Invertebrate Faunalturbation of Archaeological Sites; Assessing the Impact on Archaeological Stratigraphy

Thesis
submitted in fulfilment of the
requirement of the degree of Doctor of Philosophy at the
Department of Environmental Science
University of Stirling

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Abstract

The stratigraphy of an archaeological site is fundamental to the understanding of that site's history of occupation, use and abandonment. Archaeological stratigraphy is subject to a variety of post-depositional processes that may damage or destroy this stratigraphy. This work focuses on one such process, faunalturbation, i.e. the process of mixing by animals. The effects of the invertebrate soil mesofauna, in particular earthworms, were studied in this work. Three archaeological sites were investigated using faunal surveys, thin section micromorphology, ^{137}Cs profiling, field recording and determinations of pH, loss on ignition, bulk density and particle size distribution.

This study views faunalturbation as a system and attempts to delineate and confirm the relationships within that study. The results demonstrate that soil properties such as loss on ignition and pH have some effect on the populations of soil invertebrates and on the intensity and distribution of faunalturbation, but that there are likely to be other factors which also have a significant influence. Two models of the possible impact that invertebrate faunalturbation has on archaeological stratigraphy are advanced and tested, with one being found to be more accurate. This model posits that the most rapid and complete impact on archaeological stratigraphy is found to occur in the uppermost region of an archaeological site, with significant but lesser impact occurring more slowly in the deeper part of an archaeological site. Where a site has accumulated in an episodic fashion, there may be zones at depth within an archaeological site which have had all stratigraphic units completely reworked by invertebrate faunalturbation.

Acknowledgements

It is customary at this point to thank ones' supervisors, Dr. I.A. Simpson, Prof. D.A. Davidson and Dr. A.N. Tyler, and the support of the relevant funding body, NERC.

I would like to thank Mr. & Mrs. D. Thomson, Mr. & Mrs. D. Towrie, Mr. A Skea and Mr. And the late Mrs. A. Muir for allowing access to their land and for their general assistance.

I am indebted to Mr. G. McLeod for preparing thin sections and to Mr. D. Aitchison for preparing many of the figures in the thesis.

It is with special gratitude that I wish record my debt to my field assistants, Althea Davies, Claire Wilson and especially Erika Guttmann, both for their help in the field and in subsequent discussions.

The support of my family and of the Brownrigg family have been sources of great comfort throughout the process of this study, for which I give thanks.

Dedication

To my father

John Glyn Lancaster

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Chapter One

Introduction.

1.1 Introduction: Archaeological Stratigraphy

1.1.1 Fundamental Significance of Archaeological Stratigraphy

Prior to the late nineteenth century an archaeological site's deposits were largely regarded as a substrate from which artefacts were to be extracted (Trigger 1989: 197). With the publication of Lyell's 'Principles of Geology' (1868), archaeologists had a set of principles with which to approach the deposits of which a site was formed. The application of these principles has, of necessity, undergone some modification for use in archaeology. Nevertheless, until comparatively recently students of archaeology were told to go back to Lyell as the basis of stratigraphic thought (Woolridge 1961: 6). There is considerable debate concerning such matters as: the appropriate application of stratigraphic principle; the degree to which such principles should be rooted in geology; terminology; and most recently the techniques of classification (Harris 1977, Stein 1990, 1996, Gilbertson 1995: 101, Barham 1995: 179). Despite this the fundamentals of archaeological stratigraphy are essentially agreed (Roskams 2001: 110, 245). There is virtually no argument amongst the majority of practising field archaeologists with regard to the basic principles of stratigraphy.

The fundamental importance of studying a site's stratigraphy comes from the range and significance of information that the stratigraphic classification of a site's deposits provides (Roskams 2001: 110). Firstly, this information may be the result of the stratigraphic analysis itself or because such an analysis then permits the study of other aspects of the site's archaeology. In the first case the stratigraphy of a site provides a basis for the history of the occupation (and abandonment) of a site (Roskams 2001: 245). Building, levelling, the digging and filling of ditches and pits and a variety of other activities can be reconstructed from the stratigraphic units of a site and their spatial relationships. A particularly important element of the 'stratigraphic' approach is the ability to place these units in a relative chronological sequence. In theoretical terms it could be argued that the stratigraphic analysis of a site acts as a device to structure information.

Secondly the stratigraphic analysis is incorporated into the study of the other components of a site's archaeology. Such an analysis provides the basis of work on nearly all artefacts and environmental material. On-site sampling strategies for environmental material, be it biological or sedimentological, usually proceeds on the basis of the stratigraphic analysis. This results in the grouping of material and data derived from such material according to stratigraphic unit. Each set of data from a given stratigraphic unit is analogous to a sample in the statistical sense of the term. All comparisons are made on the implicit basis of the stratigraphic classification.

Thirdly the application of the stratigraphic analysis allows a chronosequence of structures and artefacts found on the site to be constructed. This sequence then allows the site to be linked to the regional chronology that archaeologists will have constructed. This gives the site a temporal context, from which wider interpretations may be made.

The preceding discussion demonstrates that stratigraphic analysis is essential to modern archaeology. It is not simply a matter of what should happen according to writers on methodology (e.g. Barker 1977, Harris 1989), it actually is a part of the way archaeological work is undertaken in all areas of the archaeological profession. It is intrinsic to the process of archaeological excavation. Its fundamental nature is demonstrated by the fact that the execution of such an analysis is an implicit assumption in documents on archaeological best practice e.g. MAP 2 (English Heritage 1991).

1.1.2 Post-Depositional Processes

That the stratigraphic analysis of a site's deposits is fundamental to archaeology has been established. While an appreciation of the basic principles of site stratigraphy is well established within the archaeological community (e.g. Barker 1977), knowledge of formation processes is a more recent phenomenon, and has a far weaker influence within the archaeological community (Quine 1995: 77). The value of studying such processes was in Britain first stated by archaeologists during the later 1950's and early 1960's (e.g. Pyddoke 1961, Cornwall 1958, Barker 1977) (see 1.2.3). The impact of the Processualist School, particularly the system outlined by Schiffer (1983), is the advent of a more systematic approach. This approach includes the execution of studies of specifically archaeological situations. This subsequently led to work on a wide range of site formation processes being undertaken.

The situation has emerged where there is some awareness of the significance of formation processes. It is considered axiomatic that an understanding of the formation processes that have created the stratigraphy of a site is essential (Atkinson 1957). But whereas the broad application of stratigraphic principles to archaeological excavation is both agreed upon and actually used, the position with regard to the study of formation. The translation of a general awareness of the problems that post-depositional processes may present into active attempts to detect or remedy this are highly variable. The problem of detection of post-depositional effects is probably the main reason for this. It has been suggested that field recording techniques do not allow the separation of the primary properties of a stratigraphic unit i.e. those deriving from the time of deposition and the secondary properties of the unit i.e. those deriving from post-depositional processes (Barham 1995: 155). It is debatable whether these properties can be separated in the field, but an awareness of the possible problems and improvements in field recording would allow such effects to be detected at the post-excavation stage, by, for example, the application of a range of soil and sediment analyses as suggested by Barham (1995).

For most field archaeologists awareness of the significance of formation processes, particularly post-depositional disturbance, is expressed through the concept of stratigraphic integrity. This is a somewhat nebulous concept. Despite being a frequently used concept it seems to have no formal definition. Although treated as a single concept it seems to consist of at least two ideas that have become conflated. The first of these ideas concerns post-depositional change. For a unit to have 'high' or 'good' stratigraphic integrity it should have undergone minimal post-depositional change, in particular in the sense of mixing or the intrusion of non-contemporaneous material into the unit. The second idea concerns the composition of the unit at the time of deposition. While a unit may be largely unaffected by post-depositional change, it may not necessarily have high or good stratigraphic integrity. The unit may be composed of constituents of either a number of pre-existing archaeological deposits or a mixture of material from archaeological contexts and material circulating in active use immediately prior to deposition (effectively Schiffer's 'systemic' context (Schiffer 1983: 677)).

The overall concept of stratigraphic integrity has developed largely with regard to dating, a major function of stratigraphy (see 1.1.1). In particular the concept has been applied to the selection of suitable material for laboratory based dating procedures, in particular radiocarbon dating (Aitken 1990: 87, Gillespie 1986, Moot & Waterbolk 1985). Outside of the selection of dating material, the concept is less often used. Some archaeologists are aware of some of the problems that post-depositional effects may cause for stratigraphic analysis and interpretation (see 1.1.1 and 1.1.3). These archaeologists are also aware of various approaches to these problems, and apply them to fieldwork projects. There is, however, a further issue that for the most part the work on formation processes, and in particular post-depositional disturbance, are not carried out in an overall framework that would allow the different studies to be linked to one another. This tends to make the application of such studies even more of an *ad hoc* affair. A framework would allow comparisons between studies and allow evidence and principles derived from various studies to be applied to a wide range of situations in archaeology. Such a framework is available, which would allow studies of formation processes to be linked to one another and to be applied to excavation work more effectively. This framework is the pedological-sedimentological approach, detailed further in the following chapter. Here it suffices to note that most geoarchaeologists are already working within this framework to some degree.

With regard to the issue of awareness of the potential significance of post-depositional processes amongst field archaeologists, it should be noted that such awareness is largely nominal. This leads to the assumption of stratigraphic integrity of any given unit. This assumption has been noted by at least one author in the past (Atkinson 1957). Since then, the situation has probably improved somewhat due to the work of scholars such Schiffer (1983) and Binford (1983) in raising awareness and the improvement in excavation techniques by figures such as Barker (1977). The assumption still remains, largely because post-depositional effects are often not regarded as significant (Guttmann pers. comm., Brown pers. comm.). There is a tendency to assume that it is the norm for archaeological sites not to change without obvious external disturbance be it natural e.g. sea erosion or human e.g. agriculture. This tendency may be explained by the fact that an excavation provides a snapshot of the state of preservation of the site at the time of excavation. This can give the impression that post-depositional processes, even if they are identified, are short lived and have occurred in the past. The failure to realise that post-depositional processes may be ongoing leads to the belief that sites are effectively preserved if left free from direct human interference. This view influences the assumption in favour of preservation over excavation that is the official policy of the various public bodies that are concerned with archaeology (e.g. ACAO 1993, DoE 1990). The implications of any findings that post-depositional processes are on-going rather than short lived, and that archaeological stratigraphy may be destroyed, could be substantial in terms of archaeological resource management.

1.1.3 Faunalturbation and Archaeological Stratigraphy

One of the major sets of post-depositional formation processes is faunalturbation. It is on this set of processes that this study will focus. As will be discussed below, work to date on the effects of faunalturbation on archaeological sites has concentrated on the movement of artefacts and, latterly, biological remains through the sediment matrix. The reworking of the stratigraphy itself of a site has very little considered. The mixing of a site's deposits may have a variety of stratigraphic effects, which can be broadly classified as follows.

The stratigraphic units of an archaeological site may be divided into two broad types, deposits and interfaces (Harris 1989: 15), with deposits including sub-soils. Reworking by soil animals obviously directly affects deposits. However, as interface units are the boundaries between deposits, reworking that has an impact on the boundaries between deposits must also affect interface units. The reworking of deposits by soil animals may be thought of in terms of a tendency towards the homogenisation of stratigraphic units. Total homogenisation of two deposits, and thus three units including an interface is included, into a single unit is conceivable. Such an effect is difficult to demonstrate using archaeological examples. It should be noted that the 'topsoil' that overlies most sites (e.g. the uppermost deposit in fig 1.1, adapted from Alexander 2000) may in some cases constitute such a case. Where this happens stratigraphic information will be lost; part of the history of the occupation of a site is lost or seriously distorted. Partial homogenisation may also occur, such homogenisation will tend to lead to adjacent deposits having similar characteristics in terms of colour and texture, leading to situations where the top and bottom of the homogenised material are clearly distinguishable but it is impossible to distinguish a boundary. It is possible that has

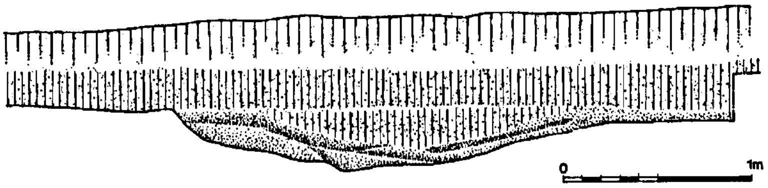
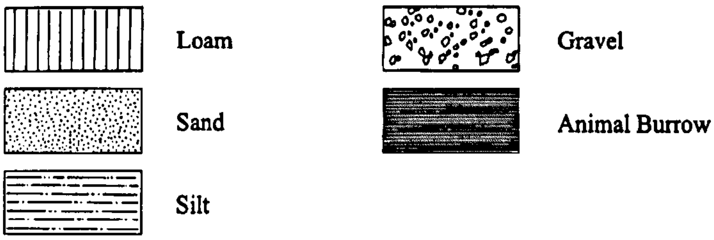


Fig. 1.1 Site section showing possible impact of faunalturbation in upper loamy deposits (adapted from Alexander 2000).



occurred in the case of the upper deposits of section in fig. 1.1. Here the interfaces are described as being indistinct and the deposits are described as loams with slightly varying sand contents, suggesting the possibility of mixing of materials between deposits (Alexander 2000). Even where an interface is identified, its original depth is going to be difficult to determine, particularly if sectional records are created through the method of the continuous section, as there is a tendency to over-excavate where deposit boundaries are indistinct. While loss of stratigraphic information is not so complete in this circumstance, problems of interpretation may still arise. Evidence for the original processes of formation and other post-depositional processes may be obscured or lost, including evidence for rates of deposition, or whether deposition on a site has been continuous or intermittant.

A different situation arises where there is highly localised intensive mixing of the deposits over their boundary. This is particularly noticeable as an effect of rabbit burrowing (see fig. 1.2, adapted from Alexander 2000). It is not as serious a problem, partly because it causes less stratigraphic disruption, partly because it is more easily detected. It does mean that samples cannot be taken from the mixed areas and artefacts in them may have moved (Roskams 2001: 219). This pattern is interesting as it may indicate the earlier stages of certain disturbance processes.

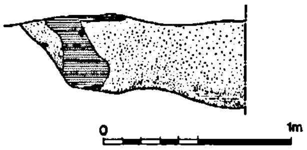


Fig. 1.2 Site section demonstrating impact of intense, localised animal burrowing (see fig. 1.1. for key)(adapted from Alexander 2000).

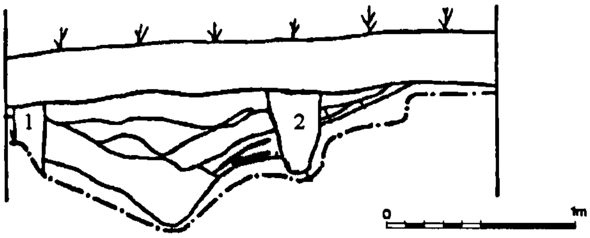


Fig. 1.3. Site section showing truncation of deposits through soil reworking (adapted from Wooliscroft 2000).

A further variation is the truncation of deposits. A vertical deposit such as a post-hole infill may have the top part homogenised with the adjacent deposits but not its lower section e.g. the deposits numbered 1 and 2 in fig. 1.3 (adapted from Wooliscroft 2000). In this situation the loss of information on the feature itself and its stratigraphic relationships occurs.

Other effects include the movement of artefacts, a subject, which is relatively well covered elsewhere (see 1.2), so it will not be expanded on here, and the movement of biological material or ecofacts (see 1.2.4). This movement has a number of implications. The first is the same as that which affects the movement of artefacts - spatial and temporal relationships are lost as a result. Many biological remains, such as insect sclerites or plant macrofossils are quite fragile and may be damaged by movement through sediment. Most importantly the assemblages formed as a result of different processes or by different communities may become mixed, making reconstruction of past activities or environments difficult or producing spurious results.

The above discussion has established the critical role that stratigraphy plays in interpreting archaeological sites and the need to understand formation processes in archaeology in general and in particular with regard to the actual stratigraphy of a site's deposits. It has also demonstrated the near ubiquity of faunalturbation as a potential process of disturbance. It should be noted that sites will tend to bare the strongest traces of the most recent processes, so that recent faunalturbation may destroy evidence of earlier post-depositional processes, thus obscuring evidence both of other sources of stratigraphic disturbance and of subsequent land use or environmental conditions at a site. It has been stated that little account has been taken of the processes of faunalturbation as a potential process of stratigraphic disruption. While this is true with regard to the majority of archaeological field workers, this is not to claim that the issues surrounding the faunalturbation of archaeological sites have never been investigated. At this point it is necessary to consider earlier work in this field and what significance, if any, it has for the current study.

1.2 The study in relation to previous work published on faunalturbation

1.2.1 Introduction

There is a small corpus of published works concerning the effects of faunalturbation on archaeological sites. The issues addressed by these papers and the manner in which they have addressed them has developed over time. These developments are themselves related to the broader historical development of archaeology, and some of these broader developments also have significance for this study, as will be noted below.

1.2.2 The work of Charles Darwin

Darwin's book 'The Formation of Vegetable Mould through the Action of Worms' (1881) was the first major English language work on earthworms. It should be noted that no other invertebrates are considered. The book contains a full chapter on the effects of earthworms on ancient structures. Another area of emphasis is on the movement of objects, which, whilst dealt with separately, Darwin points out is applicable to the burial and movement of archaeological artefacts. This emphasis is particularly important in terms of subsequent publications on the archaeological effects of earthworms. From Darwin onwards the main emphasis has been on the movement of artefacts and thus the disruption of their stratigraphic relationships.

