem, A.W. and McRae, S.G., 1984. The effects on topsoil of long-term storage in stockpiles. *Plant and Soil*, 76: 357-363.

Acott, T.G., unpublished. *Soil micromorphology and image analysis; a study of Bronze Age to recently improved soils at Lairg, Sutherland, Scotland.*, University of Stirling, Stirling, 1993.

Acott, T. G., Cruise, G. M. and Macphail, R. I. (1997) Soil micromorphology and high resolution images. In (eds. Shoba, S., Gerasimova, M. and Miedema, R.) *Soil micromorphology: diversity, diagnostics and dynamics.* Moscow - Wageningen: pp. 372-378.

Adams, M., unpublished. *The Ingram and Upper Breamish Valley landscape project, 1995.* Archaeological reports of the Department of Archaeology, University of Durham, 19: 1995.

Adams, M. and Carne, P., unpublished. *The Ingram and Upper Breamish Valley landscape project, 1996.* Archaeological reports of the Department of Archaeology, University of Durham, 20: 1996.

Adams, M. and Carne, P., unpublished. *The Ingram and Upper Breamish Valley landscape project.* Archaeological reports of the Department of Archaeology, University of Durham, 21:1997.

Aguilar, J., Guardiola, J.L., Barahona, E., Dorronsoro, C. and Santos, F., 1983. Clay illuviation in calcareous soils. In: P. Bullock and C.P. Murphy (Editors), *Soil micromorphology 2: soil genesis.* A B Academic Publishers, Berkhamstead, pp. 541-550.

Alcock, L., 1972. *'By South Cadbury is that Camelot...?', excavations at Cadbury Castle 1966-1970.* Thames and Hudson, London, 224 pp.

Allen, M.J. and Macphail, R.I., 1987. Micromorphology and magnetic susceptibility studies: their combined role in interpreting archaeological soils and sediments. In: N. Federoff, L.M. Breeson and M.A. Courty (Editors), *Micromorphologie des Sols - Soil Micromorphology.* Proceedings of the VIIth International Working Meeting on Soil Micromorphology, Paris - July 1985. PLAISIR, Paris, pp. 669-676.

Armour-Chelu, M. and Andrews, P., 1994. Some effects of bioturbation by earthworms (Oligachaeta) on archaeological sites. *Journal of Archaeological Science,* **21**: 433-443.

Arocena, J.M. and Ackerman, J.D., 1998. Use of statistical tests to describe the basic distribution pattern of iron oxide nodules in soil thin sections. *Soil Science Society of America Journal.* **62**: 1346-1350.

Ashbee, P., 1966. The Fussels Lodge Long Barrow excavation, in 1961. *Archaeologia*, **100**: 1-80.

Atkinson, R.J.C., 1957. Worms and weathering. *Antiquity*, **31**: 219-233.

Aurousseau, P., 1983. Diagnostic properties and microfabrics of acid B horizons: comparisons with Podzolic Bs, Cambic Bw and acid eluvial horizons. In: P. Bullock and C.P. Murphy (Editors), *Soil Micromorphology, 2: soil genesis.* A B Academic Publishers, Berkhamstead, pp. 551-557.

Avery, B.W., 1980. *Soil classification for England and Wales (higher categories).* Technical Monograph 14. Soil Survey of England and Wales., Harpenden, 67 pp.

Balaam, N.D., Smith, K. and Wainwright, G.J., 1982. The Shaugh Moor project: fourth report - environment, context and conclusion. *Proceedings of the Prehistoric Society*, **48**: 203-278.

Ball, D.F., 1964. Loss-on-ignition as an estimate of organic matter and organic carbon in non-calcareous soils. *Journal of Soil Science,* **15**: 84-92.

Banin, Y.A. and Borochovitch, A., 1983. Effect of potassium on soil structure in relation to hydraulic conductivity. *Geoderma*, **30**: 135-147.

Barber, J. and Brown, M.M., 1984. An Sithean, Islay. *Proceedings of the Society of Antiquaries of Scotland*, **114**: 161-188.

Barclay, G.J., 1983. Sites of the third millenium bc to the first millenium ad at North Mains, Strathallan, Perthshire. *Proceedings of the Society of Antiquaries of Scotland,* **113**: 122-281.

Barclay, G.J., 1989. Cultivation remains beneath the North Mains Strathallan Barrow. *Proceedings of the Society of Scottish Antiquaries*, **119**: 59-62.

Barclay, G.J., Maxwell, G.S., Simpson, I.A. and Davidson, D.A., 1995. The Cleaven Dyke Neolithic cusus monument / bank barrow in Tayside region, Scotland. *Antiquity*, **69**: 317-326.

Bascomb, C. L., 1968. Distribution of pyrophosphate-extractable iron and organic carbon in soils of various groups. *Journal of Soil Science*, **19**; 251-268.

Bascomb, C.L., 1974. Physical and chemical analyses of <2mm samples. In: B.W. Avery and C.L. Bascomb (Editors), *Soil Survey laboratory methods. Soil Survey of England and Wales*, Harpenden, pp. 14-41.

Bell, M., 1996. Understanding how earthworks change. *British Archaeology*, **17**.

Bell, M., Fowler, P.J. and Hillson, S. W., 1996. *The experimental earthwork project 1960-1992.* C B A Research Report 100, York, pp. 257.

Beuselinck, L., Govers, G., Poesen, J., Degraer, G. and Froyen, L., 1998. Grain-size analysis by laser diffractometry: comparison with the sieve-pipette method. *Catena*, **32**: 193-208.

Beven, k. and Germann, P., 1981. Water flow in soil macropores, II. a combined flow model. *Journal of Soil Science*, **32**: 15-29.

Birkeland, P.W., *1984. Soils and geomorphology.* Oxford University Press, Oxford, 372 pp.

Bockheim, J.G., 1980. Solution and use of chronofunctions in studying soil development. *Geoderma*, **24**: 71-85.

Bos, R.H.G. and Sevink, J., 1975. Introduction of gradational and pedomorphic features in descriptions of soils: a discussion of the soil horizon concept with special reference to paleosols. *Journal of Soil Science*, **26**: 223-233.

Bouabid, R., Nater, E.A. and Bloom, P.R., 1995. Characterization of the weathering status of feldspar minerals in sandy soils of Minnesota using SEM and EDX. *Geoderma*, **66**: 137-149.

Breunig-Madsen, H. and Holst, M.K., 1996. Genesis of iron pans in Bronze Age mounds in Denmark. *Journal of Danish Archaeology*, **11**: 80-86.

Breunig-Madsen, H. and Holst, M.K., 1998. Recent studies on the formation of iron pans around the oaken log coffins of the Bronze Age burial mounds of Denmark. *Journal of Archaeological Science*, **25**: 1103-1110.