1.2.3 The Empiricist approach (1957-c1975).

Between 1890 and 1957 there were no English language publications concerning the impact of invertebrate faunalturbation on archaeological sites. It should be noted that research into the biology, ecology and impact of the soil fauna, particularly earthworms, flourished from around the 1930's onwards e.g. Evans and Guilds' four substantial papers all appearing in 1948 (Guild 1948, Evans & Guild 1948a, Evans 1948, Evans & Guild 1948b).

In 1957 Atkinson's paper 'Worms and Weathering.' was published. While drawing heavily on Darwin's work this paper was the first to draw on the preceding research in soil biology. The use of data gathered for agricultural and ecological research was common in works on faunalturbation of archaeological sites published at this time. The use of such data was, and to some degree still is, a necessity. From the 1957 paper up to c.1975 the use of such data was often rather uncritical. Neither does there appear to have been any attempt made to undertake systematic research in on the effects of faunalturbation in a specifically archaeological setting. This is not to say that no new data was gathered. Atkinson's paper contains a number of useful *ad hoc* observations.

Other publications at this time include more general books on site formation processes and the application of soil science to archaeology (e.g. Cornwall 1958, Pyddoke 1961). These tended to include small sections on the effects of earthworm activity. The influence of other invertebrates in a British context was generally not addressed. An exception to this is Limbrey's book "Soil Science and Archaeology" (1975: 238), in which some mention is made of other invertebrates. These summaries were a mixture of Darwin's work, the non-archaeological work on earthworms and observations and experiences of the writers and their peers. Excavation manuals also made some reference to the effects of earthworms. The most popular simply cites Atkinson verbatim (Barker 1977).

Barker's work is in fact typical of the work of most archaeologists at this time. The entire approach was very much a 'common sense' approach. The formal theoretical approach of the Processualist movement, which was emerging in the later part of this period, was generally avoided (Trigger 1989: 358, Barker 1977: 12). With regard to publications on formation processes, the period is characterised by Atkinson's paper (1957), which throws together two very different sets of formation processes i.e. the movement of artefacts by earthworm activity and the effects of weathering processes on sub-soil features.

Throughout this period the main emphasis was on the movement of artefacts down archaeological profiles. Some quantitative data were presented by most authors for the distances artefacts have moved, again largely derived from *ad hoc* observations. The other effects of faunalturbation are not generally mentioned although Atkinson does point out some of the implications of soil mixing for buried soils (Atkinson 1957). However the possibility of disruption of deposit stratigraphy does not seem to have been considered in the context of other types of archaeological deposits which occur more commonly. Due to the *ad hoc* nature of the evidence presented in these publications there is a lack of coherence to the overall view of the effects of faunalturbation on archaeological sites.

1.2.4 The Processualist/Systematic Approach (1975 onwards).

During the later 1960's and early 1970's there arose within archaeology the 'Processualist' school (Trigger 1988: 294). Even though there was resistance to certain aspects of Processualism amongst more traditional practitioners of archaeology (e.g. Daniel 1973) and many criticisms that are more trenchant have been voiced from the 1980's onwards by 'Post-Processualist' theoreticians, Processualism still has considerable influence (Trigger 1989: 349). Processualist archaeology may be defined as an approach to archaeology that stresses the dynamic relationship between social and economic aspects of culture and the environment as the basis for understanding the processes of culture change. It is characterised by the adoption of the scientific methodology of problem statement, hypothesis formulation and subsequent testing (after Renfrew and Bahn 1991).

It could be argued that Processualist ideas have been particularly popular and durable in environmental archaeology and formation process studies, where the broadly scientific and ecological approach of the Processualist School naturally finds sympathy. Indeed the formal concept of formation processes constitutes one of the major contributions of the Processualist school, both in terms of theory and of programmes of practical research.

As has been implied above, prior to the work of Binford and, in particular, Schiffer there was very little systematic research on formation processes. The response to their programmatic statements (e.g. Binford 1983, Schiffer 1983) has been in the form of a substantial number of systematic studies of a wide range of different formation processes in specifically archaeological settings. Part of this work has been concerned specifically with the processes of faunalturbation, as will be discussed in greater detail in this section.

One other effect of the increasing systematisation within archaeology, due to the influence of Processualism and increasing professionalism within the field, has been the rise of a particular type of review paper (Trigger 1989: 301). These have taken the form of statements of the current state of knowledge/speculation concerning a particular broad topic, reinterpreted from a Processualist point of view. Schemes of (largely unfulfilled) research plans were also laid out. Formation and disturbance processes were particularly favoured for these types of papers. The various types of processes have been classified into groups. Faunalturbation has been listed in most such papers as one of these processes (e.g. Wood and Johnson 1978, Rolfsen 1980, Schiffer 1983). While such papers attempt to bring the issue of faunalturbation to the attention of the archaeological community, very little new data was published in these papers. Other disturbance and formation processes for which there was more (non-archaeological) data e.g. cryoturbation generally take a larger share of such papers (e.g. Wood and Johnson 1978).

Despite the ambitious programmes outlined in some of the review papers relatively little research was undertaken concerning the processes of faunalturbation in specifically archaeological situations in the earlier part of this period. The main period of activity for publications has been the 1990's, with three papers concerning the effects of invertebrate faunalturbation on temperate zone archaeological sites (Armour-Chelu and Andrews 1994, Carter 1990, Davidson *et al.* 1999) and at least a further two papers on this subject in tropical zone settings (McBrearty 1992, Grave & Kealhoffer 1999). The research on faunalturbation published from 1975 onwards shares characteristics which previous work has not generally exhibited. The main characteristics relate to the broad approach adopted by the various authors of these papers. All the papers are systematic, problem led pieces of research rather than collections of *ad hoc* observations. Most of the papers also have a shared area of concern, that of the effects of faunalturbation on the post-depositional movement of biological material that might be used in environmental reconstruction (Armour-Chelu & Andrews 1994, Carter 1990, Davidson *et al.* 1999). This emphasis is a new one, reflecting the growing importance of environmental archaeology. The concentrations of these papers on the fate of particular components of archaeological sites means that, as with the publications of the previous period, there is little coherent view of faunalturbation as a system or set of interrelated processes that may have a wide range of impacts.

The single most significant paper on the subject of faunalturbation since 1975 actually predates the papers discussed above. Stein's paper (1983) is the first work to suggest that faunalturbation by earthworms may have a variety of stratigraphic effects. Movement of artefacts and ecofacts are mentioned. So, for the first time, is the possible transfer of chemical markers. Most significantly for the current study, the possibility of the movement of the particles and aggregates of which the stratigraphy of a site is formed is for the first time posited. Both the possible blurring of boundaries and the complete reworking of stratigraphic units are mentioned. While the study did not use soil micromorphology, this is recommended for future work on the subject. This technique has subsequently been employed in more recent studies (Carter 1990, Davidson *et al.* 1999),and will be employed in this study (see 4.10 and 6.3).

There has been considerable criticism of the Processualist School. Such criticisms can be divided into two broad types. One type has been essentially concerned either with some of the theoretical 'excesses' and deficiencies, or with detailed problems of application of the earlier programmatic statements and the first attempts to apply Processualism. Such an approach may be characterised by the work of archaeologists such as Flannery (e.g. Flannery 1976) and Renfrew (summarised in Renfrew & Bahn 1991). The positions arrived at by these critics broadly form the theoretical background of most studies of formation processes and environmental archaeology, and indeed much of archaeology in general. It also constitutes the broad epistomological approach of this study.

While there has been a long-standing interest in the effects of invertebrate faunalturbation in archaeology, there has been little systematic work. Those systematic investigations that have occurred have generally been during the later 1980's and 1990's, largely as a result of the application of wider programmes of research into site formation processes that initially emerged under the aegis of the Processualist approach. Even these papers have not generally looked at the effects of faunalturbation on archaeological stratigraphic units. This study is seeks to investigate the effects of faunalturbation on the stratigraphic units themselves, as fundamental elements in the practice of archaeology (see 1.1).

1.3 The Sedimentological-Pedological Framework

In the course of the review of previous work on the faunalturbation of archaeological sites one constant problem was identified. This problem is the difficulty of comparing the findings of the different papers. This difficulty arises because the various studies concentrate on particular components of archaeological sites. Observations on casting and the movement of artefacts through the soil profile are presented without any way of relating these two sets of processes. Solutions to this problem have already been partially articulated. Stein (1983, 1987) has articulated a broadly sedimentological approach. This allows all components of archaeological sediments to be placed within a single explanatory framework and thus related to one another. Artefacts and ecofacts are effectively viewed as particles within a sediment. The stratigraphic units identified by archaeologists may be regarded as sedimentary units, in the case of deposits, and sedimentary discontinuities in the case of 'interface' units such as floor surfaces and ditch cuts. The advantage of having a framework into which the various observations may be incorporated is that this will give greater coherency to the combined findings of different studies, allowing the wider application of findings and also a more ready appreciation of the defects in different studies. A coherent framework should also allow the possible interplay of different formation processes to be examined.

To be applicable to the formation of the archaeological record any approach needs to take account of post-depositional changes: archaeological deposits are not necessarily unchanged sedimentary units. As such other approaches from the natural sciences need to be adopted and added to the overall framework to allow site formation process research to be ordered into a coherent whole. One example of the natural sciences that are valuable in this respect is geomorphology. It has been applied to problems such as the formation of lynchets on hillsides, and the silting of ditches (e.g. Crabtree 1996). The most useful addition to the sedimentological framework, from the point of view if this study, is the pedological approach. Such an approach is also implied in Stein's work (1987). Johnson has articulated a broad theoretical statement on pedoturbation of archaeological sites, positing an evolutionary model. While this is an interesting attempt, the framework has problems in that it is tied to a classificatory scheme, which uses a crudely dichotomous evolutionary approach. This aspect of the model potentially obscures the relationships between various pedoturbatory formation processes and their archaeological effects, rather than elucidating them (Johnson 1990). This study will use a broad sedimentological-pedological framework, wherein artefacts and ecofacts are regarded as sedimentary particles, and archaeological deposits are treated as sedimentary units, and as potential or actual parent materials for soils. The explicit use of a combined sedimentalogical-pedological framework is a novel aspect of this study. It is reflected in certain methodological choices e.g. the field recording method (see 4.3) and analysis of the results of the study (see 9.2).

1.4. Objectives

The above discussion has established the critical role that stratigraphy plays in interpreting archaeological sites and the need to understand formation processes in archaeology in general and in particular with regard to the actual stratigraphy of a site's deposits. It has also demonstrated the near ubiquity of faunalturbation as a potential process of disturbance. From the preceding review of work on archaeological faunalturbation it will be apparent that there are a number of areas concerning the processes of faunalturbation of archaeological sites which the extant archaeological literature does not address. The objectives of this study have been formulated with a view to rectifying this situation.

The objectives of the study are as follows:

- To develop an explanatory model of faunalturbation which will allow the effects on all archaeological materials to be explained in an integrated manner. The model will seek to explain both the processes of faunalturbation and the factors that may cause variation in such processes. The model will be developed on the basis of the currently available scientific literature.

- To test the model, both qualitatively and statistically, using data derived from the upper regions of archaeological sites, where faunalturbation can be demonstrated to be ongoing. Such testing will be based around hypothesised relations between factors, derived from the model itself. Consequent upon the results of the testing the model will be modified as necessary.

- To apply the model to, and further test it with, data derived from the deeper regions of archaeological sites, where the nature and magnitude of ongoing faunalturbation is less clear.

Through these objectives this study will seek to assess the significance of faunalturbation on site stratigraphy. While the actual methodology is discussed in chapter three it is worth prefiguring the type of approach that has been adopted. Faunalturbation is a current, ongoing process. As such, one way of assessing the impact of faunalturbation is to examine the fauna involved and their current or recent effect. Archaeological strata will be examined for evidence of faunalturbation, both modern/recent and ancient, the latter to be identified by comparison with modern analogues. From this, possible implications for the interpretation of archaeological stratigraphy and the other areas of research that rely on stratigraphic analysis can then be assessed.

Chapter Two

The Agents and Mechanisms of Faunalturbation

2.1 Introduction

The focus of this study on the effects of invertebrate faunalturbation has already been detailed above. In order to construct the conceptual models of faunalturbation it is now necessary to consider the agents of faunalturbation and the mechanisms by which these organisms mix sediments and soils. As a means of classifying of the different agents, the concept of functional groups has been developed.

The concept of functional groups is an important one for this study. The term may be defined as the group of organisms whose behaviour causes them to move the solid components of the soil in a similar way and with broadly similar results. Thus the criterion of classification is the mechanism of faunalturbation. The word functional is used to denote the function of the group in the processes of faunalturbation of the soils and sediments of which an archaeological site is composed. The term functional group is in use in functional ecology. The ecological use of the term may be defined as those organisms that use a habitat resource in a similar manner (Faber 1991). As can be seen, there is some overlap in these two forms of classification, in that the mechanism of faunalturbation is related to the manner in which an organism utilises the soil. The term 'community guild' overlaps still further if Jaksic's insistence that similarity of utilisation is measured in terms of effect on the resource under consideration is followed. However it has been decided that the functional group, as defined above, will be a more appropriate concept, as it connotes mechanism, agent and effect (Jaksic

1981). It has also been designed specifically for the scales at which this study operates. Throughout the study only the definition specific to this work will be used.

The functional groups are as follows; endogeic earthworms; anecic earthworms; geophagous enchytraeids; Coleopteran and Dipteran larvae; burrowing Coleopteran adults. The different functional groups and their associated mechanisms of faunalturbation are presented below (see following sections). With regard to these groups, the different species that make up each group are assumed to be mutually interchangeable within that group. This has consequences for the methods adopted (see below 5.4).

The classification of the soil fauna is based upon a single set of criteria. The most important of these criteria is the actual mechanism by which an organism moves and mixes soil and sediment. Other criteria are the location in a soil profile at which this happens and the frequency with which the organism uses this mechanism. As the mechanisms, location and frequency are a result of the organism's lifestyle, some of the functional groups are also accepted ecological groupings (see below). These criteria allow the adoption of the functional groups given above, which correspond to ecological groupings, in the case of the earthworms (Edwards and Bohlen 1996: 113), and broad taxonomic and age groupings for the other organisms (Didden 1993, Tashiro 1990: 1255, Tesky 1990: 1192).

2.2 The Agents and Mechanisms of Faunalturbation: Introductory Comments on the Literature

It is unsurprising that there is a substantial literature concerning the organisms that affect the structure and physical and chemical properties of the soil, considering that it is a resource of the highest importance. However the coverage of the different groups of soil organisms is highly variable. It is estimated that for all types of earthworms considered together that there were, in 1996, c. 4500 references in the scientific literature (Edwards and Bohlen 1996). It is not unrealistic to suggest that at the time of writing that this figure is likely to have passed the 5000 mark. By contrast the literature on soil burrowing beetles, either as larvae or adults, is very small. A proliferation of publications does not necessarily imply a large quantity of relevant material. Of the references on earthworms only a small proportion have any relevance to this study.

There are also the issues of detail and inter-study comparability to be considered. Many papers, particularly earlier ones, leave out detail that might be significant in assessing the results and concepts. A number of papers neglect to mention the types of soil in which research has been undertaken. Species are often treated as interchangeable. While these sorts of problems of lack of detail tend to improve with the later papers, some of the generalisations accepted within the field of study and perpetuated in more generalised texts are often based on some of these earlier papers. There is also the issue of comparability. Within ecology, and for that matter archaeology, absolute comparability between data sets is not sought, because it is regarded as unattainable. However, that does not mean that an investigator may regard any combination of data sets as comparable. Treating results drawn from disparate ecosystems as comparable can lead to misleading conclusions, and it has been a particular concern in collating the results of literature reviewed in this section to ensure that this has not been done. Summaries of current knowledge concerning the effects of physico-chemical and ecological factors are tabulated within the relevant section on each of the functional groups.

The majority of research concerning the soil fauna, particularly the Lumbricidae, has been undertaken with economic, usually agricultural, goals in mind. This has lead to a concentration on such aspects as transport of chemical elements, porosity and water conductibility. Movement of the soil material itself has been mentioned, and indeed overall turnover figures have been frequently estimated (e.g. Guild 1955, Muller-Leman and Van Dorp 1996). But such movement has had relatively little examination in terms of direction, or variation according to differences in the soil ecosystem.

2.3 The Agents and Mechanisms of Faunalturbation: Endogeic Earthworms

In this section those aspects of the biology and ecology of the endogeic group of earthworms which are relevant to this study will be discussed. These characteristic aspects are given in table 2.1 below. The aspects of the biology and ecology of the group under consideration are those that are thought to affect overall population sizes, population distributions and population activity. Working from the assumption that the overall population size and activity level of the fauna effects the degree of faunalturbation that occurs (see 3.4) the relevance of these aspects becomes clear. The characteristic mechanisms of faunalturbation of this group will also be examined. This section begins with some notes that cover all the taxa of earthworms that are relevant to this study, which are grouped in this section to avoid repetition.

Earthworms belong to the class Oligochaeta. The majority of British earthworms belong to the family Lumbricidae (Sims and Gerard 1985: 44). There is some debate as to the precise definition of the various species and sub-species (Edwards and Bohlen 1996: 37-39). The taxonomy and thus keys used by Sims and Gerard (1985: 43-119) have been adopted for this study as these are the most widely used in British (and other northwestern European) studies.

As noted above, earthworms have also been classified into ecological groups. The most commonly used of the ecological classifications used is that of Bouché, first proposed in 1972 and revised in 1977 (Edwards and Bohlen 1996: 113). Under this system earthworms are classified into one of three groups: epigeic, anecic and endogeic. This system of classification has been used with considerable success throughout the temperate zones (Edwards and Bohlen 1996: 115). In essence, the Bouché system divides earthworms into three groups on the basis of their broad ecological differences. These differences coincide with significant differences in the mode and location of faunalturbation (Edwards and Bohlen 1996: 113), allowing two of the groups to be incorporated into the system of functional groups that this study is using (See 2.2). The first of Bouché's groups is the epigeic group. This group dwell in at very shallow levels in the soil, or in far greater numbers in leaf litter (Curry 1998). They are litter consumers and as such they do not move significant quantities of soil or sediment (Edwards and Bohlen 1996). Because of this, this group will not be examined in this study, and will only be referred to in the context of their interactions with the groups directly involved with faunalturbation.

Table 2.1 The effect of physico-chemical and ecological factors on endogeic earthworm populations.

	Endogeic Earthworms
Moisture	Controls overall population size through mortality, fecundity and migration (Edwards and Bohlen 1996: 134-136, Evans and Guild 1948a, Sims and Gerard 1985: 28). Activity levels also influenced by moisture levels, including onset of diapause (Curry 1998). Vertical and lateral distribution also affected. In conditions of sufficient moisture most individuals found in top 10cm. Drier conditions force individuals to depth of 15-30cm (Barley 1959, Edwards and Bohlen 1996: 105). Affects species composition of the group (Edwards and Bohlen 1996: 117).
Texture	Effects complex and minor. Largest populations recorded in loams and light sandy soils, but positive correlations of population and clay content up to 25% also recorded (Curry 1998 Edwards and Bohlen 1996: 147). Species composition seems little affected by texture (Guild 1951).
Organic Matter	Major factor of population sizes as source of nutrients – nitrogen content probably main constraint (Curry 1998, Syers and Springett 1983). Feeding preference variation within the group means that the species composition of the group may vary with organic matter type (Phillipson *et al.* 1976. Patchiness of distribution of organic matter is significant as a factor in determining the distribution of earthworm activity (Cook and Linden 1996).
pH	Current lower limit for indigenous species believed to be pH 3.5 – most species above 4.5. Optimum pH for commonest species thought to fall between 5 and 6 (Edwards and Bohlen 1996: 144, Satchell 1958).
Density	Effect of density on populations unknown. High degrees of compression (as by heavy machinery) reduces and changes burrowing behaviour to resemble that of the anecic species (Joschko *et al.* 1989, Langmaack *et al.* 1999).
Dispersal	Population levels affected in short term by active migration. Main effect is on species composition of group. Active transport given at 2.5-10 m per year (Edwards and Bohlen 1996: 123). Colonisation probably driven by passive transport (Curry 1998).
Predation & Parasitisation	Range of predators generally taken as indicator of controlling role on population, however, range on Sanday limited (Edwards and Bohlen 1996: 124-125, 127). While overall predation of earthworms may be significant, epigeic species likely to bear the greatest losses. Parasites constitute an 'uncertain and variable control on populations' (Curry 1998).
Competition	Some competition with other groups of earthworms possible, but niche differentiation will reduce the impact of competition, particularly with regard to food (Curry 1998).

Endogeic earthworms dwell in the soil, usually to depths of 10-15 cm in temporary burrows (Curry 1998). They are true geophages, consuming large quantities of soil, from which they derive nutrients. Anecic earthworms occupy permanent burrows, at depths of up to 3m (usually no more than 1m). The burrows are maintained through ingesting or pushing aside intrusive soil material. They are litter consumers, emerging usually at night to feed on the surface (Edwards and Bohlen 1996: 113).

The common endogeic species of the British Isles are; *Allolobophora chlorotica* (Savigny); *Aporrectodea calignosa* (Savigny), morphs *turgida, tuberculata,* and *trapezoides; Aporrectodea rosea (Savigny); Octolasion cyaneum* (Savigny); *Octolasion tyrtaeum tyrtaeum* (Savigny). Other species belonging to this group are known but are rare, particularly in Scotland (Sims and Gerard 1985: 50-115).

The endogeic species of earthworms burrow by two basic mechanisms. The first of these is by pushing through cracks and crevices in the soil. While the actual process need not be described in detail here, the worm effectively opens up pre-existing pores by pushing out the walls of pores. Those soil or sediment particles that are moved are simply compressed into the wall of the earthworm's burrow. The material moved in this fashion is not moved any great distance and is relatively unmixed. Even over substantial periods of time this is unlikely to be a particularly significant as a mechanism of faunalturbation.

The other mechanism of faunalturbation is that of ingestion. As the endogeic species are geophagus this potentially constitutes a significant contribution to the faunalturbation of sites. Material is ingested as the animal everts its pharynx, fills it with soil and then retracts it. This process also creates burrows. The egesta are mainly cast into voids in the soil, with some being cast on the surface, 23% in the case of one set of determinations using *A. tuberculata* (Cook and Linden 1996). As has been noted in table 2.1 the proportion of burrowing through utilising pre-existing voids versus geophagy is partly dependent on soil density, as is the proportion of surface casting (Cook and Linden 1996, Muller-Lemans and Van Dorp 1996). Because this mechanism involves frequent intakes of materials and transport over some distance (although rarely more than 20 cm vertically), greater mixing of material is likely to occur in the sections of a soil profile where endogeic earthworms are active.

As noted above, endogeic earthworms do not typically create permanent burrows by ingestion in exceptionally compressed soils and sediments (Muller-Lemans and Van Dorp 1996). It would therefore seem a reasonable assumption that in usual conditions of soil compression endogeic earthworms use both mechanisms interchangeably. Such burrows are not permanent, and may be partially or, more rarely, fully filled by the worm casts, or collapse as other burrows are opened nearby (Bohlen and Edwards 1996: 113, Cook and Linden 1996).

There are a number of traces left by these mechanisms that may be detected at the microscopic level. Perhaps the most obvious traces are the remains of burrows. As voids these would be classified as channels by soil micromorphologists (Bullock *et al.* 1985). The excrement of the organisms is also left. This may take a number of forms. Some species line chambers with small stones, probably to assist in preventing desiccation (Fitzpatrick 1993). When such linings are detected under the microscope they would be described as textural pedofeatures (Bullock *et al.* 1985). There are the discrete excremental pellets left. Those left by earthworms are generally described as having spherical or mamillated shapes (Bullock *et al.* 1985). The excremental material may be welded to the walls of voids. Finally, the infilling of a channel may be so complete that activity can only be traced as a fabric pedofeature, whereby the fabric of the infilling is different to the fabric of the surrounding soil. The archetypal feature of this kind has a crescentic structure (Bullock *et al.* 1985, Fitzpatrick 1993). There are issues concerning definition, attribution and interpretation surrounding all these types of traces. These issues will be discussed in the methodology (5.3.3).

2.4 The Agents and Mechanisms of Faunalturbation: Anecic Earthworms

This ecological group contains far fewer species than the endogeic group, all of which are more common across Britain (Sims and Gerard 1985: 30). The group consists of; *Lumbricus terrestris* (Linnaeus); *Aporrectodea longa* (Ude); *Aporrectodea calignosa* (Savigny) morph *nocturna* (Sims and Gerard 1985: 31). As has been noted above (2.3), many of the factors that affect endogeic earthworms also affect the anecic species. As such much of this section will largely be concerned with the exceptions to those effects with regard to the anecic species and any additional effects which need to be noted.

The effects of the various physico-chemical and ecological factors may have on this group are given in table 2.2.

Table 2.2 The Effect of Physico-Chemical and Ecological Factors on Anecic Earthworm Populations.

	Anecic Earthworms
Moisture	Controls population size, though has less impact than on the endogeic species (Sims and Gerard 1985: 28, Phillipson *et al.* 1976). Also affects lateral and vertical distribution. Drier conditions force individuals to burrow to greater depth. While feeding activity reduced, burrowing activity little affected (Edwards and Bohlen 1996: 136). May affect species composition of group.
Texture	Positive correlation between population size and clay content up to 25% noted (Edwards and Bohlen 1996: 147). May also affect species composition: *A. longa* less significant in high sand and gravel content soils (Guild 1948). Available depth may also affect population size.
Organic Matter	Factor of population size and density. As litter feeders, surficial organic matter levels most significant. Vegetation cover/land use significant as determinant of input of fresh organic matter (Phillipson *et al.* 1976). Variations of food preferences may also affect the species composition of the group (Edwards and Bohlen 1996: 149).
pH	Known lower limits from pH 3.5 –4.5. Optimum falls between pH5 and 7 (Edwards and Bohlen 1996: 144, Satchell 1958).
Density	Density unlikely to affect overall activity or population size. May affect location of casting and thus of identifiable traces of faunalturbation (Jocshko *et al.* 1989, Langmaack 1999).
Dispersal	Little research on dispersive capacities of group. Probably similar to or greater than that of endogeic group (Edwards and Bohlen 1996: 123).
Predation & Parasitisation	Physiologically adapted to evade predation by surface dwelling predators (Sims and Gerard 1985: 17). Range of vertebrate predators relatively limited on Sanday. More prone to predation by *Artioposthia triangulata* than endogeic earthworms, however this predator is currently unknown on Sanday (Boag pers comm.).
Competition	Competition with endogeic groups is unlikely (see above), however competition between endogeic and epicgeic groups cannot be ruled out. Commensal relationships between some endogeic and anecic species have been posited (Curry 1998).

Anecic earthworms are primarily litter feeders. They construct permanent or semi-permanent burrows. As such an individual anecic earthworm is unlikely to ingest the large quantities of soil or sediment as an endogeic earthworm. However, in constructing and maintaining their burrows anecic earthworms do ingest some soil. The significance of this particular mode of faunalturbation is that the ingested material may come from considerable depth (*L. terrestris* has been found at depths of 3 m) and that most of the material is cast on the surface (Edwards and Bohlen 1996: 114), Muller-Lemans and Van Dorp 1996). Some material is worked into the walls of burrows to maintain them. This material may either be excremental matter or non-ingested material pressed into the walls of the burrow. Many of the resulting traces are similar to those of the endogeic earthworms. While the excremental pellets and passages of anecic species are likely to be of greater dimensions than those of the endogeic species, there are practical difficulties in using this as a criterion of differentiation. These issues will be discussed in greater detail in the methodology (see 5.3.3).

2.5 The Agents and Mechanisms of Faunalturbation: Geophagous Enchytraeids

The literature on the Enchytraeidae is considerably smaller than that on the related Lumbricidae. Many of the areas for which there is data available for the lumbricid groups are not well served with regard to the Enchytraeidae. While the Enchytraeidae are being treated as a single group in this study on functional grounds, there is in any case little choice in the matter as many ecological studies of the enchytraeids do not specify the species compositions of the populations under examination.

The Enchytraeidae are a large group, including aquatic, littoral and terrestrial species. The adults are usually 1-2 cm in length, some species occasionally reaching up to 5 cm (Dash 1990: 311). They are generally white, although individuals may be tinged slightly with green, brown or yellow. This is due to gut content rather than a direct consequence of interspecies variation (Dash 1990: 311). The lifetime of most species seems to be 12 to 18 months (Dash 1990: 313). Most species feed through ingesting particles which they gather using the sticky pharyngeal pad, in a similar fashion to the earthworms. The enchytraeids are classed as decomposers in ecological terms, although there is some debate concerning which part of that community they belong to (Dash 1990: 316, Didden 1993).

Table 2.3 The Effect of Physico-Chemical and Ecological Factors on Geophagous Enchytraeidae Populations.

	Geophagous Enchytraeidae
Moisture	Partial determinant of population size, degree of effect uncertain due to considerable degree of interspecies variation in moisture preferences. Will also effect species composition of group on a site (Dash 1990: 322, Didden 1993)
Texture	No published data available on the role of soil texture as a factor of population size and species composition.
Organic Matter	Predominantly microbivorous. Organic matter significant as substrate for microbes. Small scale variations in organic matter distribution may be significant as a factor in the clustered population densities associated with this group (Didden 1993)
pH	Associated in literature with acidic soils. However, research suggests optimum pH falls around 7 (Didden 1993).
Density	No direct information on the effects of density. Given tendency to occupy pre-existing soil pores, high densities may reduce population size (Didden 1990).
Dispersal	No estimates of rates of active dispersal available. Likely to be low in comparison with earthworms. Colonisation probably relies on passive transport with soil.
Predation & Parasitisation	Wide range of predators suggests a significant impact on population sizes. Effects of parasitisation unknown, although high pollution levels seem to increase proneness to infestation (Didden 1993).
Competition	Main effect seems to be in determining species composition of the group rather than overall population size. Previous assumptions concerning competitive relationships with earthworm taxa largely explicable in terms of responses to abiotic factors (Didden 1993).

The distribution of enchytraeids throughout a site profile is potentially significant in terms of the distribution of any effect the organisms may have on the archaeological stratigraphy. A number of factors have been demonstrated to affect the distribution of enchytraeid worms through a soil profile. Enchytraeids are generally found in the upper part of a soil profile, the majority occurring in the top 6 cm. It is very rare for any to be found below 30 cm, and when so found are usually in very low concentrations. Those found at depths greater than 6 cm are thought to have migrated to avoid adverse conditions, especially drought (Dash: 1990: 319, Didden 1993).

There are other factors which, because of the moisture sensitivity of some enchytraeid species, also affect distribution. As mentioned above these include the pore size distribution and heterogeneity of organic matter distribution. These both affect the distribution of desiccation resistant microhabitats that are available to enchytraeids in drought conditions. The distribution of organic matter is also significant as a food source – enchytraeids have been found concentrated at the plough depth in fields because of the additional organic matter deposited by the ploughing (Didden 1990).

That the lateral distribution of enchytraeids has a tendency to be locally clustered has been noted in the literature. The clusters range from 100 to 1000 cm^2 in extent. Organic matter distribution, changes in physical factors and the normal depth range of different species have been put forward as reasons for this clustering (Dash 1990: 319, Didden 1993). What has not been established is the duration of such clusters.

Enchytraeids move soil and sediment by ingesting particles and egesting them as droppings. The distance such material is moved is uncertain. Both organic and mineral particles are ingested. The mineral particles are thought to be ingested for the microbes that coat them (Didden 1993). There seems to a tendency for enchytraeids to follow larger pores in the soil, thus reducing the amount of burrowing undertaken and the impact this has in terms of faunalturbation. There has been some debate about the burrowing capacity of enchytraeids, but at least one species has been recorded in the process of burrowing (Didden 1993). The burrows created are lined with mucus.

The main traces enchytraeids leave in the soil are their characteristic droppings (Rusek 1985). Some horizons of certain soils are in fact largely composed of such droppings (Dawod and Fitzpatrick 1993). It is worth noting here that enchytraeids feed on the droppings of other soil invertebrates, particularly earthworm casts and the droppings of collembolans and orbatid mites. Thus the presence of this group could easily mask the previous activity of other groups. The other trace the group leaves is the remains of their burrows. How easy these are to identify and attribute is debatable (see 5.3.3).

2.6 The Agents and Mechanisms of Faunalturbation: Coleoptera and Diptera, larvae

When dealing with the biology and ecology of members of the class Insecta there is a consistent problem with lack of data. Relatively little research has been undertaken with regard to juveniles in most of the taxa under consideration in this section (Newton 1990: 1140, Teskey 1990: 1195). The information in many of the publications is of a highly generalised nature (see table 2.4). In some cases, e.g. the Staphylinid, it is apparent that adults and larvae occupy the same habitats and have similar requirements (Newton 1990: 1142). This cannot be assumed in all cases.

Table 2.4 The Effect of Physico-Chemical and Ecological Factors on Populations of Soil Dwelling Larvae of Coleoptera and Diptera.

	Coleoptera and Diptera; larvae
Moisture	Little direct evidence of effects. Physiology suggests sensitivity to desiccation (Gullan and Cranston 1994: 173). Coleoptera larvae better suited to drier soils, Diptera larvae to moister conditions (Teskey 1990: 1256, Wallwork 1970: 107). Some evidence for moisture as a factor in vertical distribution (Crowson 1981: 135).
Texture	Larger populations on loamy and sandy soils. Some species composition variation between clayey and sandy soils (Crowson 1981: 137, Wallwork 1970: 107).
Organic Matter	Factor in species composition of the population. Some effect on population size, both directly as food source for saprophagous species and indirectly as partial determinant of prey species population sizes for predatory species (Wallwork 1970: 109).
pH	No comprehensive study of effects of pH on this group. Thought to affect vertical distribution. No evidence of effect on overall population size of functional group. (Crowson 1981: 142).
Density	No direct information on the effects of density. Given mechanism of faunalturbation, high density, low porosity sediments would reduce habitat availability.
Dispersal	Active dispersal low as a larvae; substantially greater for adult phase, which is responsible for most of dispersal (see below). Some migration through the profile in response to changing conditions (Crowson 1981: 143, Gullan & Cranston 1994: 202).
Predation & Parasitisation	No quantitative data available for this group. Shallow habitat would probably make group more prone to bird predation than either earthworm group.
Competition	Group displays a wide range of ecological preferences (Bell 1990: 1061, Newton 1990: 1143, Tashiro 1990: 1193). Competition thus may affect species composition, but is unlikely to have any effect on overall population size.

More species of both Coleoptera and Diptera behave as soil dwelling organisms in their larval stages than in their adult stages (Crowson 1981: 106, Wallwork 1970: 133). Generally the soil dwelling species of these orders in the British Isles live in the upper part of the soil profile.

This group has two mechanisms of faunalturbation. One is a process of pushing or compressing soil material to modify voids. It is somewhat like the mechanism employed by the Oligochaete groups, but the anatomy of the larvae means that they are unable to exert the same sort of pressure and as such have less effect than the other groups already discussed. This mechanism is probably more important among the Dipteran members of the group. Where this mechanism leaves any trace it is likely to be in the form of slightly smoothed and compressed void walls.