Brewer, R., 1964. *Fabric and mineral analysis of soils.* John Wiley & Sons, Inc, London.

Brewer, R., 1972a. The basis of interpretation of soil micromorphological data. *Geoderma*, **8**: 81-94.

Brewer, R., 1972b. Micromorphology, a discipline at the chemistry mineralogy interface. *Soil Science*, **115**: 261-267.

Bridges, E.M., 1978. Interaction of soil and mankind in Britain. *Journal of Soil Science*, **29**: 125-139.

Bronger, A. and Catt, J.A., 1998. Summary outline and recommendations on paleopedological issues. *Quaternary International*, **51**: 5-6.

Bryant, R.G. and Davidson, D.A., 1996. The use of image analysis in the micromorphological study of old cultivated soils: an evaluation based on soils from the Island of Papa Stour, Shetland. *Journal of Archaeological Science*, **23**: 811-822.

Buhmann, C., Rapp, I. and Laker, M.C., 1996. Differences in mineral ratios between disaggregated and original clay fractions in some South African soils as affected by amendements. *Australian Journal of Soil Research*, **34**: 909-923.

Bullock, P., Federoff, N., Jongerius, A., Stoops, A. and Tursina, T., 1985. *Handbook for soil thin section description.* Waine Research Publications, Wolverhampton, 152 pp.

Buurman, P., 1980. Palaeosols in the Reading beds (Paleocene) of Alum Bay, Isle of Wight, UK. *Sedimentology*, **27**: 593-606.

Buurman, P., Pape, T. and Muggler, C.C., 1997. Laser grain-size determination in soil genetic studies; 1. practical problems. *Soil Science*, **162**: 211-218.

Canti, M., 1989. *A buried soil from Castle Rising, Norfolk. 89/71*, English Heritage, London.

Canti, M., 1992a. *Research into natural and anthropogenic deposits from excavations at Flixborough, Humberside.* 53/92, Ancient Monuments Laboratory, London.

Canti, M., 1992b. *Soil report on calcareous features from the excavations at Godmanchester, Cambridgeshire.* 4/92, Ancient Monuments Laboratory, London.

Canti, M., 1994. *Sourcing a silt loam found at Tintagel churchyard excavations 1991.* 59/94, English Heritage, London.

Canti, M.G., 1997. An investigation of microscopic calcareous spherulites from herbivore dung. *Journal of Archaeological Science*, **24**: 219-231.

Canti, M.G., 1998. The micromorphological identification of faecal spherulites from archaeological and modern materials. *Journal of Archaeological Science*, **25**: 435-444.

Carter, M.R., Angers, D.A. and Kunelius, P., 1994. Soil structural form and stability, and organic matter under cool season perennial grasses. *Soil Science Society of America Journal*, **58**: 1194-1199.

Carter, S.P., Tipping, R., Davidson, D., Long, D. and Tyler, A., 1997. Multi-proxy approach to the function of post-Medieval ridge and furrow cultivation in upland northern Britain. *The Holocene*, **7**: 447-456.

Carter, S.P. and Davidson, D.A., 1998. An evaluation of the contribution of soil micromorphology to the study of ancient arable agriculture. *Geoarcheaeology*, **13**: 535-547.

Catt, J.A., 1987. Palaeosols. *Progress in Physical Geography*, **11**: 487-510.

Catt, J.A., 1991. Soils as indicators of Quaternary climatic change in mid-latitude regions. *Geoderma*, **51**: 167-187.

Catt, J.A., 1996. Recent work on Quaternary palaeosols in Britain. *Quaternary International*, 34: 183-190.

Chaney, K. and Swift, R.S., 1984. The influence of organic matter on aggregate stability in some British soils. *Journal of Soil Science*, 35: 223-230.

Chisci, G., Lorenzi, G. and Piccolo, L., 1978. Effects of a ferric conditioner on clay soils. In: W.W. Emerson, R.D. Bond and A.R. Dexter (Editors), *Modification of soil structure*. John Wiley and Sons., Brisbane, pp. 309 - 314.

Chorom, M., Rengasamy, P. and Murray, R.S., 1994. Clay dispersion as influenced by pH and net particle charge of Sodic soils. *Australian Journal of Soil Research*, **32**: 1243-1252.

Collins, J.F. and Buol, S.W., 1970. Effects of fluctuations in the Eh-pH environment or iron and / or manganese equilibria. *Soil Science*, **110**: 111-118.

Conry, M.J., De Coninck, F. and Stoops, G., 1996. The properties, genesis and significance of a man-made iron pan podzol near Castletownebere, Ireland. *European Journal of Soil Science*, 47: 279-284.

Cornwall, I.W., 1953. Soil science and archaeology with illustrations from some British Bronze Age monuments. *Proceedings of the Prehistoric Society*, **2**: 129-147.

Cornwall, I.W., 1958. *Soils for the Archaeologist*. Phoenix House, London, 230 pp.

Courty, M. and Federoff, N., 1985. Micromorphology of recent and buried soils in a semi-arid region of northwestern India. *Geoderma*, 35: 287-332.

Courty, M.A., Goldberg, P. and Macphail, R.I., 1989. *Soils and micromorphology in archaeology*. Cambridge University Press., Cambidge, 344 pp.

Craddock, P.T., Gurney, D., Proyor, F. and Hughes, M.J., 1985. The application of phosphate analysis to the location and interpretation of archaeological sites. *Archaeological Journal*, **142**: 361-376.

Creemans, D.L., 1995. Pedogenesis of Cotiga mound, a 2100 year old woodland mound in Southwest West Virginia. *Soil Science Society of America Journal*, 59: 1377-1388.

Crowther, J., MacPhail, R.I. and Cruise, G.M., 1996. Short-term, post-burial change in a humic Rendzina soil, Overton Down experimental earthwork, Wiltshire, England. *Geoarchaeology*, **11**: 95-117.

Dalrymple, J.B., 1958. The application of soil micromorphology to fossil soils and other deposits from archaeological sites. *Journal of Soil Science*, **9**: 199-205.

Dalrymple, J.B. and Theocharopoulos, S.P., 1989. Intrapedal cutans - lateral differences in their properties and spatial clustering. *Geoderma*, **41**: 149-180.

Davidson, D.A. and Carter, S. P. (1998) Micromorphological evidence of past agricultural practices in cultivated soils: the impact of a traditional agricultural system on soils in Papa Stour, Shetland. *Journal of Agricultural Science*, **25**; 827-838.

Davidson, D.A., Carter, S.P. and Quine, T.A., 1992. An evaluation of micromorphology as an aid to archaeological interpretation. *Geoarchaeology*, **7**: 55-65.