The other mechanism is more associated with the Coleopteran members of the group. That is of active burrowing using the forelimbs and mandible (Newton 1990: 1143). Material thus excavated is either ejected from the mouth of the burrow or pushed into convenient voids. The trace that this would leave would be the channel. The usual problems of assigning a channel to a given functional group would again emerge (see 5.3.3).

The other trace that this group would leave is excrement. The excremental pellets of various group members is deemed to be quite distinctive e.g. that of Tipulid and Bibionid Diptera (Bullock *et al.* 1985: 137).

2.7 The Agents and Mechanisms of Faunalturbation: Coleoptera, burrowing adults

While there is more information concerning the adult soil-dwelling Coleoptera than their larvae, the range of data is still not particularly comprehensive (table 2.5). The families that provide most of the species in this group are the Carabidae, Scarabidae, Elateridae, and the Staphylinidae (Bell 1990: 1153, Newton 1990: 1138, Tashiro 1990:

1256, Wallwork 1970: 108). The species occurring in the British Isles are generally found at quite shallow levels (Crowson 1981: 132).

Table 2.5 The Effect of Physico-Chemical and Ecological Factors on Populations of Burrowing Adult Coleoptera.

	Coleoptera; burrowing adults
Moisture	Highly scleratized body reduces impact of dry conditions (Teskey 1990: 1256). Interspecies variation in moisture preferences probably means that moisture is a factor in group species composition (Crowson 1981: 135).
Texture	Preference towards sandy and loamy soils (Brussard 1985). Such soils may support larger populations. Some effect on species composition of the group (Crowson 1981: 132, Wallwork 1970: 108).
Organic Matter	Factor of population size, as a food source, both directly and for prey species. Factor of species composition of the group (Crowson 1981).
pH	Cited as a factor in distribution, but no comprehensive survey known. No evidence of effect on overall population size of functional group (Crowson 1981: 238, Wallwork 1970: 106).
Density	No direct information on the effects of density. Given mechanism of faunalturbation, high density, low porosity sediments would reduce habitat availability.
Dispersal	Variable capacity for active dispersal due to wing reduction/loss in soil dwelling taxa – likely to affect species composition of group rather than overall population size. Active transport more significant than passive in establishing populations (Newton 1990: 1142).
Predation & Parasitisation	Little quantitative data is available for this group. Wallwork (1970: 109) suggests that parasitism is a population control for the Scarabidae. Predation by birds is likely to be significant.
Competition	Individual species in competition with species from other functional groups, which may affect species composition of the group. Otherwise, the situation is largely the same as for the larvae.

This group has one mechanism of faunalturbation. That is of active burrowing using the forelimbs and mandible (Newton 1990: 1140). Material thus excavated is either ejected from the mouth of the burrow or pushed into convenient voids. Some species may backfill burrows after themselves (Brussard 1985). The traces that this would leave would be the channel, and the form of any backfilling. The usual problems of assigning a channel to a given functional group would again emerge (see 5.3.3). Brussard claims that the species he studied create a 'convex infilling' which is identifiable. However no further description or illustration of what this might look like is given, so recognising such a phenomena would be difficult (Brussard 1985).

The other trace that this group would leave is excrement. The excremental of some members of the group are quite distinctive (Bullock *et al.* 1985). The overall issues of discriminating between different traces and the agent responsible will be discussed in the methodology (see 5.3.3).

The data presented above represents that which is available in the scientific literature. From this information conceptual models of faunalturbation on archaeological sites will be constructed in the following chapter.

Chapter Three

Two Models of Faunalturbation on Archaeological Sites

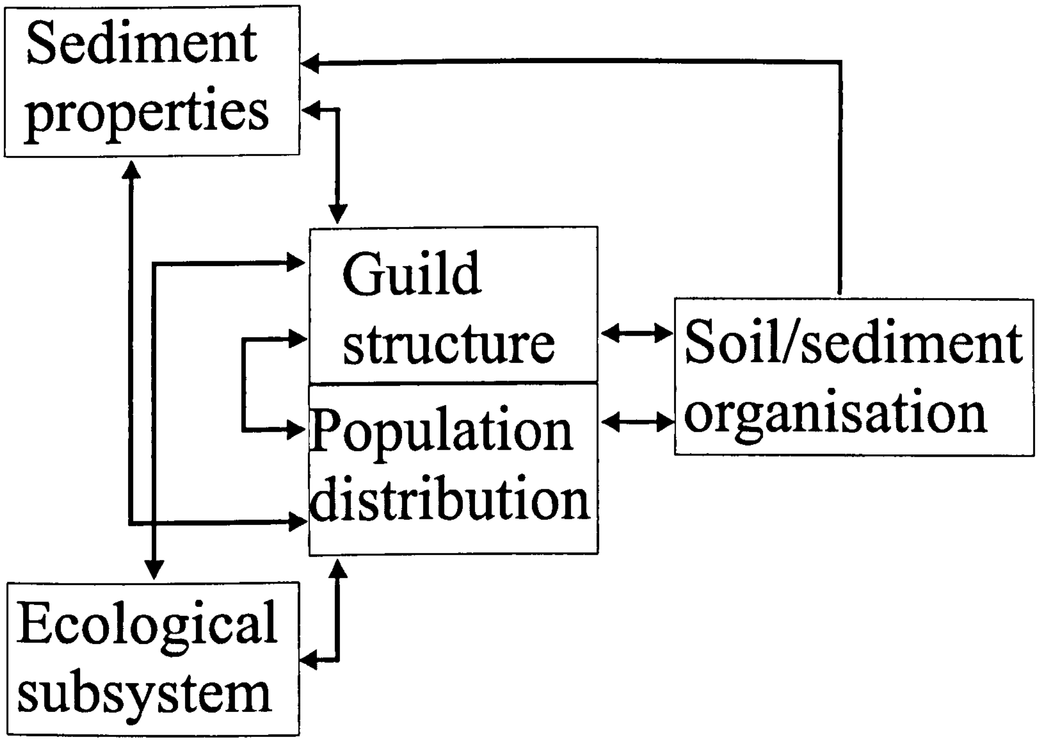
3.1 Introduction

In this chapter two contrasting conceptual models of the processes of faunalturbation will be described. These models are both based on the material reviewed in chapter two. Given the common evidential basis of the two models it is unsurprising that in most respects the two models resemble each other. It is these common aspects of the two models that will be discussed first. Subsequent sections will deal with the differences between the models. Following on from this means of testing the models and discriminating between them will be proposed, followed by a research design that allows testing and discrimination to be accomplished. Model one assumes minimal archaeological impact from faunalturbation. Model two assumes greater archaeological impact resulting from faunalturbation.

3.2 Faunalturbation as a System

The comments in this section can be taken to apply equally to both models. The processes of faunalturbation can be viewed as a system composed of a set of interrelated and interacting components. The components of the system are the factors of faunalturbation. The links between the components are the sets of processes that govern the relations between the components - they could all be designated, directly or indirectly, as processes of faunalturbation. As can be seen from the diagrams, the linkages allow for two-way feedback between components (see figs. 3.1 and 3.2). This is not to suggest that all components or their sub-components will be equally subject to change - many links in the system will transmit change preferentially in one direction. The primary purpose of the models is to provide an explanatory framework for the systems of interrelated processes that constitute faunalturbation. Within this framework, the models posit explicit links between specific components of the model. These relationships can be directly tested, through checking for statistically significant correlations, and are thus the source of most of the hypotheses formulated in this work.

Fig.3.1 Interactions of the main components in the faunalturbation system.



3.3 The Models' Components: Soil/Sediment Organisation

Soil/sediment organisation is the physical arrangement of the discrete soil and sediment units of which a site is composed. In reference to the pedological-sedimentological framework outlined above, the stratigraphic deposits of which an archaeological site is composed are sediment units. Faunalturbation may change the organisation of the soil and sediment units of a site.

3.4 The Models' Components: Guild Structure and Population Distribution

These two components are treated together because they are closely connected. The effects of the sediment properties and the ecological sub-system on the stratigraphy of an archaeological site are mediated through these components.

A guild is defined as 'A group of species that exploit the same class of environmental resources in a similar way' (Begon *et al.* 1990: 853). The guild concept has been used in the model over that of community because not all the organisms in the soil, or interacting directly with its inhabitants, are agents of faunalturbation. The concept of the guild, with its more limited composition, is more appropriate.

There has been some debate amongst ecologists concerning the usefulness of the guild concept with regard to the soil fauna. Other classifications such as the functional groups and leagues have been suggested as being more appropriate concepts in some circumstances (Faber 1991). Whilst a variation on the concept of functional group has been employed for classifying the soil fauna in terms of the mechanisms of faunalturbation, that concept is not sufficiently inclusive at the level that is required for the model component. The guild structure refers to the composition, population size and structure of the guild in terms of the different functional groups. Species composition of individual functional groups is also subsumed within this.

Population distribution is a less controversial concept. It is simply the distribution of each group across the site, encompassing variation in distribution both laterally as well as vertically.

As has been noted above these two components are the direct determinants of faunalturbation. Different functional groups have different mechanisms and differing rates of faunalturbation. Given this, the structure of a guild and the distributions of its constituent populations determine the mechanisms of faunalturbation, the relative significance of each mechanism and variations in the location of each mechanism within an archaeological profile. This means that the survival of archaeological stratigraphy is dependent on the distribution of the agents of faunalturbation. To elucidate the role of agent distribution, the concept of zones has been formulated, and from this, the significant differences between the two models (see 3.7).

3.5 The Models' Components: Soil Properties

For the purposes of this study, the properties of the sediments of which archaeological sites are composed will be characterised as their chemical and physical properties.

It has been noted above that the diagrams of the system show the linkages of the system to operate in both directions between components. The main significance of the organisational properties component of the model is, accordingly, not so much a factor in the faunalturbation system, but the recipient of the effects of the other factors within that system.

On the basis of the findings from the literature (reviewed above, see 2.3-2.7), the physical and chemical properties of the sediments of the profile are predicted to be significant as determining factors within the faunalturbation system. The physical and chemical properties of the sediments determine the type of habitats available to the soil fauna within an archaeological site. While the main requirements of the various taxa of soil fauna have been covered in detail already (see tables 2.1 to 2.5), it is worth considering the how the main properties may affect the fauna to allow the types of interactions involved in the system to be made more explicit. While sediments possess a variety of physical and chemical properties, only the ones selected for this study as those most likely to have an impact on the soil fauna will be considered here. The specific properties that will be considered here: density, texture, organic content and pH. The models allow for the alteration of the various soil properties by the operation of the system, as well as being determinant factors within the system. It is worth noting that properties will not be uniformly prone to alteration because of complex interactions within the system.

Density has a number of potential effects on soil fauna. If soil bulk density is relatively high then some of the non-geophagus fauna may have difficulty moving through the soil or sediment. This is largely due to the lack of sufficiently large pores through which to move. This is particularly likely to be the case for the smaller fauna which are unable to exert sufficient pressure to open up pores, e.g. enchytraeid worms, or those that are physiologically poorly adapted to so such as Coleoptera larvae (Didden 1990). Even the more voracious geophages e.g. the earthworms of the genus *Allolobophora* or those organisms physiologically well adapted to push through soil e.g. the earthworm *Lumbricus terrestris* (Joschko *et al.* 1989, Langmaack *et al.* 1999). Very low densities indicate high soil porosity. This can lead to soils and sediments draining very quickly. Such 'droughty' soils will be dealt with below, but in brief, the lack of moisture may also effectively reduce the activity of soil fauna.

The texture of a soil or sediment also affects its suitability as a habitat for soil fauna. This is primarily through affecting drainage. In sediments with a high proportion of clay water retention is often very considerable, making the sediment liable to saturation and thus rendering it unsuitable to those groups of soil fauna that are unable to thrive in wet habitats. This can be a particular problem for Lumbricid populations. The problems of high density material to the soil fauna have already been covered above, but it should also be noted that in dry weather clay rich soils and sediments might dry to a hardness that makes them impenetrable.

Textures that encourage good, but not excessive, drainage are generally most acceptable to most groups of soil fauna. Such conditions encourage increased species diversity as well as high numbers of individuals (White 1997: 44). Soils with a very high sand content, with little clay and organic matter tend to have very low water retention. Such very 'droughty' soils are unlikely to support large populations of most soil fauna. Many taxa of the soil fauna are prone to desiccation. Those animals that can cope will tend to be those that are able to operate at some depth where there is likely to be more moisture, and enter relatively easily into diapause if conditions become too harsh, e.g. the anecic earthworm species.

The texture of a soil or sediment may also have other effects. Geophagus species of earthworm tend to avoid ingesting coarse sand, i.e. >500μm. Soils or sediments containing high proportions of such material may be unpalatable to these organisms, thus effectively reducing the proneness of these sediments to this particular form of faunalturbation.

The pH of a soil or sediment will also have an impact on the species present. Different species of soil fauna have different preferences and tolerances with regard to pH. Specific tolerances have been discussed above (see 2.3). While it may be broadly stated that for the majority of soil fauna species the optimum pH lies between five and eight (White 1997: 67), there are species that can at least cope with a pH outside of this range, and some enchytraeid species are capable of thriving in low pH environments (Dash 1990). In contrast, earthworms are generally found in largest numbers in neutral soils, seem to be unable to tolerate a pH below 4.2, and are found in much reduced numbers in habitats of pH range 4.2-6.5 (Edwards & Lofty 1977: 229). As has been discussed above, different mechanisms and scales of effect of faunalturbation are associated with the different species (see tables 2.1-2.5). From the combination of the significance of different species with the influence of pH on guild structure and population distribution it could be argued that pH has a profound impact on the pattern and magnitude of faunalturbation that a site undergoes.

The question of the significance of the organic carbon content of archaeological sediments as a possible determinant of faunalturbation is a complex one. The majority of the soil fauna is detrivorous, either obligately or facultatively. The facultative detrivores may also consume living plant material, especially rootlets. The remaining fauna prey on other soil dwelling species. The population size of the predaceous fauna will be partly dependent on the population size of the other fauna in the ecosystem. The population size of the detrivores will vary, partly with the input organic residues into the soils and sediments on the site. There is therefore an indirect relationship between the organic carbon content of the deposits and the numbers of predaceous soil organisms, and thus the degree of faunalturbation that this group of organisms is responsible for.

The significance of soil organic matter as a determinant of the sizes of the detritivore populations depends on its distribution. This is itself dependent on the source of the organic matter, and the feeding behaviour of the various functional groups. When an archaeological sediment is initially deposited it may contain saprogenous material that the organisms which feed directly on such material may consume, provided it is within the depth range of the organisms. Many of these organisms are generally fairly restricted in their normal depth range (see chapter two). This in itself may reflect the effect of limitations on the distribution of food (i.e. organic carbon) on organisms that only move relatively small distance in search of nutrients, rather than innate depth restriction of range. Over time, this original organic carbon content will be supplemented, as organic matter is added to the soil, as well as being diminished due to decay. The new organic matter may be plant litter, animal dung or the remains of dead animals. This last input of course includes the soil fauna itself. Thus, the quantity of organic material available to the soil fauna as food is dependent on organic carbon input, which is known to be heavily dependent on land use (White 1997: 36). As has been suggested above, part of the significance of organic matter as a potential determinant of faunalturbation lies in its distribution. It is apparent from the foregoing discussion that the distribution of organic matter may vary over time. In general, it is true that available organic material tends to be concentrated within the upper part of the profile. The next issue that needs to be addressed, therefore, is the feeding behaviour of the soil fauna and the interplay of this factor with the distribution of soil organic matter.

Among the detritivore species, the functional groups can be divided into those organisms that feed directly on saprogenous material and those which ingest soil (geophages) for its organic content. The first group can be further sub-divided. One sub-division consists of the organisms that live in the upper part of the profile. The second sub-division consists of the anecic earthworms, which feed on litter but dwell at greater depth.

The interaction between the feeding behaviour of the soil fauna and the original distribution of organic material is difficult to assess because the potential for variation in organic carbon distribution between sites is enormous. The best generalisation that could be offered is that the availability of organic matter at depths generally unknown in natural settings could alter the distribution of the various functional groups and thus of their effects in terms of faunalturbation. An example might be the possibility of the endogeic earthworms burrowing at greater than normal depths if there was sufficient organic matter at these depths.

The effects of the subsequent input of organic material are easier to predict. This will occur at the surface of the site, where the matter is consumed by the litter feeding species (White 1997: 40). These animals will incorporate organic matter into the upper horizon of the profile in the form of droppings and some comminuted but unconsumed organic matter (White 1997: 38, 40). This material will thus be available to the geophagus species. In the case of model two, material will also be incorporated to a lesser degree into the zone of partial preservation. The input of materials such as fresh plant litter and animal dung would encourage not just the surface dwelling species but also the anecic earthworms (Edwards and Bohlen 1996: 157), thereby potentially affecting faunalturbation at greater depths.