Davidson, D.A. and Simpson, I.A., 1984. The formation of deep topsoils in Orkney. *Earth Surface Processes and Landforms*, **9**: 75-81.

Davidson, D.A. and Smout, T.C., 1996. Soil Change in Scotland: the legacy of past land improvement processes. In: A.G. Taylor, J.E. Gordon and M.B. Usher (Editors), *Soils, sustainability and the Natural Heritage*. H.M.S.O, Edinburgh, pp. 44-54.

Davies, G. and Turner, J., 1979. Pollen diagrams from Northumberland. *New Phytologist*, **82**: 783-804.

Dawod, V. and FitzPatrick, E.A., 1993. Some population sizes and effects of the Enchytraeid (Oligachaete) on soil structure in a selection of Scottish soils. *Geoderma*, **56**: 173-178.

Dockrill, S.J. and Simpson, I.A, 1994. The identification of prehistoric anthropogenic soils in the northern isles using an integrated sampling methodology. *Archaeological Prospection*, **18**: 75-92.

Dormaar, J.F. and Lutwick, L.E., 1983. Extractable Fe and Al as an indicator for buried soil horizons. *Catena*, **10**: 167-173.

Downes, J., 1994. Excavation of a Bronze Age burial at Mousland, Stromness, Orkney. *Proceedings of the Society of Antiquaries of Scotland.*, **124**: 141-154.

Edgerton, D.L., Harris, J.A., Birch, P. and Bullock, P., 1995. Linear relationship between aggregate stability and microbial biomass in three restored soils. *Soil Biology and Biochemistry*, **27**: 1499-1501.

Edwards, K.J., and Ralson I., 1980. New dating and environmental evidence from Burghead Fort, Moray. *Proceedings of the Society of Antiquaries of Scotland*, **109**; 202-210.

Evershed, R.P., Bethell, P.H., Reynolds, P.J. and Walsh, N.J., 1997. 5B-stigmastanol and related 5B-stanols as biomarkers of manuring: analysis of modern experimental material and assessment of the archaeological potential. *Journal of Archaeological Science*, **24**: 485-495.

Exaltus, R.P. and Miedema, R., 1994. A micromorphological study of four Neolithic sites in the Dutch coastal provinces. *Journal of Archaeological Science*, **21**: 289-301.

Farmer, V.C. and Fraser, A.R., 1982. Chemical and colloidal stability of sols in the Al2O3-Fe2O3-SiO2-H2O system: their role in podzolisation. *Journal of Soil Science*, **33**: 737-742.

Farmer, V.C., Russell, J.D. and Berrow, M.L., 1980. Imagolite and proto-imagolite allophane in spodic horizons: evidence for a mobile aluminium silicate complex in podzol formation. *Journal of Soil Science*, **31**: 673-684.

Farmer, V.C., Russell, J.D. and Smith, B.F.L., 1983. Extraction of inorganic forms of translocated Al, Fe, and Si from a podzol Bs horizon. *Journal of Soil Science*, **34**: 571-576.

Fechner, K. and Kleiner, F., unpublished. The combination of SEM, microchemical, XRD, micromorphological and other phosphate analyses for interpreting archaeological sites in Wallonia and Brussels (Belgium). *Soil micromorphology in archaeology workshop*, London, 1998.

Federoff, N., Courty, M.A. and Thompson, M.L., 1990. Micromorphological evidence of palaeoenvironmental change in Pleistocene and Holocene paleosols. In: L.A. Douglas (Editor), *Soil micromorphology: a basic and applied science.* Proceedings of the VIIIth International Working Meeting of Soil Micromorphology, San Antonio, Texas-July 1988. Elsevier Science Publishers, Amsterdam, pp. 653-665.

Ferrari, G.A. and Magaldi, D., 1975. Micromorphological aspects of feldspar weathering in some palaeosols of Tuscany. In: G.K. Rutherford (Editor), *Soil Microscopy: proceedings of the fourth international working-meeting on soil micromorphology, 27th-31st August, 1973.* Kingston: The Limestone Press, Kingston, Ontario, Canada, pp. 383-393.

Ferrari, G.A. and Magaldi, D., 1983. Degree of soil weathering as determined by abrasion pH: applications in soil study and palaeopedology. *Pedologie*, **33**: 93-104.

Finke, P.A., Mucher, H.J. and Witter, J.V., 1991. Reliability of point counts of pedological properties on thin sections. *Soil Science*, **151**: 249-253.

Fisher, P.F., 1982. A review of lessivage and Neolithic cultivation in southern England. *Journal of Archaeological Science*, **9**: 299-304.

Fisher, P.F. and Macphail, R.I., 1985. Studies of archaeological soils and deposits by micromorphological techniques. In: N.R.J. Fieller, D.D. Gilbertson and N.G.A. Ralph (Editors), *Palaeoenvironmental investigations: research designs, methods and analysis.* BAR Int. 258, Oxford, pp. 93-122.

Fitzpatrick, E.A., 1984. *Micromorphology of soils*. Chapman & Hall Ltd., London, 433 pp.

Fitzpatrick, E.A., 1993. *Soil microscopy and micromorphology*. John Wiley & Sons Ltd., Chichester, 304 pp.

Fortun, A., Fortun, C. and Ortega, C., 1989. Effect of farmyard manure and its humic fractions on the aggregate stability of a sandy-loam soil. *Journal of Soil Science*, **40**: 293-298.

French, C.A.I., 1988. Aspects of buried prehistoric soils in the lower Welland Valley and fen margin north of Peterborough, Cambridgeshire. In: W. Groenman-van Waateringe and M. Robinson (Editors), *Man-made soils*. BAR Int 410, Oxford, pp. 115-128.

French, C.A.I., 1992. Fengate to Flag Fen: summary of the soil and sediment analyses. *Antiquity*, **66**: 458-461.

French, C.A.I., 1994. *Excavation of the Deeping St. Nicholas Barrow complex, South Lincolnshire*. Lincolnshire Archaeology and Heritage Report Series, 1, 138 pp.

Futty, D.W. and Dry, F.T., 1977. *The soils of the country round Wick (sheets 110, 116 and part 117)*. The Macaulay Institute for Soil Research, Aberdeen, 287 pp.

Gebhardt, A., 1992. Micromorphological analysis of soil structure modifications caused by different cultivation implements. In: A.D.L.T. Ronde. (Editor), *Prehistoire de l'agriculture: nouvelles approaches experimentales et ethnographies*. C. N. R. S., Valborne, pp. 373-383.

Gebhardt, A., 1995. Soil micromorphological data from traditional and experimental agriculture. In: A.J. Barham and R.I. MacPhail (Editors), *Archaeological sediments and soils: analysis, interpretation and management.* The Institute of Archaeology, London, pp. 25-39.