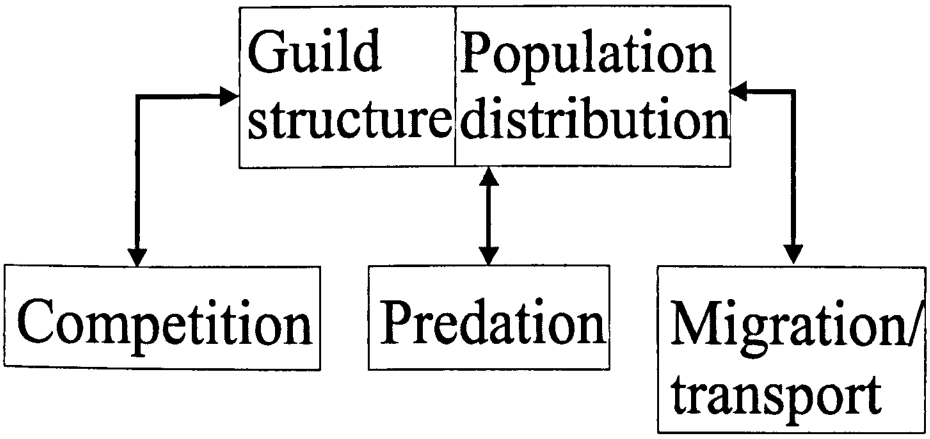
The relationship between the quantity of organic carbon in the soil and its effects on degree of faunalturbation caused by detrivores is difficult to determine precisely because of the issue of foraging. While it is likely that a greater quantity of organic matter in the sediments of an archaeological site will result in larger populations of soil fauna, it does not necessarily mean that more extensive faunalturbation will occur. Studies have indicated that in situations where there is abundant organic matter available earthworms forage less than in comparison with situations where organic matter is less abundant (Cook & Linden 1996). Geophagic species consume less soil each and the anecic species are likely to maintain fewer permanent tunnels to the surface (Cook & Linden 1996) where there is abundant organic material of an appropriate kind.

3.6 The Ecological Sub-system

In this section the other main set of factors are discussed, and the relative importance of this set of factors assessed. The sediment properties of a site are not the only factors which may affect the processes of faunalturbation. Figure 3.1 makes it clear that guild structure and population distribution are potentially also influenced by ecological processes.

The potential importance ecological and stochastic factors in determining the composition of whole communities has been stressed in the context of environmental reconstruction by Gee and Giller (1991: 7) who refer to these as the ‘intrinsic’ factors. This is in contrast to environmental factors, such as the sediment properties, are classed as 'extrinsic' factors. For the purposed of generating testable hypotheses the assumption is made that the sediment properties are the most significant set of factors in the system. This assumption is based on the use of functional groups, as defined for the purposes of this study (see 2.1). The information presented in the review of the biology and ecology of the soil fauna suggests that the main role of the ecological processes are in determining the species composition of the different functional groups, rather than the overall population of each group. This appears to be particularly the case with regard to processes of competition and transport. Should this assumption prove to be incorrect, it is likely that variation within the ecological sub-system, i.e. due to the intrinsic factors, would be the cause of variation in the degree of faunalturbation. Gee and Giller (1991: 8) have argued that at limited spatial, and temporal, scales intrinsic factors are more important in determining community composition.

Fig. 3.2 The ecological sub-system of the faunalturbation system.



The three main factors within the ecological sub-system are to be seen in fig. 3.2: competition, predation and transport/migration. This is not necessarily an exhaustive list, merely the most significant. Other minor intrinsic factors might include, for example, the voltinism of the insect fauna.

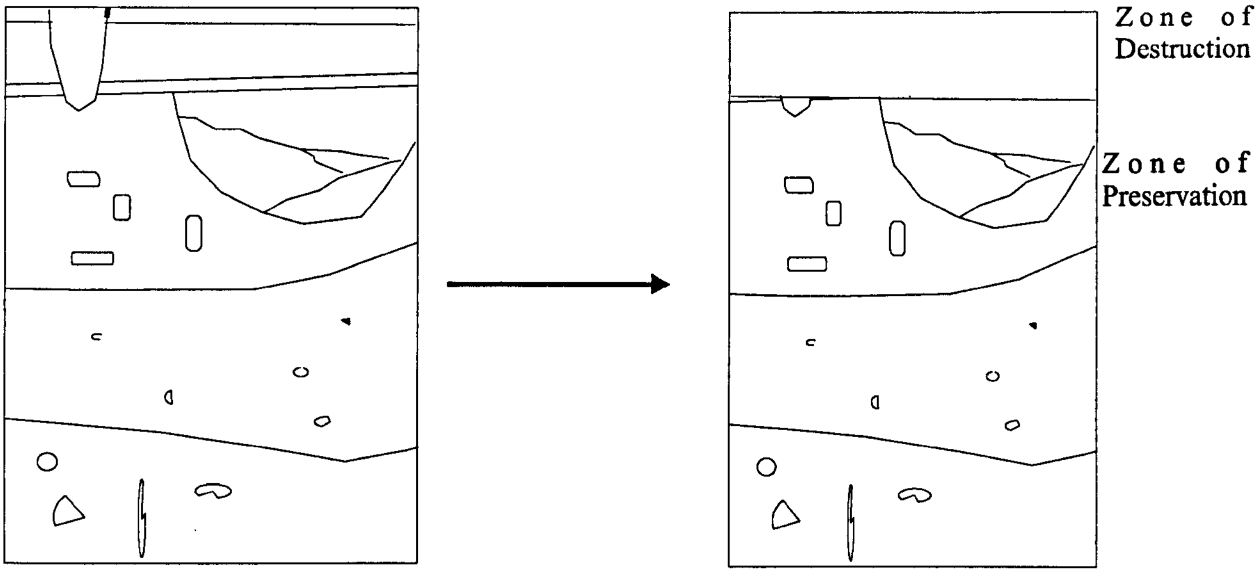
Given the probable dominance of soil/sediment properties in determining the population sizes of the different functional groups over the long term, and therefore the degree of faunalturbation, these parts of the faunalturbation system are the focus of this study. As such it is unnecessary to consider the ecological sub-system in any greater detail.

3.7 The Concept of Zones and its Role in the Models.

Thus far the two different models of faunalturbation are the same. It is with the introduction of the concept of zones that the two different models become different to one another. Both the models presented in this chapter use the concept of zones of destruction and survival. The zones are three dimensional volumes of soil and sediment. At a given location they will are envisaged as each being of uniform depth, as layers that are approximately parallel with the current ground surface. Their precise extent and depth is posited to be dependent on the population densities of the different groups of faunalturbating organisms.

The zone of destruction is the volume of soil which the processes of faunalturbation have caused the complete homogenisation of originally discrete stratigraphic units (see fig 3.3). Generally this zone conforms to the A horizons of biologically active soils which have formed on archaeological deposits. It tends to be the zone in which the vast majority of the soil fauna is active – that is faunalturbation is still ongoing. The depth of the zone will depend on the predominant functional groups and thus mechanisms of faunalturbation, which are in turn dependent on the soil properties. In most temperate zone soil conditions this is likely to be that of the endogeic earthworms. This would suggest that the zone is generally in the region of 15 cm deep (Edwards and Bohlen 1996: 103-104). There are conceivable situations where the complete homogenisation of archaeological deposits may not be restricted to this relatively minor depth. The first is where the A horizons of buried soils have formed on archaeological deposits. In this situation, while faunalturbation has occurred in the past as part of the process of pedogenesis, it is unlikely to be ongoing due to the depth of burial of paleosol. The second exception is where the deposits of a site have accumulated sufficiently gradually to be completely reworked by faunalturbation, but the aggradation of material has subsequently covered the lower part of the zone to a depth that prevents the majority of soil fauna from reaching it. While faunalturbation will have caused the complete homogenisation of the deposits that were within this zone, faunalturbation does not cease with the complete destruction of the stratigraphy, with the exception of the two types of cases noted above.

Fig. 3.3 Model one: two zones, the upper, where all stratigraphy has been destroyed through reworking and the lower zone where stratigraphy is preserved.



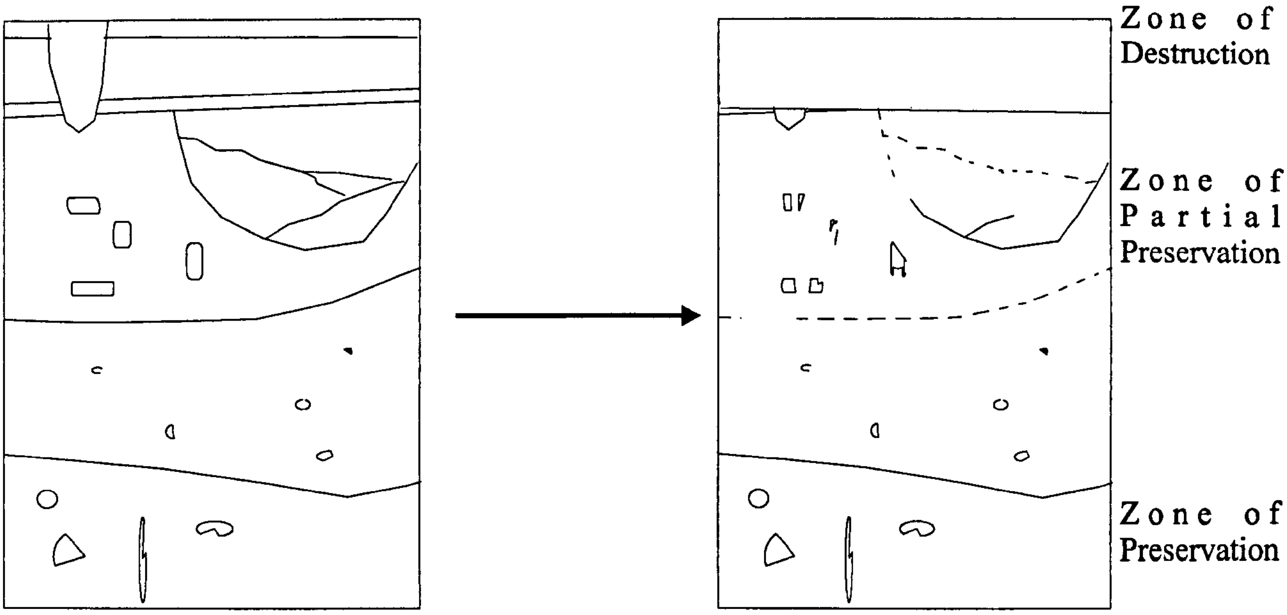


Fig. 3.4 Model two: three zones. The additional zone, in comparison to model one, is an intermediate zone where stratigraphy is partially preserved.

The zone of preservation is the zone in which no significant homogenisation of the discrete archaeological deposits has occurred. This is not to say that there has been no penetration of these deposits by the soil fauna living on the site. The capacity of anecic earthworm species to penetrate to substantial depths has already been noted (see 2.4). The essential stratigraphic order of the profile has however survived. A brief survey of the variety of different types of archaeological sites, in particular with regard to the variation of depth of archaeological deposits from site to site, is enough to demonstrate that the zone of preservation may form a depth from two or three metres to being non-existent.

The zone of partial preservation is that volume of sediment in which there has been partial homogenisation of the originally discrete units. Some deposits within the zone may have been completely homogenised with each other. Other deposits may have had a whole section, or sections, of their volume completely reworked into another deposit. In other parts of the zone there will be deposits where the boundaries of units have become 'blurred' through reworking or have had volumes of reworked material within them. This zone forms between the zone of destruction and the zone of preservation. The deepest burrowing earthworms in Britain have been found at depths as great as two metres (Edwards and Bohlen 1996: 104). From this it is apparent that this zone may be of some depth, although it is unlikely that it would reach as great a depth as the two metres cited above – earthworms at this depth tend to be aestivating rather than active (Edwards and Bohlen 1996: 105). By its very nature and its processes of formation this zone tends to still be undergoing homogenisation through faunalturbation when encountered by the archaeologist. As such, it is possible that eventually such a zone could become completely reworked i.e. have no surviving stratigraphy and become part of the zone of destruction.

3.8 Model One: Minimal Stratigraphic Disruption

In model one, only two of the zones described in section 3.7 are used: the zones of destruction and preservation respectively. The model assumes that the impact of the relatively much smaller numbers of deeper burrowing fauna, essentially the anecic earthworms, is insignificant. Thus it is the shallower dwelling functional groups, i.e. the adult Coleoptera, Coleopteran and Dipteran larvae, geophagous enchytraeidae and most importantly the endogeic earthworms which are the effective agents of faunalturbation. The implication of this is a concentration of activity within the zone of destruction and the insignificance of the residue of activity outside of that zone. This effectively restricts the effect of soil fauna on archaeological stratigraphy. While there has been some destruction of stratigraphy, ongoing faunalturbation is essentially constrained to the damaged area, so that further damage is minimal.

3.9 Model Two: Ongoing Stratigraphic Disruption

In the second model there are three zones within a profile. The uppermost zone is the zone of destruction. This zone is essentially the same as in model one. The main difference is that if model two is closer to reality than model one, then it is less likely that the zone of destruction will be completely congruent with the A horizon. This is because in contrast to model one the impact of the deeper burrowing soil fauna is assumed to have a significant impact on the survival of stratigraphy. It is assumed that the activity of the deep burrowing fauna takes considerably longer to have a major effect on the state of preservation of archaeological stratigraphy. In effect, the destruction of the archaeological stratigraphy occurs in two phases. While the zone of destruction is initially caused by the activity of the shallow burrowing soil fauna, which usually form the majority of the soil fauna population, the depth of the zone of destruction may be increased over time due to the effect of the deeper burrowing fauna.

The deeper burrowing fauna, due to their lower population densities and the processes by which they move particles around within a sediment or soil, will tend to cause stratigraphic homogenisation at a slower rate. To reflect this model two has an additional zone. As in the first model, the lowest of the zones is the zone of preservation. Under model two, it is assumed that the impact of the deeper burrowing earthworms is significant. As such, it is likely that in general this zone is to expected at a greater depth than under the assumptions of model one. Indeed, over time, the upper boundary of this zone will be effectively pushed back due to the effects of deep faunalturbation.

It has been argued above that it is necessary to place studies of archaeological formation processes, in particular faunalturbation, within the framework of a sedimentological-pedological approach. It may initially appear that the models presented above do not obviously fit into such a framework. It can, however, be demonstrated that the models do operate within this framework. In addition to this, it can be argued that the models can be used to bind the established archaeological stratigraphic approach into this framework.

It has been demonstrated above that the processes of faunalturbation occur at the level of the soil/sediment particle or aggregate. The zones delineate regions in a profile that are (or are not) subject to varying degrees to the different processes of faunalturbation. That is, the zones represent regions where differing quantities of particles have been moved and mixed with each other over varying distances. The usual stratigraphic classification approach fits into the framework as well, as can be demonstrated through the concepts of the different zones. In the zone of preservation the original, discrete archaeological deposits are effectively identified in the field by their shared sedimentary characteristics: texture, sorting of components, presence or absence of particular types of particles – which in the case of archaeological deposits are often artefacts – and above all colour (Stein 1987). The deposits can be considered as unmodified sediments. Within the zone of partial preservation the deposits have been subject to some faunalturbation, i.e. they are sediments that have undergone some degree of pedogenesis. Within the zone of destruction the sediments have been subjected to sufficient pedogenesis to have completely obliterated their original sedimentary structure, and convert them to a soil in which only characteristics such as the lithology of the particles may offer any clue as to the nature of the precursor sediments. Considered in this respect it becomes possible to think of archaeological stratigraphy, formation processes and taphonomy in terms of a single framework (as outlined in 1.3), thus making a wide range of work more easily accessible and intelligible.

In both models, the relative size of the different zones, the rate at which zones grow or shrink (if at all) and thus the state of preservation of the archaeological stratigraphy are all determined by the different factors which form the overall faunalturbation system. As will be apparent from fig. 3.1 there is an element of feedback between the components within the system, and this may run in two directions. This is not to claim, however, that all the feedback and interactions within the system are of equal significance.

3.10 Hypotheses

3.10.1 Systemic Relationships.

In order to test the models, and thus assess their relative validity, testable hypotheses are required. That part of the models framed in terms of faunalturbation as a system has a series of implicit hypotheses embedded within it in the form of the systemic relationships. These are common to both of the models. These are the different sets of relationships that the model posits. To allow the mode of testing to be determined it is necessary to state the hypotheses explicitly:

- 1. The population sizes and distributions of the different functional groups that comprise the soil dwelling guild of invertebrates are largely determined by the physical and chemical properties of the soil.

- 2. The distribution of the functional groups determines the degree and distribution of faunalturbation on archaeological sites.
- 3. Thus the physical and chemical properties of the soil or sediments of which an archaeological site is formed determine the degree and distribution of faunalturbation of a site.

To test the hypotheses suitable data must be acquired. The data must be largely derived from archaeological sites (see 4.2). It will comprise measurements of selected soil/sediment properties, population counts of the fauna, and assessments of the degree of faunalturbation/survival of archaeological stratigraphy (see 4.3 and chapter 5). To allow comparability, and in particular the application of statistical approaches, the different types of data must be closely linked in terms of sampling (see 4.4, 4.5 and figure 4.2). The required data sets and methods of analysis required for the testing of the hypotheses concerning the operation of the faunalturbation system are given in table 3.1.

Table 3.1 Data sets and analytical methods for testing systemic relationship hypotheses.

Hypothesis	Data Sets		Analytical Methods	
	Type	Section	Type	Section
1	Faunal Populations Soil Properties	7.3 7.2	Bivariate Correlation Multiple Linear Regression Chi-Squared	8.2.1 8.2.2 8.2.3
2	Faunal Populations Radiocaesium	7.3 6.5	Bivariate Correlation	8.4
3	Soil Properties Field Descriptions Thin Section Micromorphology	7.3 6.3 6.4	Bivariate Correlation	8.5 8.3

3.10.2 Testing and Discriminating Between Model One and Model Two.

Testing and discriminating between the two models requires a different approach. Direct statistical testing will be of limited applicability to this process. Instead, the alternative hypotheses of two and three zone models of faunalturbation will have to be tested in a different manner. These hypotheses are numbered 4 to 8 to follow on from the preceding set of hypotheses.