Gebhardt, A. and Langohr, R., 1996. Archaeo-pedological study of post-occupational processes from a medieval motte in Werken (West Flanders, Belgium). In: Colardelle (Editor), *L'homme et la nature au Moyen age*. Editions errance, Grenoble, pp. 214-217.

Giovanni, G. and Segui, P., 1976. Iron and aluminium as cementing substances of soil aggregates. II. Changes in stability of soil aggregates following extraction of iron and aluminium by acetylacteone in a non-polar solvent. *Journal of Soil Science*, **27**: 148-153.

Goldberg, P., 1983. Applications of micromorphology in archaeology. In: P. Bullock and C.P. Murphy (Editors), *Soil Micromorphology, 1: techniques and applications*. A B Academic Publishers, Berkhamsted, pp. 139-150.

Goldberg, P. and Macphail, R.I., 1990. Micromorphological evidence of Middle Pleistocene landscape and climatic changes from southern England: Westbury-Sub-Mendip, Somerset and Boxgrove, West Sussex. In: L.A. Douglas (Editor), *Soil Micromorphology: a basic and applied science*. Proceedings of the VIIIth International Working Meeting of Soil Micromorphology, San Antonio, Texas-July 1988. Elsevier Science Publishers, Amsterdam, pp. 442-447.

Graef, F., Singer, A., Stahr, K. and Jahn, R., 1997. Genesis and diagenesis of palaeosols from Pliocene volcanics on the Golan Heights. *Catena*, **30**: 149-167.

Haggerty, A.M., 1988. Iona: some results from recent work. *Proceedings of the Society of Antiquaries of Scotland*, **118**: 203-213.

Hall, N.W., 1994. Soil structure transformations over the growing season - A micromorphological approach. In: A.J. Ringrose-Voase and G.S. Humphreys (Editors), *Soil Micromorphology: studies in management and genesis.* Proceedings of the Ixth International Working Meeting on Soil Micromorphology, Townsville, Australia, July 1992. Elsevier Science, Amsterdam, pp. 659-667.

Hallaire, V. and Curmi, P., 1994. Image analysis of pore space morphology in soil sections in relation to water movement. In: A.J. Ringrose-Voase and G.S. Humphreys (Editors), *Soil micromorphology: studies in management and genesis*. Proceedings of the IXth Int. Working Meeting on Soil Micromorphology. Developments in Soil Science, 22. Elsevier, Amsterdam, pp. 559-567.

Harkness, D.D., 1981. The extant of natural 14C deficiency in the coastal environment of the United Kingdom. In: W.G. Mook (Editor), *1st International Symposium on C-14 and Archaeology*. Groningen.

Harris, J.A. and Birch, P., *1989*. Soil microbial activity in opencast coal mine restorations. *Soil Use and Management*, **5**: 155-160.

Harris, J.A. and Birch, P., 1990. The effects of heavy civil engineering and stockpiling on the soil microbial community. In: P. Howsham (Editor), *Microbiology in Civil Engineering*. E. & F. N. Spon, Cranfield Institute of Technology, UK, pp. 274-287.

Harris, J.A., Birch, P., Short, K. C., 1989. Changes in the microbial community and physico-chemical characteristics of top soils stockpiled during open cast mining. *Soil use and management*, **5**: 161-168.

Harris, J.A., Birch, P. and Short, K.C., 1993. The impact of storage of soils during open cast mining on the microbial community: a strategist theory interpretation. *Restoration Ecology,* **1**: 88-100.

Hatano, R., Kawamura, N., Ikeda, J. and Sakuma, T., 1992. Evaluation of the effect of morphological features of flow paths on solute transport by using fractal dimensionsof methylene blue staining pattern. *Geoderma*, **53**: 31-44.

Hedges, J., 1975. Excavation of two Orcadian burnt mounds at Liddle and Beaquoy. *Proceedings of the Society of Antiquaries of Scotland*, **106**: 39-98.

Heil, D. and Sposito, G., 1993. Organic matter role in illitic soil colloids flocculation. *Soil Science Society of America Journal*, **57**: 1246-1251.

Hodgson, 1976. *Soil survey field handbook: describing and sampling field handbook.* Soil Survey of England and Wales, Harpenden, 99 pp.

Hodson, M.E., Langan, S.J., Kennedy, F.M. and Bain, D.C., 1998. Variation in soil surface area in a chronosequence of soils from Glen Feshie, Scotland and its implications for mineral weathering rate calculations. *Geoderma*, **85**: 1-18.

Hopkins, D.W., 1999. Interfaces of soil biology with archaeological investigations. *Soil Biogeochemistry*, **10**: 1-50.

Horgan, G.W., 1998. Mathematical modelling for analysing soil structure from images. *European Journal of Soil Science*, **49**: 161-173.

Hunter, F. and Currie, J.A., 1956. Structural changes during bulk soil storage. *Journal of Soil Science*, **7**: 75-80.

Hunter, J.R., 1988. Sanday, Pool (Cross and Burness Parish). Multi-period site. *Discovery and Excavation,* **29**: 1-65.

Hunter, J.R. and Dockrill, S.J., 1982. Some Norse sites on Sanday Orkney. *Proceedings of the society of Antiquaries of Scotland*, **112**: 570-576.

Institute of Field Archaeology (1997). *Directory of British Archaeology.* Current Archaeology, 33 pp.

Jenkins, D.A., 1994. Interpretation of interglacial cave sediments from a hominid site in North Wales: translocation of Ca-Fe-phosphates. In: A.J. Rinrose-Voase and G.S. Humphreys (Editors), *Soil Micromorphology: studies in management and genesis.* Proceedings of the IXth International Working Meeting on Soil Micromorphology, Townsville, Australia, July 1992. Elsevier Science Publishers, Amsterdam, pp. 293-305.

Jenny, H., 1941. *Factors of soil-formation.* McGraw and Hill, New York, 281 pp.

Johnson, D.L., 1985. Soil thickness processes. In: P.D. Jungerius (Editor), *Soils and Geomorphology.* Catena Supplement 6. Catena Verlag, Braunschweig, pp. 29-40.

Johnson, D.L. and Watson -Stegner, D., 1987. Evolution model of pedogenesis. *Soil Science,* **143**: 349-366.

Johnson, D.L., Watson-Stegner, D., Johnson, D.N. and Schaetzl, R.J., 1987. Proisotropic and proanisotropic processes of soil pedoturbation. *Soil Science*, **143**: 278-292.

Jongerius, A., 1970. Some morphological aspects of regrouping phenomena in dutch soils. *Geoderma*, **4**: 311-331.

Jongerius, A., 1983. The role of micromorphology in agricultural research. In: P. Bullock and C.P. Murphy (Editors), *Soil Micromorphology, 1: techniques and applications*. A B Academic Publishers, Berkhamsted, pp. 111-138.

Keeley, H.C.M., 1982. Pedogenesis during the later prehistoric period in Britain. In: H.A. F. (Editor), *Climatic change in later pre-history*. Edinburgh University Press, Edinburgh, pp. 114-126.

Kemp, R.A., 1985. *Soil Micromorphology and the Quaternary*, Technical Guide No. 2. Quaternary Research Association,, London:, 80 pp.

Kemp, R.A., 1987. Genesis and Environmental significance of a buried middle Pleistocene soil in Eastern England. *Geoderma*, **41**: 49-77.

Kemp, R.A. and Faulkner, J.S., 1998. Short-range variations in the micromorphology of a paleosol from Wivenhoe in southeast England. *Journal of Quaternary Science*, **13**: 233-243.

Kemp, R.A., McDaniel, P.A. and Busacca, A.J., 1998. Genesis and relationship of macromorphology and micromorphology to contemporary hydrological conditions of a welded Argixeroll from the Palouse in Idaho. *Geoderma*, **83**: 309-329.

Kennedy, J.J., 1992. *Analyzing qualitative data: log-linear analysis for behavioural research*. Praeger Publishers, New York, 299 pp.

Keren, R. and Sparks, D.L., 1995. The role of edge surfaces in flocculation of 2:1 clay minerals. *Soil Science Society of America Journal*, **59**: 430-435.

King, J., 1962. The *Festuca-Agrostis* grassland complex in south-east Scotland. *Journal of Ecology*, **50**: 321-365.

Kinnear, P.R. and Gray, C.R., 1999. *SPSS for Windows made simple*. Psychology Press, Hove, 386 pp.

Knoke, D. and Burke, P.J., 1980. *Log-linear models*. Quantitative applications in Social Sciences, 7. SAGE Publications Ltd, Beverly Hills, 80 pp.

Kooistra, M.J. and Tovey, N.K., 1994. Effects of soil compaction on microstructure. In: B.D. Soane and C. van Ouwerkerk (Editors), *Soil compaction in crop production*. Elsevier Science., pp. 91-111.

Kretzschmar, R., Robarge, W.P. and Weed, S.B., 1993. Flocculation of kaolinitic soil clays: effects of humic sustances and Fe oxides. *Soil Science Society of America Journal*, **57**: 1277-1283.

Kubiena, W.L., 1938. *Micropedology*. Collegiate Press Inc., Iowa, 242 pp.

Kubiena, W.L., 1953. *Soils of Europe*. Thomas Murphy & Co., London, 317 pp.

Kubiena, W.L., 1970. *Micromorphological features of soil geography*. Rutgers University Press, New Jersey, 256 pp.

Lamb, R.G., 1980. Sanday and North Ronaldsay: an archaeological survey of two of the NorthIsles of Orkney, Royal Commission on the Ancient and Historical Monuments of Scotland, Edinburgh.

Leigh, D.S., McSweeny, K. and Knox, J.C., 1989. Micromorphology of a "welded" Sangamonian to Wisconsinan Age paleosol in southwestern Wisconsin. *Catena*, **16**: 575-587.

Levy, G.J. and Torrento, J.R., 1995. Clay dispersion and macro-aggregate stability as affected by exchangeable potassium and sodium. *Soil Science*, **160**: 352-358.

Limbrey, S., 1975. *Soil science and archaeology*. Academic Press, London, 384 pp.

Limbrey, S., 1992. Micromorphological studies of buried soils and alluvial deposits in a Wiltshire river valley. In: S. Needham and M.G. Macklin (Editors), Alluvial archaeology in Britain. Oxbow Monograph 27, Oxford, pp. 53-63.

Longin, R., 1971. New method of collagen extraction for radiocarbon dating. *Nature*, **230**: 241-242.

Loveland, P.J. and Digby, P., 1984. The extraction of Fe and Al by 0.1M Pyrophosphate solutions: a comparison of some techniques. *Journal of Soil Science*, **35**: 243-250.

Mackie, E.W., 1964. New excavations on the Monamore Neolithic chambered cairn, Lamlash, Isle of Arran, in 1961. *Proceedings of the society of Antiquaries of Scotland*, **97**: 1-34.

Mackie-Dawson, L.A., Mullins, C.E., FitzPatrick, E.A. and Court, M.N., 1989a. Seasonal changes in the structure of clay soils in relation to soil management and crop type, 1: effects of crop rotation at Cruden Bay, NE Scotland. *Journal of Soil Science*, **40**: 269-281.

Mackie-Dawson, L.A., Mullins, C.E., Goss, M.J., Court, M.N. and Fitzpatrick, E.A., 1989b. Seasonal changes in the structure of clay soils in relation to soil management and crop type, 2: effects of cultivation and cropping at Compton Beauchamp. *Journal of Soil Science*, **40**: 283-292.

Macphail, R.I., 1983a. The micromorphology of dark earth from Gloucester, London and Norwich: an analsis of urban anthropogenic deposits from the late Roman to early medieval periods in England. In: P. Bullock and C.P. Murphy (Editors), *Soil Micromorphology, 1: techniques and applications.* A B Academic Publishers, Berkhamsted, pp. 245-252.

Macphail, R.I., 1983b. The micromorphology of spodosols in catenary sequences on lowland heathlands in Surrey, England. In: P. Bullock and C.P. Murphy (Editors), *Soil Micromorphology, 2: soil genesis.* A B Academic Publishers, Berkhamsted, pp. 647-653.

Macphail, R.I., 1986. Paleosols in archaeology: their role in understanding Flandrian pedogenesis. In: P.V. Wright (Editor), *Paleosols; their recognition and interpretation.* Blackwell Scientific Publications, Oxford, pp. 263-290.

Macphail, R.I., 1987. A review of soil science in archaeology in England. In: H.C.M. Keeley (Editor), *Environmental archaeology: a regional review*, volume 2. English Heritage, HBMCE, London, pp. 332-386.

Macphail, R.I., 1990a. *Soil report on Carn Brea, Redruth, Cornwall: with some reference to similar sites in Brittany, France.* 55/90, Ancient Monuments Laboratory, London.

Macphail, R.I., 1990b. *Soil report on the Hullbridge Project, Essex: the sites of Purfleet, the Stumble and others on the Blackwater River.* 39/90, Ancient Monuments Laboratory, London.