Table 3.2 The Predicted Outcomes From Model One and Model Two

Two Zone Model	Three Zone Model
4.There should be a macromorphological resemblance of the deposits on a site, i.e. an upper homogenous zone and a lower zone of discrete stratigraphic units.	4.There should be a macromorphological resemblance of the deposits on a site, i.e. an upper homogenous zone, a central zone of partially preserved stratigraphic units and a lower zone of preserved units.
5.The above apparent contrast should be confirmed by substantive micromorphological contrast between the zones, with the upper zone being largely composed of completely faunalturbated material, and the lower having few if any micromophological traces of such.	5.The above apparent contrast should be confirmed by substantive contrast in micromorphology between the upper and lower zones. The middle zone should combine significant traces of faunalturbation with unaffected areas, with a possible increase in unaffected areas down the profile.
6. Where a stoneline is present, it should conform to the base of the zone of destruction.	6. Where a stoneline is present it need not conform to the base of the zone of destruction, and will probably be somewhat above it in the profile.
7. Radiocaesium should be concentrated in the zone of destruction, with a sharp reduction concentration at the base of the zone.	7. Bulk of radiocaesium will be above the base of the zone of destruction, with a less abrupt reduction of concentration.
8. Majority of anecic earthworms will be found within the zone of destruction, above the stoneline.	8. Majority of anecic earthworms will be found below the zone of destruction, and the stoneline.

Each model has logical corollaries in terms of its expression in the soil profile of an archaeological site, that is, predicted outcomes of the two different models. In order to test the models, and be able to reject one, such predicted outcomes need to be isolated and compared with the evidence gathered in the field and laboratory. Such corollaries can be stated as paired alternative hypotheses for the two models. Such an approach is adopted in the table below, with the numbering of each pair of hypotheses following on from the numbering of the hypotheses on the systemic relationships. The particular sets of data required to test and discriminate between the two models are implicit in table 3.1.

The two models of faunalturbation have been presented. Both are based on the known habits of the British soil fauna (see 2.3 – 2.7). Both models are based on the interaction of the various components of an environmental system (see 3.2). Two sets of hypotheses have been derived from the models, one set concerning the operation of the mechanisms of faunalturbation, the other designed to test and discriminate between two models.

Chapter Four

Methodology: Field Sites and Sampling

4.1 Introduction

This study concentrates on the effects of faunalturbation on a particular type of archaeological site. This site type is the farm mound. Prior to detailing the reasons for selecting this site type for the study, consideration of the site type and the broader archaeological context is appropriate.

Farm mounds are settlement sites found across, and seemingly unique to, the European North Atlantic (RCAHMS 1980: 7). Examples of the strict farm mound type are known from north Norway, Iceland and parts of Orkney, primarily the islands of Sanday and North Ronaldsay (Bertelsen and Lamb 1993: 547, RCAHMS 1980: 7, 16-20). There is some variation in form across the North Atlantic Region, and the form discussed here is the Orcadian variant. The farm mounds have a wide range of dates associated with them, those on Orkney have been argued to have existed as a class at the time of the Scandinavian settlements (ninth to tenth century), with material continuing to accumulate well into the Norse period (Davidson *et al.* 1986, Bertelsen and Lamb 1993: 548). The radiocarbon dates generated from the farm mound samples could be argued to demonstrate either a pre-Scandinavian or early Scandinavian origin for the farm mounds, although given the possibility of residuality effects the layers dated were probably formed in the early Scandinavian period or later. Radiocarbon dates have been generated for two of the sites selected for this study. Two samples from

Westbrough were dated as part of a previous study. These dates (SRR-2349 and 2350) gave dates that were calibrated to the seventh to eighth centuries (Davidson *et al.* 1986). The site of Tofts provided dateable samples (see fig 6.11). The earlier ^{14}C determinations from Westbrough are presented along other radiocarbon dates for farm mound sites on Sanday for the purposes of comparison. All dates other than those from the site of Tofts are taken from Davidson *et al.* 1986. Both sets of data have been calibrated/recalibrated using the program Calib, version 4.3, provided on-line by Queen's University, Belfast (www.calib.org).

Table 4.1 Radiocarbon Dates From Farm Mounds on Sanday

Location	Composition	Depth (m)	Lab. Code No.	Conventional ^{14}C Age (yrs BP ± 1σ)	$\delta^{13}C$ PDB	Calibrated Age (year AD)
Tofts	Charcoal, Pinus sylvestris	.80	AA 33828	950 ± 55	-25.0	990-1220
Tofts	Charcoal, fragments	.80	AA 33834	980 ± 40	-25.1	998-1160
Tofts	Charcoal rich sediment	.80	SRR 6400	1025 ± 40	-27.9	902-1157
Westbrough	Peat	1.52	SRR 2349	1330 ± 60	-29.7	620-810
Westbrough	Peat	1.98	SRR 2350	1360 ± 50	-28.6	600-770
Skelbrae	Soil	1.98	SRR 2351	1330 ± 80	-27.4	540-860
Langskail	Soil	1.65	SRR 2352	820 ± 80	-26.1	1020-1380
Langskail*	Shell	1.65	SRR 2353	1000 ± 70	+1.2	1270-1460
Langskail*	Shell	1.85	SRR 2354	1010 ± 60	+1.8	1280-1450
Langskail	Soil	2.62	SRR 2355	910 ± 50	-27.6	1020-1250
Langskail*	Shell	2.62	SRR 2356	1060 ± 60	+1.8	1240-1420
Langskail	Charcoal	3.25	SRR 2357	1190 ± 90	-27.6	660-1020
Langskail	Soil	3.25	SRR 2358	1010 ± 70	-26.6	890-1210
Langskail*	Shell	3.25	SRR 2359	1110 ± 60	+1.2	1190-1390
Langskail*	Shell	4.05	SRR 2360	1170 ± 50	+1.4	1140-1310

Samples with an asterisk have been calibrated on the basis of their carbon content being obtained from marine reservoirs, all other samples have been calibrated on the basis of their carbon being obtained from the atmospheric reservoir (Aitken 1990: 70).

The radiocarbon dates from Tofts are closely comparable with those from Langskail, and place the formation of the materials dated within the Viking and earlier Norse era. The dates for the accumulation of the farm mounds are probably later than these dates, given that material is often in circulation for a number of years prior to deposition. In particular the charcoal identified as *Pinus sylvestris* must have either been deliberately imported to the island or have been found as drift wood as the species is not native to Orkney (Miller pers. comm.).

The Orcadian mounds generally have a working or recently abandoned farm on the top of them (hence their name). The general form of the farm mound is a moderately steep sided mound, with a fairly level top with a height of between 1-2 m, occasionally reaching 2.5m above surrounding ground level (Bertelsen and Lamb 1993: 547). The mounds are formed by the dumping of peat, turf, dung, ash and other waste materials (Davidson *et al.* 1986). There has been some speculation in the past as to the reasons for the accumulation of these sites, generally centring on the non-necessity/impracticability of dispersing the materials which now form the mounds (Bertelsen 1979, Bertelsen and Lamb 1993: 550-552).

The farm mounds are a highly significant class of monuments in the European North Atlantic region (Bertelsen and Lamb 1993: 545). Given this, an understanding of their formation processes is essential to understanding the evidence of material culture in this region and might also illuminate some of economic and agricultural processes of this region over time. For example, Bertelsen's hypothesis of the impracticability of the dispersal of the materials from which the mounds are formed hinges on the development of commercial fishing, with a consequent reduction in the work force available for such tasks as the removal of domestic and byre waste (Bertelsen 1979).

The farm mound has been selected as a site type for a variety of reasons. Research on the formation of Norse settlement sites in the North Atlantic, and related questions of subsistence form an ongoing research interest at the University of Stirling (see e.g. Davidson *et al.* 1986, Simpson *et al.* 1998). The primary purposes, however, in selecting sites from this class of monument lie in their form and more recent history of occupation and use.

The first important characteristic of the sites is that they are of anthropogenic origin. This means that all the soils and sediments encountered on such a site are essentially archaeological deposits or are derived from them. It is unusual for this to be so unequivocally the case with the majority of archaeological sites. The significance of this circumstance to this study is that where there are significant volumes of faunalturbated material, up to and including fully developed soils, it is possible to be certain that these have been formed by the mixing of archaeological deposits. Any consequent effective loss of stratigraphic units can also be attributed to faunalturbation in these circumstances.

This in itself not sufficient to test the models advanced in chapter two: a site composed of relatively shallow anthropogenic deposits could be entirely faunalturbated throughout. This would not leave sufficient evidence to be able test and discriminate between the models, as both effectively predict the complete faunalturbation of shallow sites. Farm mounds are, as has been noted above, deep sites. As such completely or partially unfaunalturbated deposits should remain within them. The pattern of the distribution of evidence of faunalturbation or the lack thereof should be discernible in such deep sites.

One further factor makes the farm mounds useful sites for this type of investigation. The flat topped profile of the mounds makes the erosion of surfaces, and subsequent loss of both archaeological deposits and evidence of faunalturbation unlikely. Local informants advise that the low lying island of Sanday is very rarely subject to ground frost, so cryoturbation is also likely to be insignificant. It would therefore seem that the only major set of natural post-depositional processes affecting the sites is that of faunalturbation. Post-depositional processes of human origin are another issue. While the local population has tended to treat known antiquities with respect (RCHAMS 1980: 7), substantial impact is possible. In comparison with other types of monument in Orkney farm mounds tend to have been relatively undisturbed. The mound tops are generally either built over or permanent pasture, reducing the probability of agricultural impact, particularly through ploughing. Some sites, however, are known to have been heavily damaged by modern human activity. Therefore, attempting to screen out sites that may have been thus affected is an important part of the site selection process (see

4.2). The relative lack of alternative natural forms of post-depositional processes on the farm mounds, combined with an awareness of the possibility of human disturbance means that the potential problem of distinguishing between overlapping post-depositional effects is substantially diminished.

4.2 Selection of Sites

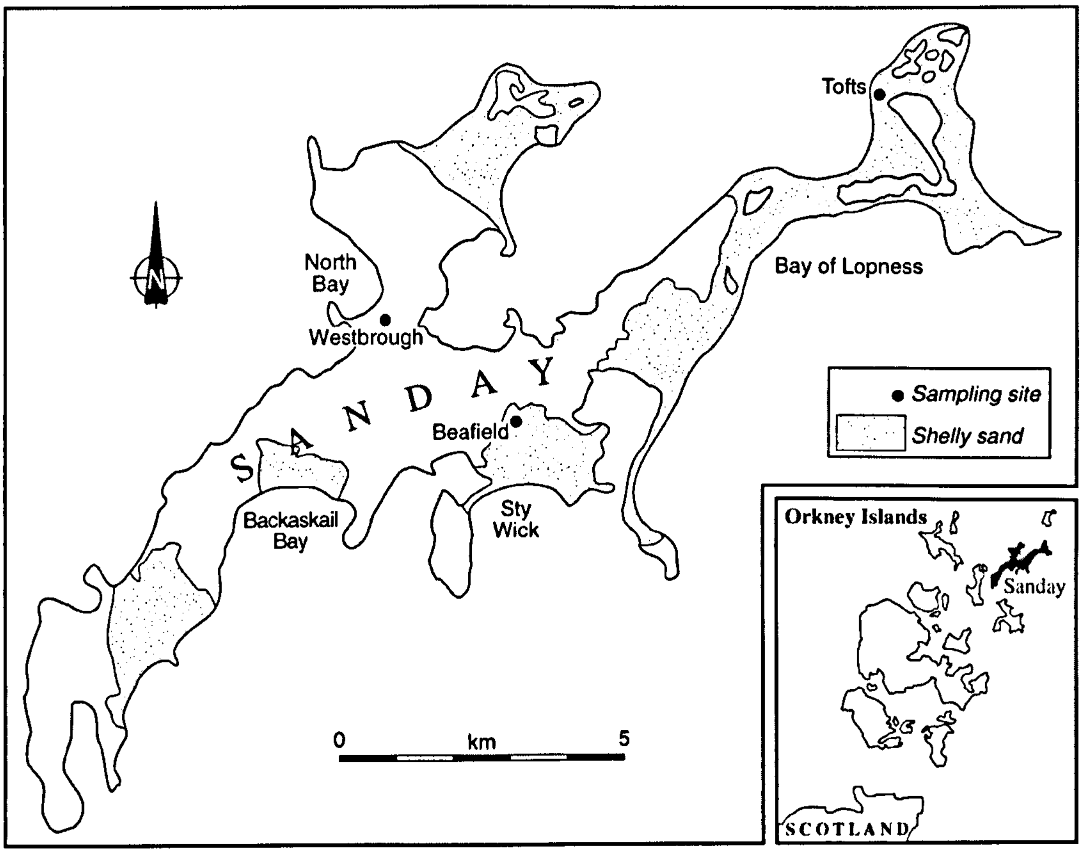
To select the sites used in this study a series of decisions were taken, based on a number of criteria. Some of these criteria were formulated on the basis of the scientific needs of the study, others with regard to the overall management of the project. The first decision was that all the sites should be on the island of Sanday, rather than trying to use farm mounds on all the three islands where they occur in Orkney. This decision was taken to reduce transport difficulties within the islands. Sanday was selected over Papa Westray and North Ronaldsay as it has more farm mounds to make the selection from, and because the mounds tend to be deepest on that island (RCHAMS 1980: 8). The other criterion derived from the question of overall feasibility of the study was that of access, both with regard to being physically able to safely reach and work on the sites and obtaining permission to work on the sites. Access proved to be largely unproblematic, with most of the farm mounds easy to reach and the landowners generally forthcoming with their permission. The few sites which were not accessible would have been unlikely to be suitable on the grounds of the other selection criteria.

Three of the main criteria of selection reflect the original decision to use the farm mounds. These were that the sites should be sufficiently deep, level topped and largely undisturbed by processes other than faunalturbation. The reasons for these criteria are discussed above. While farm mounds should generally meet these criteria, it was of course necessary to check each of them in the field.

Two further, technically related, criteria were used. The first was to try to avoid sites with pre-existing eroded sections, particularly if the section was due to coastal erosion or was likely to be very close to the probable location of sampling. This was to avoid the possibility of a substantial moisture gradient across the site, which might affect the fauna so as to give a systematic bias of distribution across the site. Sea-sections would also potentially introduce another possible source of bias through a possible salinity gradient, also potentially affecting faunal distributions. The other technical criterion employed was too avoid sites that had deposits of pure or near pure sand in their top 30cm. This criterion was used as sands would be unlikely to provide sufficient adsorption sites for caesium to be able to use ^{137}Cs profiling as a technique.

Potential sites were identified using the RCHAMS survey on the antiquities of Sanday and North Ronaldsay (1980: 16-20). This gave an initial range of c. 20 possible sites. Inspection of these sites eliminated quite a proportion on grounds of shallowness, having open sea sections and in two cases not actually being farm mounds. The advice of the then Orkney Islands Archaeologist, Dr Raymond Lamb was also taken into consideration with regard to site selection. The three sites selected for this study were Beafield (HY 6865 4050), Tofts (HY 7475 4615) and Westbrough (HY 6633 4235) (see fig 4.1). These three sites best fulfil the criteria listed above. At each of these locations, control samples were taken close to the monument (see 4.5).

Fig. 4.1. The locations of the study sites.