Macphail, R.I., 1990c. The soils. In: A. Saville (Editor), *Hazleton North: the excavation of a Neolithic long cairn of the Cotswold-Severn group.* English Heritage, Archaeological Report No. 13, London, pp. 223-226.

Macphail, R.I., 1991. *Soil report on the Deansway Archaeology Project, Worcester.* 82/91, Ancient Monuments Laboratory, London.

Macphail, R.I., 1992. Soil micromorphological evidence of ancient soil erosion. In: M. Bell and J. Boardman (Editors), *Past and present soil erosion: archaeological and geographical perspectives.* Oxbow Monograph 22, Oxford, pp. 197-215.

Macphail, R.I., 1998. A reply to Carter and Davidson's "An evaluation of the contribution of soil micromorphology to the study of ancient arable agriculture". *Geoarchaeology*, **13**: 549-564.

Macphail, R.I., Courty, M. and Goldberg, P., 1990a. Soil micromorphology in archaeology. *Endeavour*, **14**: 163-171.

Macphail, R.I., Courty, M.A. and Gebhardt, A., 1990b. Soil micromorphological evidence of early agriculture in north-west Europe. *World Archaeology*, **22**: 53-69.

Macphail, R.I., Cruise, G.M., Mellalieu, S.J. and Niblett, R., 1998. Micromorphological interpretation of a "turf-filled" funerary shaft at St. Albans, United Kingdom. *Geoarchaeology*, **13**: 617-644.

Macphail, R.I. and Goldberg, P., 1995. Recent advances in micromorphological interpretations of soils and sediments from archaeological sites. In: A.J. Barham and R.I. Macphail (Editors), *Archaeological sediments and soils: analysis, interpretation and management.* Institute of Archaeology, London, pp. 1-24.

Macphail, R.I., Romans, J.C.C. and Robertson, L., 1987. The application of micromorphology to the understanding of Holocene soil development in the British Isles; with special reference to early cultivation. In: N. Federoff, L.M. Bresson and M.A. Courty (Editors), *Micromorphologie des Sols - Soil Micromorphology.* PLAISIR, Paris, pp. 647-656.

Matthews, W., 1995. Micromorphological charaterisation and interpretation of occupation deposits and microstratigraphic sequances at Abu Salabikh, Southern Iraq. In: A.J. Barham (Editor), *Archaeological sediments and soils: analysis, interpretation and management.* Institute of Archaeology, London, pp. 41-74.

Matthews, W., French, C.A.I., Lawrence, T., Cutler, D.F. and Jones, M.K., 1997. Microstratigraphic traces of site formation processes and human activities. *World Archaeology*, **29**: 281-308.

Matthews, W. and Payne, J.N., 1994. The imprint of living in an early Mesopotamian city: questions and answers. In: R. Luff and P. Rowley-Conwy (Editors), *Whither environmental archaeology?* Oxbow Monograph 38, Oxford, pp. 171-212.

Mattingly, G.E.G. and Williams, R.J.B., 1962. A note on the chemical analysis of a soil buried since Roman times. *Journal of Soil Science*, **13**: 254-258.

Mausbach, M.J., Wingard, C. and Gamble, E.E., 1982. Modification of buried soils by postburial pedogenesis, Southern Indiana. *Soil Science Society of America Journal*, **46**: 364-369.

McBratney, A.B. and Moran, C.J., 1994. Soil pore structure modelling using fuzzy random pseudofractal sets. In: A.J. Ringrose-Voase and G.S. Humphreys (Editors), *Soil micromorphology: studies in management and genesis.* Proceedings of the IXth International Working Meeting on Soil Micromorphology, Townsville, Australia, July 1992. Elsevier Science, Amsterdam, pp. 495-506.

McCarthy, P.J., Martini, I.P. and Leckie, D.A., 1998. Use of micromorphology for palaeoenvironmental interpretation of complex alluvial paleosols: an example from the Mill Creek formation (Albian), southwestern Alberta, Canada. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **143**: 87-110.

McCarthy, P.J., Martini, J.P. and Leckie, D.A., 1999. Pedogenic and diagenetic influences on void coating formationin Lower Cretaceous paleosols of the Mill Creek Formation, southwestern Alberta, Canada. *Geoderma*, **87**: 209-237.

McKeague, J.A., 1983. Clay skins and argillic horizons. In: P. Bullock and C.P. Murphy (Editors), *Soil Micromorphology, 2: soil genesis.* A B Academic Publishers, Berkhamsted, pp. 367-387.

McKeague, J.A., Guertin, R.K., Valentine, K.W.G., Belisle, J., Bourbeau, G.A., Howell, A., Michalyna, W., Hopkins, L.,Page, F. and Bresson, L.M., 1980. Estimating illuvial clay in soils by micromorphology. *Soil Science*, **129**: 386-388.

Mercer, R. and Tipping, R., 1994. The prehistory of soil erosion in the Northern and Eastern Cheviot Hills, Anglo-Scottish Borders. In: S. Foster and T.C. Smout (Editors), *The history of soils and field systems.* Scottish Cultural Press, Aberdeen, pp. 1-25.

Molope, M.B., Grieve, I.C. and Page, E.R., 1987. Contributions of fungi and bacteria to aggregate stability of cultivated soils. *Journal of Soil Science*, **38**: 71-77.

Mucher, H.J. and Van Vliet-Lanoe, B., unpublished. Application of micromorphology in Quaternary Geology and Geomorphology. Fourth European Intensive Course on Soil Micromorphology. 1997, Granada, Spain.

Munsell Colour Company, 1954. *Munsell Soil Colour Charts*, Baltimore.

Murphy, C.P., 1983. Point counting pores and illuvial clay *in thin section. Geoderma*, **31**: 133-150.

Murphy, C.P., 1986. *Thin section preperation of soils and sediments.* A B Academic Publishers, Berkhamsted, 149 pp.

Murphy, C.P., McKeague, J.A., Bresson, L.M., Bullock, P., Kooistra, M.J., Miedema, R. and Stoops, G., 1985. Description of soil thin sections: an international comparison. *Geoderma*, **35**: 15-37.

Nater, E.A. and Boubaid, R., 1990. Micromorphology of the initial weathering products of feldspars. In: Douglas, L.A. (Editor), *Soil micromorphology: a basic and applied science.* Elsevier Science, Amsterdam, pp. 525-550.

O'Kelly, M.J. and Brade-Birks, S.G., 1951. Some soil problems in archaeological excavation. *Journal of the Cork Historical and Archaeological Society*, **51**: 29-44.

Olson, C.G. and Nettleton, W.D., 1998. Paleosols and the effects of alteration. *Quaternary International*, **51**: 185-194.

Palmer, J.A., Phillips, G.N. and S., M.T., 1989. Palaeolsols and their relevance to PreCambrian atmospheric composition. *Journal of Geology*, **97**: 72-92.

Payton, R.W., 1992. Fragipan formation in argillic brown earths (Fragiudalfs) of the Milfield Plain, north-east England. I. Evidence for a periglacial stage of development. *Journal of Soil Science*, **43**: 621-644.

Payton, R.W., 1993a. Fragipan formation in argillic brown earths (Fragiudalfs) of the Milfield Plain, north-east England. II. Post Devensian development processes and the origin of fragipan consistence. *Journal of Soil Science*, **44**: 703-723.

Payton, R.W., 1993b. Fragipan formation in argillic brown earths (Fragiudalfs) of the Milfield Plain, north-east England. III. Micromorphological, SEM, EDXRA studies of fragipan degradation and the development of glossic features. *Journal of Soil Science*, **44**: 725-739.

PiPujol, M.D. and Buurman, P., 1994. The distinction between ground-water gley and surface water gley phenomena in Tertiary paleosols of the Ebro Basin, N. E. Spain. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **110**: 103-113.

Pipujol, M.D. and Buurman, P., 1997. Dynamics of iron and calcium carbonate redistribution and paleohydrology in Middle Eocene alluvial paleosols of the southeast Ebro Basin margin (Catalonia, northeast Spain). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **134**: 87-107.

Pipujol, M.D. and Buurman, P., 1998. Analyzing ground-water gley and surface-water (pseudogley) effects in paleosols. *Quaternary International*, **51**: 77-79.

Pizl, V., 1992. Effect of soil compaction on earthworms (LUMRICIDAE) in apple orchards. *Soil Biology and Biochemistry*, **24**: 1573-1575.

Porter, D.A., McCahon, T. and Ransom, M.D., 1998. Differentiating pedogenic and diagenetic properties in a Cretaceous paleosol in Kansas. *Quaternary International*, **51**: 35-54.

Pryor, F., and French C.A.I., 1985. *Archaeology and environment in the lower Welland Valley.* East Anglian Archaeology Report No. 27.

Puentes, R., Wilding, L.P. and Drees, L.R., 1992. Microspatial variability and sampling concepts in soil porosity studies in Vertisols. *Geoderma,* **53**: 373-385.

Quine, T., 1995. Soil analysis and archaeological site formation studies. In: A.J. Barham and R.I. Macphail (Editors), *Archaeological sediments and soils: analysis, interpretation, and management.* Institute of Archaeology, London, pp. 77-98.

Ramsay, W.J.H., 1986. Bulk soil handling for quarry restoration. *Soil Use and Management*, **2**: 30-39.

Rapp G. and Mulholland S. C. (1992), *Phytolith systematics: emerging issues.* Plenum Press, New York, pp. 357.

Read, G., 1998. The establishment of a buried soil chronosequence with a feldspar weathering index. *Quaternary International*, **51**: 39.

Read, G., Kemp, R.A. and Rose, J., 1996. Development of a feldspar weathering index and its application to a buried soil chronosequence in southeastern England. *Geoderma*, **74**: 267-280.

Retallack, G.J., 1990. *Soils of the past: an introduction to paleopedology.* Unwin Hyman Ltd., London, 520 pp.

Retallack, G.J., 1991. Untangling the effects of burial alteration and ancient soil formation. *Annual Review of Earth and Planetary Sciences*, **19**: 183-206.

Ringrose-Voase, A.J. and Humphreys, G.S., 1994. Some principles to be observed in the quantitative analysis of sections of soil. In: A.J. Ringrose-Voase and G.S. Humphreys (Editors), *Soil micromorphology: studies in management and genesis.* Proceedings of the Ixth International Working Meeting on Soil Micromorphology, Townsville, Australia, July 1992. Elsevier Science, Amsterdam, pp. 483-493.

Romans, J.C.C., 1986. Some notes on the soils at Scord of Brouster, Shetland. In: A. Whittle (Editor), *Scord of Brouster: an early agricultural settlement on Shetland.* Oxford University Committee for Archaeology, Monograph 9, Oxford, pp. 125-131.

Romans, J.C.C. and Durno, S.E., 1971. Kilphedir- hut circle excavation site. In, (eds. Fairhurst, H. and Taylor, D. B.). *Proceedings of the Society of Antiquaries of Scotland*, **103**: 65-99.

Romans, J.C.C. and Roberston, L., 1975. Some genetic characteristics of the freely drained soils of the Etterick association in E. Scotland. *Geoderma*, **14**: 297-317.

Romans, J.C.C. and Robertson, L., 1975. Soils and archaeology in Scotland. In: J.G. Evans, S. Limbrey and H. Cleere (Editors), *The effect of man on the landscape: the highland zone.* CBA Research reports No. 11, York, pp. 37-39.

Romans, J.C.C. and Robertson, L., 1983. The general effects of early agriculture on the soil profile. In: G.S. Maxwell (Editor), *The impact of aerial reconnaisance on archaeology.* CBA Research Report. No. 49., Oxford, pp. 136-141.

Ruhe, R.V., 1956. Geomorphic surfaces and the nature of soils. *Soil Science*, **82**: 441-455.

Ruhe, R.V. and Olsen, C.G., 1980. Soil welding. *Soil Science*, **130**: 132-139.

Runia, L.T., 1988. So-called secondary podzolization in barrows. In: W. Groenman-van Waateringe and M. Robinson (Editors), *Man-made soils.* BAR Int 410, Oxford, pp. 115-129.

Runia, L.T. and Buurman, P., 1987. The so-called 'sekundarpodsolierung' in burial mounds: chemical data from dutch barrows. *Journal of Archaeological Science*, **14**: 97-105.

Rushton, S.P., 1986. The effects of soil compaction on *Lumbricus terrestris* and its possible implications for populations on land reclaimed from open-cast coal mining. *Pedobiologia*, **29**: 85-90.

Scaife, R.G. and Macphail, R.I., 1983. The Post-Devensian development of heathland soils and vegetation. In: C.P. Burnham (Editor), *Soils of heathland and chalk grassland.* South-east soils discussion group, Ashford, Kent, pp. 70-99.

Schaetzl, R.J. and Sorenson, C. J., 1987. The concept of 'buried' versus 'isolated' paleosols: examples from northeastern Kansas. *Soil Science*, **143**: 426-435.

Simpson, I.A., 1996a. The physical nature of the burial environment in archaeological sites and landscapes. *Preserving archaeological remains in situ*, Museum of London, pp. 55-59.

Simpson, I.A., 1996b. Thin section soil micromorphology. In: R. Peterson (Editor), *Fordhouse barrow excavations, second interim report: the 1995 season.* The National Trust for Scotland Report No. 4, pp. 12-16.