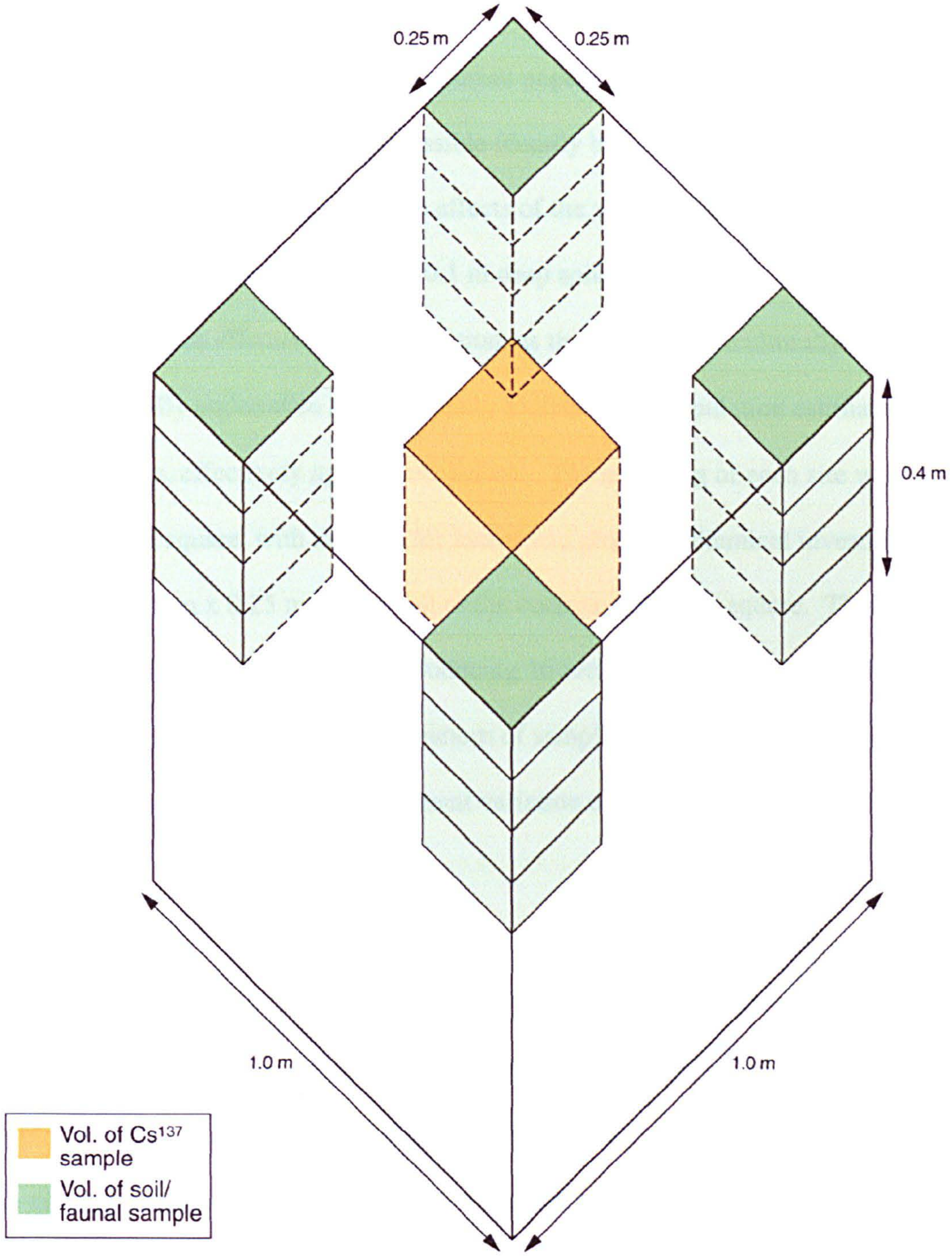
4.3 Field Recording: method

The test pit sections were recorded using a combination of approaches from soil survey and archaeological excavation. The combined method is adopted for a variety of reasons. The first is that the descriptive methods derived from the soil sciences are more methodical, and more importantly, involve the recording of a wider range of characteristics than most traditional archaeological approaches, which allows for the identification of pedogenic processes, which on an archaeological site are also post-depositional processes. One advantage of archaeological recording methods is a tendency to divide up sediments or soils into units on the basis of their properties to greater degree than in soil science. The expectation of a soil scientist is to find broadly uniform horizons, which while justified in many situations is unrealistic on archaeological sites, where many spatially limited deposits may occur. Investigating the relationships between such deposits is a normal procedure for archaeologists, and recording is conducted in such a manner as to assist in this. As such the deposits on the sites were described in this more ‘unitary’ manner. The assignment of units to horizons, where applicable, was undertaken at the analytical stage, as can be seen from the section drawings (see 6.10 to 6.12). Further variance from the strict soil survey approach was required by the fact that archaeological sites have 'sedimentary' features that do not conform to the system delineated in the soil survey handbook.

4.4 Methods of Sampling: Archaeological Sites

The sampling system was designed to provide two, interlinked, sets of data. One set of data was more directly concerned with the current populations of soil organisms and the conditions in which they exist and the other set with the effects that these populations have had over time. The sampling strategy was also designed to characterise the site in terms of fauna and physical and chemical properties as thoroughly as possible and to take into account as far as possible intrasite variability. It was decided to use the smallest possible intervention into the sites, to reduce impact on the sites. Each site was therefore sampled through the use of a 1 m x 1 m test pit (see fig 4.2). The recording of the field data derived from the test pits is discussed below. The initial excavation of the test pits was through the various sampling procedures discussed below for the faunal and physical-chemical sampling. After the sampling had occurred, the rest of the sediment in the test pit was removed in 1 m by 0.25 m areas, working carefully down to a depth of 40 cm, to provide a sequence of sections. It was planned that excavation of the test pit would cease once substantial, well preserved, deposits were encountered. This did not occur in the first 40 cm of any of the test pits. One of the central areas was removed to either the depth of the substantial surviving deposits or until a depth of 120 cm was reached. This deeper section was also recorded and was the section from which the samples for thin section micromorphology and caesium profiling were taken.

Fig. 4.2 Orthographic projection of the sampling pattern employed in each test pit to obtain samples for determining soil properties, fauna counts and Cs^{137} activity.



The set of samples concerned with the current populations of soil fauna was taken as an integrated set, to ensure the closest possible identity between the different measurements. To take account of the effects of the vertical distribution of the fauna, the sampling was depth stratified into 0.1 m deep spits. This part of the approach seems to have been effectively an innovation, as the (largely agriculturally based) surveys generally undertaken have generally looked to get population estimates of $1m^2$ areas of a given, effectively aggregated, solum. The sampling of each site was based on a 1 m x 1 m square, with samples for faunal and physical-chemical investigation taken from 0.25 m x 0.25 m areas in all of the corners of the 1m square. This sampling was undertaken to a depth of 0.4 m, producing 16 sets of samples per site, that is 4 sets of sample for each 0.1 m depth. The pattern of sampling within the square metre was designed to give some indication of lateral variation of soil properties and faunal populations.

The order of sampling at each site was to take the faunal samples, each 0.25 m x 0.25 m and 0.1 m deep. The ground surface area for the faunal sampling was based on the area employed by the Scottish Crop Research Institute (Boag *et al.* 1997). The division of the sampling area was done to allow for the possible lateral variation of distribution of fauna within the test pit. Each column of samples was completely removed before the next sample was taken, to reduce the chances of the anecic earthworms from retreating from the sample volume, as they are known to be able to do if samples are not removed rapidly (Boag *et al.* 1997). From each of these blocks a small subsample of c. 100g was taken, handsorted to remove any non-enchytreid fauna and bagged for later physical and chemical analysis. Further samples were taken from the remaining sides of the holes from which the sample columns had been removed using Kubiena tins of known volume for the purpose of determining bulk density and to provide additional sample reserves in the event of analytical problems or sample loss.

The other set of samples taken was for the purpose of evaluating how much faunalturbation had occurred. This consisted of samples taken for two sets of laboratory techniques, ^{137}Cs profiling and soil thin-section micromorphology. These sets of samples were taken from the central portion of the test pit. This was because the same pattern of sampling used for the other samples would not be feasible, given the time consuming nature of the two techniques. Taking these samples from the central region of the test pits meant that the caesium and thin section samples were surrounded by the physico-chemical and faunal samples, allowing the relating of the two sets of data in an interpolatary manner.

The samples for caesium profiling were taken as 0.01 m thick slices from an area of 0.3 m x 0.3 m. The overall sample depth was to 0.3 m. This depth was adopted as it was thought to present the depth limit to which detectable quantities of caesium would be found. Each 'slice' was carefully removed, with line levels and measurements from a section line being used to ensure that the slices were of uniform thickness. An initial attempt was made to remove the sample in a single monolith tin, but it was found that the sediment of which the sites are composed was too friable to use this method without substantial sample loss or mixing.

Samples for thin section micromorphology were taken in the following fashion. A series of overlapping samples were taken from the top 40cm of the test pit using Kubiena tins. These samples were taken to be directly comparable to the analytical and faunal samples. Further samples were taken throughout the rest of the profile, to allow the characterisation of the rest of sediment units recorded and to assess the degree and impact of any faunalturbation that they had undergone (see figs. 6.1 – 6.3).

4.5 Methods of sampling: control sites

The sampling of control sites was based on the requirement for data concerning the relationship between the agents of faunalturbation and soil properties in the absence of significant archaeological deposits. The sampling strategy was again designed to characterise the site in terms of fauna and physical and chemical properties as thoroughly as possible and to take into account as far as possible intrasite variability.

The set of samples for the soil fauna populations and soil properties at each control site was taken as an integrated set, to ensure the closest possible identity between the different measurements. To take account of the effects of the vertical distribution of the fauna, the sampling was depth stratified into 0.1 m deep spits. This part of the approach seems to have been effectively an innovation, as the (largely agriculturally based) surveys generally undertaken have generally looked to get population estimates of 1 m^2 areas of a given, effectively aggregated, solum. The sampling of each site was based on a 1 m square, with samples for faunal and physical-chemical investigation taken from 0.25 m x 0.25 m areas in all of the corners of the 1 m square. This sampling was undertaken to a depth of 0.4 m, producing 16 sets of samples per site.

The order of sampling at each site was to take the faunal samples, each 0.25 m x 0.25 m and 0.1 m deep. The ground surface area for the faunal sampling was based on the area employed by the Scottish Crop Research Institute (Boag *et al.* 1997). The division of the sampling area was done to allow for the possible lateral variation of distribution of fauna within the test pit. Each column of samples was completely removed before the next sample was taken, to reduce the chances of the anecic earthworms from retreating from the sample volume, as they are known to be able to do if samples are not removed rapidly (Boag *et al.* 1997). From each of these blocks a small subsample of c. 100 g was taken, handsorted to remove any non-enchytreid fauna and bagged for later physical and chemical analysis. Further samples were taken from the remaining sides of the holes from which the sample columns had been removed using Kubiena tins of known volume for the purpose of determining bulk density and to provide additional sample reserves in the event of analytical problems or sample loss.

Samples for a control caesium profile were taken in conjunction with the other sample types at Beafield. The method employed was as at the archaeological sites, with the overall depth sampled being 0.3 m. As with the archaeological sites this depth was adopted as it was thought to constitute the depth limit to which detectable quantities of caesium would be found.

Chapter Five

Methodology: Laboratory Methods and Statistical Analyses

5.1 Introduction

In this chapter the laboratory methods and analytical procedures required to produce the data sets necessary to test the models are described. Also examined is the general role of the statistical techniques to be applied to the data, along with a list of the techniques employed. More detailed discussion of these techniques is given in chapter eight, in conjunction with the analyses.

5.2 Assessing Faunalturbation: Caesium 137 Profiling

5.2.1 Introduction: Sources and Chronology.

Caesium 137 is an anthropogenic radionuclide derived from nuclear fission. It is found in the terrestrial environment, largely as a result of atmospheric testing of nuclear weapons. The peak of deposition through atmospheric fallout from weapons testing occurred around 1963 (Wright *et al.* 1999). The only additional significant release of radiocaesium into the terrestrial environment has been from the Chernobyl accident in 1986. The fallout plume from this incident is known not to have covered the Orkney Islands, and as such possible problems from a double input of radiocaesium is avoided (Tyler *et al.* 2001). The element has thus been incorporated into soils and sediments following aerial deposition in the last forty years.

5.2.2 Fixation and Initial Migration.

The processes of radiocaesium adsorbtion in soils are well understood. The precise mechanism, selectivity and stability of fixation is determined by the material to which the ^{137}Cs bonds and the environment in which bonding occurs (Tyler *et al.* 2001). With regard to this study there are two main fractions of material which are significant as sites of ^{137}Cs fixation. The two fractions are silt size particles and organic matter (Cook *et al.* 1984, Hird *et al.* 1995).

The initial migration of radiocaesium after deposition is thought to be rapid, with processes such as diffusion being of greatest significance (Ivanov *et al.* 1997, Smith and Elder 1999). This has formed the basis of most modelling of ^{137}Cs migration, for time periods of months to years, that has been undertaken to date (Tyler *et al.* 2001). The earliest models were diffusion based models (e.g. Silant'ev and Shkuratova 1988). These models have been duly tested and criticised and new approaches formulated, such as diffusion advection models (Antonolopoulos-Domis *et al.* 1995) and convective stochastic models (Kirchner 1997). What all these models have in common is that they have been constructed using diffusion coefficients and migration velocities of ^{137}Cs derived from empirical studies of young fallout, particularly from the Chernobyl accident.

5.2.3 Faunalturbation and the Movement of Fixed ^{137}Cs.

It has been argued that in the short term (months to years) that faunalturbation is relatively unimportant as a mechanism of migration of ^{137}Cs, but that over the medium term (years to decades) that the role of faunalturbation more significant (Tyler *et al.* 2001). Muller-Leman and van Dorp (1996) have suggested that complete homogenisation of ^{137}Cs occurs within 5-20 years. This increased significance is largely due to the rapid fixation of ^{137}Cs, with subsequent migration of ^{137}Cs being largely due the movement of the different soil fractions to which the element is fixed. Due to the criteria employed in the selection of sites for sampling (see 4.2) faunalturbation should constitute the only significant mechanism for the migration of fixed ^{137}Cs.

The fixation of a recent, traceable, addition to the soil should allow the detection of soil mixing, and give some indication of the depth and rate of movement of the soil, or more strictly, the fractions to which the ^{137}Cs has adsorped. Where ^{137}Cs is detectable, then the boundary of the distribution of this isotope should conform to the depth to which substantial mixing and reworking of soil and sediment has occurred in the time since initial fixation. The distribution within such a boundary may also give some indication of relative biological activity, but it must be remembered that any given distribution is the net result of mixing. Soil with adsorped caesium may have been reworked back up a profile, as well as down by the activities of soil fauna. Even taking due regard of these caveats, it is evident that ^{137}Cs distributions may be used as a proxy indicator of soil mixing.

5.2.4 Measuring ^{137}Cs Distributions and Assessing Faunalturbation Distribution.

For the purposes of assessing faunalturbation it is necessary to have a baseline from which to work. Using the diffusion coefficients and migration velocities of ^{137}Cs derived from empirical studies of young fallout, particularly from the Chernobyl accident it is possible to construct idealised initial distributions of ^{137}Cs for this purpose (see below).

To obtain the actual distribution of ^{137}Cs activity at each site the following procedure was followed. The samples taken for ^{137}Cs determination were oven-dried at 105^{0}C, ground and packed into sample containers. A laboratory based n-type 35% relative efficiency HPGe detector, housed within a Cu-Cd lined lead shield was used to collect γ ray emission spectra. The counting times used normally varied between 10,000s and 30,000s, with the times used dependent on ^{137}Cs counting statistics of 5% or better. The longest counting times were in the region of 240,000s, which were used to check samples that had no apparent detectable ^{137}Cs content. The gamma spectra were analysed using the EG&G Gamma Vision software package. The detector efficiency calibrations had been established using a range of deeply buried (i.e. having no detectable ^{137}Cs content) soils, with differing densities, spiked with mixed gamma solution of known activity (NPL R08-03). Individual corrections for sample density variations were made. Calibrations were checked with standard reference material conforming to the IAEA 373 and 375 standards.

The initial data took the form of the specific activities of ^{137}Cs (Bq kg^{-1}). These were converted to activity loadings (Bq m^{-2}) by multiplying the specific activity by bulk density and dividing by the depth interval of each sample. The total activity loading for each sample set provided the ^{137}Cs inventory of the site from which it was sampled. The inventory was then used to calculate the percentage activity inventory at each depth interval.

In order to be able to assess the amount of movement of fixed ^{137}Cs, it is necessary to be able to reconstruct the distribution of the element in the short term after deposition. It is known that this distribution has a negative exponential-like form (Beck *et al.* 1972). Indeed work based on the distribution of ^{134}Cs deposited after the Chernobyl accident concluded that after 4-5 years the vertical distribution of ^{137}Cs in a soil profile may be described by a negative exponential (Tyler 1994). Such exponential curves have been used as baselines to examine the effect of bioturbation on ^{137}Cs distribution (Tyler *et al.* 2001).

To obtain the exponential curve the following equation was used to calculate the initial ^{137}Cs depth distribution. A_x, is the specific activity at a given value of x, that is mass per unit area depth.

$$A_x = A_0 \exp\left(\frac{x}{\beta}\right)$$

Equation (1)

Where A_0 is the activity at the surface of the soil profile and the exponential is described by the mass relaxation per unit area coefficient β (g cm^{-2}) (Tyler *et al.* 2001). The typical range of values for β is from 2.0g cm^{-2} for peat to approximately 4.0 g cm^{-2} for a mineral-rich soil (Tyler *et al.* 2001). To take soil/sediment density into account, β is calculated using Equation 2,

$$\beta = \frac{\rho}{\alpha} = \frac{x_{½}}{\ln 2}$$

Equation (2)

where ρ is the soil density (g cm^{-3}), α is the reciprocal of the relaxation length (cm^{-1}) and $x_{1/2}$ is the mass per unit area depth (g cm^{-2}) at which half the surface activity concentration occurs. The reciprocal of the relaxation length was assigned the value of .35 cm^{-1}. This value was selected as the mean value found, with a range from .3 to .4 cm^{-1} (Tyler 1996 and Tyler *et al.* 2001).

The vertical distribution of ^{137}Cs in undisturbed soils following atmospheric deposition quickly assumes a negative exponential-like distribution (Beck *et al.* 1972). By examining the ^{134}Cs distributions from the Chernobyl depositional event in May 1986, Tyler concluded that after 4-5 years, the vertical distribution of ^{137}Cs may usually be described by a negative exponential (Tyler 1994). This approach has been successfully applied to assess rates of ^{137}Cs movement in upland soils (Tyler *et al.* 2001). On this basis the basic ^{137}Cs data can be used to reconstruct the undisturbed ^{137}Cs depth distribution of each site can be reconstructed by applying Equation 3.

$$A_x = A_0 \exp\left(\frac{\alpha.x}{\rho_x}\right)$$

Equation (3)

where ρ_x is the dry bulk density at the mass per unit area depth x. The profiles derived from Equation 3 were then converted to profiles of ^{137}Cs inventories, as was done for the actual measurements. Both sets of data were then converted to percentage depth distributions enabling comparison with the observed percentage ^{137}Cs depth distributions within and between sites.

5.2.5 Calculating Mass Soil Movement From ^{137}Cs Distribution.

Using the ^{137}Cs inventories calculated using the methods described above (see 5.2.4) it is possible to derive the net soil movement rate within the archaeological sites. This information could provide data on the likely period of survival of archaeological stratigraphy in biologically active soils. Previous estimates have been based on the application of known casting rates of surface casting earthworms, combined with population estimates of earthworms on archaeological sites and of overall site volume (Stein 1986). The radiocaesium approach differs significantly from this approach by taking into account the combined activity of all the invertebrate fauna involved in faunalturbation, and possible variations in rates of faunalturbation with depth in a site profile.