Simpson, I.A., Bol, R., Dockrill, S.J., Petzke, K.-J. and Evershed, R.P., 1997. Compound specific d15 N amino acid signals in palaeosols as indicators of early land use: a preliminary study. *Archaeological Prospection*, 4: 147-152.

Simpson, I.A. and Davidson, D.A., in press. *Palaeosols of the Clava Cairns, Proceedings of the Society of Antiquaries of Scotland, Special Monograph: The good stones - the excavated material of Balanura of Clava.*

Smith, P. and Thomasson, A.J., 1974. Density and water release characteristics. In: B.W. Avery and C.L. Bascomb (Editors), *Soil Survey laboratory methods. Soil Survey of England and Wales*, Harpenden, pp. 42-56.

Sochtig, W. and Larin, K.O., 1992. Effect of soil compaction on activity and biomass of endogenic Lumricids in arable soils. *Soil Biology and Biochemistry*, **24**: 1595-1599.

Soulsby, J.A., 1976. Palaeoenvironmental interpretation of a buried soil at Achnacree, Argyll. *Transactions of the Institute of British Geographers*, **1**: 279-283.

Stern, R., Ben-Hur, M. and Stainberg, I., 1991. Clay mineralogy effect on rain infiltration, soil formation and soil losses. *Soil Science*, **152**: 455-462.

Stevenson, J.B., 1984. The excavation of a hut circle at Cul a Bhaile, Jura. *Proceedings of the Society of Antiquaries of Scotland*, **114**: 127-160.

Stewart, M.E.C., 1962. The excavation of two circular enclosures at Dalnaglar, Perthshire. *Proceedings of the Society of Antiquaries of Scotland*, **95**: 136-158.

Stoops, G., 1998. Key to the ISSS 'Handbook for soil thin section description'. *Natuurwat. Tijdschr.*, **78**: 193-203.

Stoops, G., Delvigne, J. and Van der Plas, L., unpublished. Parent material, weathering and neoformation, Fourth European Intensive course on soil micromorphology. 1997, Granada, Spain.

Stoops, G. and Poch, R.M., 1994. Micromorphological classification of gypsiferous soil materials. In: A.J. Ringrose-Voase and G.S. Humphreys (Editors), *Soil micromorphology: studies in management and genesis*. Elsevier: Developments in Soil Science 22, Amsterdam, pp. 327-332.

Stuiver, M. and Reimer, P.J., 1993. Extended 14C database and revised CALIB rediocarbon calibration program. *Radiocarbon*, **35**: 215-230.

Stuiver, M. et al., 1998. INTCAL98 Radiocarbon age calibration 24,000 - 0 cal BP. *Radiocarbon*, **40**: 1041-1083.

Sullivan, L.A., 1994. Clay coating formation on impermeable material: deposition by suspension retension. In: A.J. Ringrose-Voase and G.S. Humphreys (Editors), *Soil micromorphology: studies in management and genesis*. Proceedings of the IXth International Working Meeting on Soil Micromorphology. Developments in Soil Science. Elsevier Science, Amsterdam, pp. 373-380.

Terrible, F. and FitzPatrick, E.A., 1992. Applications of multilayer digital image processing techniques to thin sections. *Geoderma*, **55**: 159-174.

Terrible, F. and FitzPatrick, E.A., 1995. Image analysis applied to soil micromorphology. *European Journal of Soil Science*, **46**: 29-45.

Thompson, M.L., Singh, P., Corak, S. and Straszheim, W.E., 1992. Cautionary notes for the automated analysis of soil pore-space images. *Geoderma*, **53**: 399-415.

Tipping, R., Carter, S. and Johnston, D., 1994. Soil pollen and soil micromorphological analyses of old ground surfaces on Biggar Common, Borders Region, Scotland. *Journal of Archaeological Science*, **21**: 387-401.

Topping, P., 1989. Early cultivation in Northumberland and the Borders. *Proceedings of the Prehistoric Society*, **55**: 161-179.

Tovey, N.K., Krinsley, D.H., Dent, D.L. and Corbett, W.M., 1992. Techniques to quantitatively study the microfabric of soils. *Geoderma*, **53**: 217-235.

Turner, J., 1979. The environment of northeast England during Roman times as shown by pollen analysis. *Journal of Archaeological Science*, **6**: 285-290.

Usai, R., 1999. *Can we rely on micromorphological markers of past cultivation? Stanwix, a site near Hadrian's Wall.* Environmental Archaeology Unit Research Forum, York, 1998. http://www.york.ac.uk/inst/eau/forum99.htm

Valentine, K.W.G. and Dalrymple, J.B., 1975. The identification, lateral variation and chronology of two buried paleocatenas at Woodhall Spa and West Runton, England. *Quaternary Research*, **5**: 551-590.

Valentine, K.W.G. and Dalrymple, J.B., 1976. Quaternary buried palaeosols: a critical review. *Quaternary Research*, **6**: 209-222.

Van Vliet-Lanoe, B., Coutard, J.P. and Pissart, A., 1985. Structures caused by repeated freezing and thawing in various loamy sediments. A comparison of active, fossil, and experimental data. *Earth Surface Processes and Landforms*, **9**: 553-565.

Vinten, A.J.A. and Nye, P.H., 1985. Transport and deposition of dilute colloidal suspensions in soils. *Journal of Soil Science*, **36**: 531-541.

Visser, S., Fujikawa, J., Griffiths, C.L. and Parkinson, D.L., 1984. Effect of topsoil storage on microbial activity, primary production and decomposition potential. *Plant and Soil*, **82**: 41-50.

Vogel, H.G. and Babel, U., 1994. Experimental relationship between the morphological pore-size distribution and the soil water characteristics. In: A.J. Ringrose-Voase and G.S. Humphreys (Editors), *Soil micromorphology: studies in management and genesis*. Proceedings of the IXth Int. Working Meeting on Soil Micromorphology. Developments on Soil Science, 22. Elsevier, Amsterdam, pp. 591-599.

Vreeken, W.J., 1975. Principal kinds of chronosequence and their significance in soil history. *Journal of Soil Science*, **26**: 378-394.

Vreeken, W. J., 1984. Soil-Landscape chronograms for pedochronological analysis. *Geoderma*, **34**; 149-164.

Wheeler, D. and Mayes, J., 1997. *Regional climates of the British Isles*. Routledge, London, 343 pp.

Wilson, M.J., 1975. Chemical weathering of some primary rock-forming minerals. *Soil Science*, **119**: 349-355.

Yaalon, D.H., 1971. Soil forming processes in time and space. In: D.H. Yaalon (Editor), *Paleopedology*. Israel Universities Press, Jerusalem, pp. 29-31.