On the basis of the assumption that the modelled initial distribution of the ^{137}Cs is essentially correct then the rate of vertical soil mass movement may be obtained as follows. The fraction of soil moved, f, from one 1cm sampling depth can be calculated thus:

$$f = \frac{\alpha_m - \alpha_s}{\alpha_m}$$

Equation (4)

where α_m is the cumulative % of the modelled inventory and α_s. The mass, *m*, of the soil being moved through a square metre area of one of the 1cm 'slices' of the site can also be calculated:

$$m = \rho l$$

Equation (5)

where ρ is soil density in kg m^{-3} and *l* is the sampling depth increment in m. From this the mass movement of soil through a unit of volume per unit time may be calculated:

$$K = \frac{fm}{dt}$$

Equation (6)

Where *K* is mass moved per unit volume per unit time (kg m^{-3} yr^{-1}), *f* is the fraction of soil moved, *m* is the mass moved per unit area of sample (kg m^{-2}), *d* is the distance moved (m), and *t* is time (yr). For the purposes of this study *t* in equation (6) is always equal to 35, this being the number of years between peak ^{137}Cs fallout and the time at which the samples were taken. This allows not only the calculation of the movement rate for each 1cm depth sample, but the total rate of mass movement through that part of the profile where there is detectable radiocaesium. From the net rate of movement it is possible to derive the gross period of total movement of soil from each 1cm layer:

$$T = \frac{\rho}{K}$$

Equation (7)

where *T* is the gross period of total movement of soil.

5.3 Assessing Faunalturbation: Soil Micromorphology

5.3.1 Introduction.

Soil micromorphology is used to assess and produce quantitative estimates of faunalturbation, both within the uppermost, and thus probably most biologically active region of the soil, and at depth, where there was expected to be greater evidence of the survival of intact archaeological deposits. The pattern of sampling of Kubiena samples for soil micromorphology (see 4.4) means that the soil micromorphology samples, along with the field recording, constitute an important means of linking the other data derived from the other samples. Further, the depth to which the Kubiena samples were taken allowed comparisons between the upper part of the soil profile, where faunalturbation was known to be occurring, and the lower part of the profile to be made. The technique of soil micromorphology was applied for a specific purpose: to identify and quantify the traces in the soil which would indicate the occurrence of faunalturbation, and where possible identify the specific functional group responsible. The method by which this was done is discussed below. The micromorphological data was employed to test a number of relationships posited by the model.

5.3.2 Thin Section Preparation.

The thin sections used in this study were all produced according to the standard procedures employed at Stirling University, which are based on those formulated by Murphy (1986). All water was removed from the samples by acetone replacement, with dehydration checked through specific gravity measurement. The samples were then impregnated using a polyester crystic resin, 'type 17449', and a catalyst, 'type

Q17447' (methyl ethyl ketone peroxide, 50% solution in phthlate). The mixture was thinned with acetone, to give a standard composition of 180 ml resin, 1.8 ml catalyst and 25 ml acetone for each Kubiena tin. Some less porous blocks were immersed in a resn/hardener solution with a greater acetone component to aid impregnation. No acceleration was used but the samples were impregnated under vacuum to ensure full outgassing of the soil. The blocks were sliced, bonded on a glass slide and precision lapped to 30 µm. Polishing and cover-slipping completed manufacture of the slides. While it is not unusual for these procedures to have to be modified, due to the variable properties and thus reactions of soils to these procedures, it was essentially unnecessary in the case of the samples used in this work. The loamy nature of the samples allowed good dehydration, although there was some shrinkage of the most organic samples, mostly those from uppermost sampling points. The texture and structure of the sampled soils allowed for at least adequate, and generally good impregnation in all cases.

5.3.3 Description and Quantification of Thin Sections.

The thin sections were examined using an Olympus BX50 polarising petrological microscope. A range of magnifications were used (x10-x400) as were a range of light types (plane polarised, cross polarised and oblique incident).

The description and quantification of the thin sections was undertaken for two purposes. The first was to assist in the characterisation of the soils and sediments of which the sites were composed. The second, and main, purpose was to allow the identification of the effects of faunalturbation, and to assess the impact faunalturbation has had on the sites through quantifying the traces that faunalturbation leaves in the soil. Soil thin section micromorphology started as an essentially descriptive, qualitative method and basic description of slides still forms the basis of the insights that can be obtained using the method. The systems of description may vary, from the pedogenetic approach of the pioneer of soil micromorphology, Kubiena, to the essentially morphological approach detailed in the Handbook of Soil Micromorphological Description (Bullock *et al.* 1985), which is the system adopted here. The procedure of description is adapted from Bullock *et al.* (1985). The level of detail implied by the procedure laid down in the handbook has not been followed. While there are proponents of highly detailed descriptions of full sections, the majority of practitioners tend to carry out a brief general description and concentrate on the more those aspects of the micromorphology which directly apply to problem to be addressed, and this has been the approach followed here.

As has been noted (see 2.3-2.7), the different functional groups leave microscopic/near microscopic traces of their activity in soils and sediments. The most basic use of these traces is to simply identify that faunalturbation has occurred. Some of these traces are specific to particular functional groups, others are produced by some or all of the functional groups. By using a suite of traces it is possible to assess the relative importance of the different functional groups or small aggregations of these groups. The traces to be used for the more detailed descriptions and the categories by which the thin sections would be quantified are generally recognised as indicators of faunal activity and are taken from the published works on micromorphology, both general and archaeological. The traces selected are given in table 5.1.

Table 5.1. Micromorphological Pedofeatures Characteristic of Faunalturbation and Associated Agents of Formation.

Pedofeature	Associated Organisms
Total biological fabric	Mainly associated with Lumbricidae, especially if fabric pedofeatures present, but formation may involve any soil dwelling mesofauna (Courty *et al.* 1989: 190).
Fabric pedofeatures	Lumbricidae, with endogeic species probably most significant contributors (Bullock *et al.* 1985: 134 Fitzpatrick 1993: 141).
Textural pedofeatures	Lumbricidae, both endogeic and anecic.
Mamillated excrements	Lumbricidae, both endogeic and anecic (Bullock *et al.* 1985: 134).
Bacillo-cylindrical Excrements	Enchytraeidae. Also associated with Lumbricidae (Bullock *et al.*1985: 134).
Spheroidal Excrements	Larvae of Diptera and Coleoptera (Bullock *et al.*1985: 134).
Ellipsoidal Excrements	Orbatid mites. Possibly with larvae of Diptera and Coleoptera (Bullock *et al.*1985: 134).
Tailed Conoidal Excrements	Isoptera. Possibly Coleoptera (Bullock *et al.*1985: 134).
Cylindrical Excrements	Larvae of Diptera (Bullock *et al.*1985: 134).
Smoothed Channel Walls	Lumbricidae, predominantly anecic species (Bullock *et al.* 1985: 134, Edwards & Bohlen 1996: 127).

The form of these traces of faunalturbation is largely dependent on the specific mechanisms responsible for each, although the properties of the soil or sediment may also have some impact on the type of traces found in a given setting and how well developed they are. This means that in a given setting certain traces may not form or be weakly developed, so that they may not be useful in assessing faunalturbation in that setting. This occurred with one of the traces initially selected for this study, as will be discussed in the relevant results section (see 6.4).

The method used for quantifying the traces of faunalturbation is one that has been developed at Stirling University. The area of the slide was divided up into 1cm squares. The slide may be sampled by selecting a proportion of the squares to be quantified. In accordance with the original form of this method half the squares were selected (Chrystal 1997). The sampling pattern was essentially stratified as every other square was quantified, with the sequence of selection being altered only to ensure that each of the zones delineated in the original examination of the slide would receive 50% coverage. The percentage area of each square covered by each of the selected traces of faunalturbation was estimated by eye, to the nearest 5%. Where a trace was present but covered an area less than 5% presence alone was recorded. Where a given type of trace was intimately intermingled with another, the coverage of the dominant trace was recorded, and the other trace recorded simply as present. The visual estimations were made with the aid of charts reproducing given percentage coverage (from Bullock *et al.* 1985: 24-25). This method was adopted as it was thought to give reasonably accurate assessments of area coverage

5.4 Agents and Conditions of Faunalturbation: faunal surveys

While there has been a variable amount of work on the relationship of different taxa of soil fauna with various chemical and physical parameters, there are no substantive studies concerning all the taxa that comprise the functional groups, or all the physico-chemical parameters selected as most likely to influence population composition and size. Thus in order to test the hypothesised relationships posited by the models, it was necessary to gather data on the population composition and physico-chemical conditions of the archaeological sites and their paired control sites.

The samples taken for faunal analysis were handsorted, with the exception of the sub-samples taken for estimating enchytraeid populations (see below). A variety of methods of extraction could have been used, including wet sieving, chemical extractions, usually using formalin, and applying electrical currents to an area. Handsorting was selected for a variety of reasons. Comparisons of different extraction methods have suggested that while there is no absolutely reliable method for extracting all earthworms, handsorting gives some of the best results, with more labour intensive methods, such as wet sieving, giving relatively little marginal return on the additional effort involved (Edwards & Bohlen 1996: 96). There have been few other reviews of the methods of recovery of other soil dwelling fauna. Another advantage of the method was that it could be applied to the areas within the test pit with reasonable precision. This was deemed to be unlikely to be the case with regard to the chemical methods. Electrical methods are known to be problematic because of the difficulty of calculating the volume of soil affected by the current (Edwards & Bohlen 1996: 90). A final advantage of using the method was that handsorting has been used in a very high proportion of other studies of earthworm populations, and using the same methods would allow closer comparability of data sets, so that comparisons could be drawn more readily. Handsorting was also adopted for the recovery of the majority of the non-lumbricid components of the fauna (but see below), as it was thought that as the organisms in question were of broadly the same size, similar levels of mobility and occupied the same habitat that the same method of extraction would be appropriate.

The only soil fauna to be extracted by a separate method were the enchytraeids. These were extracted from 100g of soil using Tullgren funnels. The extractions of the enchytraeids were all undertaken by staff of the Scottish Crop Research Institute, under the supervision of Mr. Brian Boag.

Fig. 5.1 Functional Group Key for British Lumbricidae (after Sims and Gerard 1985).

1. Setae behind clitellum closely paired	2
Setae behind clitellum widely paired or distant	8
2. Prostomium tanylobus	3
Prostomium not tanylobus	4
3. Tubercula pubertatis on segments 33-36, clitellar genital tumescences 31-37 & post clitellar 38-39	Anecic
Other pattern of tubercular pubertatis and tumescence	Epigeic
4. Male pores on segment 13	Endogeic
Male pores on segment 15	5
5. Tubercula pubertatis absent or beginning on or before segment 29	Endogeic
Tubercula pubertatis beginning on or behind segment 30	6
6. Tubercula pubertatis, anterior pair behind segment 34	Endogeic
Tubercula pubertatis, anterior pair before segment 34	7
7. Tubercula pubertatis on segments 31 (32) 33	
Clitellar genital tumescences on segments 29,30,32-34	Anecic
Clitellar genital tumescences distributed otherwise	Endogeic
Tubercula pubertatis on segments (31) 32-34, clitellar genital tumescences on segments 31,33,34	Anecic
Other disposition of tubercula pubertatis and clitellar genital tumescences	Endogeic
8. Male pore tumescences confined to segment 15 (rarely extending across one furrow)	9
Male pore tumescences extend across (both) Furrows 14/15 and 15/16	10
9. Tubercula pubertatis on segments 30-33, clitellar genital tumescences absent	Epigeic
Other arrangements of tubercular pubertatis and clitellar genital tumescences	Endogeic
10. Tubercula pubertatis on segments 30-35	
Clitellar genital tumescences absent	Epigeic
Other arrangements of tubercula pubertatis and clitellar tumescences	Endogeic

The fauna were identified to the level that they could be placed in the functional groups selected for the study. In the case of the enchytaeids, this simply meant that the counts of animals were recorded. The non-lumbricid fauna was also simply counted by the broad taxonomic/age group which corresponded to the functional group. The earthworms were classified into epigiec, endogeic and anecic, using a specially adapted key (see fig 5.1), derived from Sims & Gerard (1985).

All fauna extraction and identification other than that of the enchytraeids were undertaken by the author.

5.5. Agents and Conditions of Faunalturbation: Soil Physico-Chemical Properties

5.5.1 Introduction.

The methods employed to quantify the fauna and the physical and chemical properties of the soils and sediments of the sites are essentially the standard ones found in the literature, and outlined in the main textbooks and handbooks on the subject (e.g. Rowell 1994, Tan 1996). There are a number of reasons why these methods were used. The first is that these methods are largely accepted as producing accurate results. The second is that it would mean that the results of the study would be easily comparable with the results from many other studies. The third reason for working with these methods is that measuring of these factors was not an area in which innovation was being sought, and as such reliable and widely accepted methods were used, allowing greater effort to be directed towards the novel aspects of the research.

5.5.2 Bulk Density and Moisture.

Samples for bulk density determination were taken using a variation on the method outlined in Rowell (1994: 138). The sampling was undertaken using Kubiena tins, as these were found to be better for taking the sample without significant compression of the material and also allowed rapid sampling. Otherwise the method followed was as per Rowell (1994: 86), including the determination of the moisture content of these samples.

5.5.3 Particle Size Distribution.

Hand testing of the texture of soils and sediments had already been undertaken in the field, largely as a means of discriminating between units. Although this gave a basic indicator of texture class and thus particle size distribution, the method has its limits. Rigorously quantified data cannot be obtained in this manner, and certain types of organic content can change the apparent texture in the hand (Rowell 1994: 134, Tan 1996: 73). The standard method for determining particle size distribution is a combination of sieving and sedimentation (Rowell 1994: 27). For this study a different approach, using sieving and laser grain size determination was adopted. The samples were fractionally sieved down to <500μm. The <500μm fraction was sub-sampled, and after ignition to remove organic matter, and analysed using laser grain size determination. This was undertaken using a LS230 Coulter counter. This instrument analyses the diffraction patterns formed upon passing a beam of laser light through a suspension of particles. From this data the equipment then models the particle size distribution, theoretically down to 0.04μm. Although there have been some problems reported with the determination of fine clay fractions (Buurman *et al.* 1997), this was not thought to constitute a significant problem for this study, as the soils and sediments under consideration have very low proportions of clay in them. Each sample was automatically run through the Coulter counter 3 times to give replicate data.

5.5.4 Loss on Ignition.

There are a variety of ways of determining the organic content of soils and sediments. One possible method is by potassium dichromate oxidization (Tan 1996: 230). This method involves boiling the sample in acid, and therefore would mean that calcareous material in the sample would also be oxidized, giving an inflated measurement (Rowell 1994: 50). The particular method of loss on ignition used was predicated by the known properties of the soils under consideration. Loss on ignition is recognised as providing a good estimate of organic matter for sandy soils, such as the ones under consideration. It is mainly problematic with very heavily organic soils, which the samples were known not to be, or soils with appreciable clay contents, which it was thought that the samples would not have, a supposition that proved to be correct. Three replicates were undertaken to given an estimate of precision. There are different methods of loss on ignition determination. Because at least two of the sites were known to have a significant calcareous content, the method used was a relatively long, overnight, combustion, at a temperature of 500C, to avoid decomposition of calcium carbonate, which occurs at 770C (Rowell 1994: 48).

5.5.5 pH.

The pH of a material is a logarithm of the concentration of hydrogen ions. With regard to soils and sediments, it is affected by three sets of factors. The set which is generally the most significant is the base status of the parent material. Two other sets of factors are the drainage of the soil and the biochemical status of the soil. As will be apparent from the discussion of pH in chapter three (see 3.4), the interaction of biochemical status with pH is a two way process.

The determination of pH was carried in the laboratory, using the standard methods reported in Rowell (1994: 159). The pH of the samples was determined as a suspension in both distilled water and a solution of calcium chloride. The pH of the aqueous suspension reflects the pH of the soil solution. The addition of $CaCl_2$ to the suspension causes the displacement of hydrogen ions from exchange sites at the surface of organic material or colloidal clay fractions, allowing the determination of total acidity and thus the 'reserve' acidity (Tan 1996: 104). The addition of $CaCl_2$ generally depresses the pH as the displaced hydrogen ions go into solution. Both types of determination are made, as each represents variations on the interactions of soil fauna and habitat.

5.6 Agents and Conditions of Faunalturbation: Analysing Interactions and Associations

Having posited a set of relationships that form a system, it was necessary to find some means of testing whether these relationships exist and whether they have any significance. Given the implicitly quantitative nature of the proposed models, statistical tests provide a useful means of attempting this. Given the prospect that certain easily measurable components of the model might be major determinants of other components in and the final outcomes of the system, i.e. the magnitude and distribution of faunalturbation, it was originally intended to attempt to derive an explicitly quantitative model based on statistical approaches. The statistical tests and the precise variations employed are dealt with in detail in the relevant sections of chapters four and five. It suffices at this point to list the techniques and to mention that the outcomes of the initial statistical analyses lead to the set of techniques ultimately employed. The various tests employed were selected on the basis of the requirements of the study and the requirements of the individual data sets in terms of statistical integrity. The techniques employed were bivariate correlation, using Kendall's Tau coefficient of correlation, multiple linear regression and chi-squared tests.

A general point with regard to the statistical analysis and testing of the models concerns the use of paired archaeological and control sites. The control sites were employed to compare with the archaeological sites to see if any consistent differences emerged between these two groups. This was done to see if there were any additional factors that would affect the faunalturbation system by virtue of an archaeological site being such. While specific causes would be difficult to divine, it was thought that it was possible that there might be significant anthropogenic effects other than those affecting the nature of the properties selected for measurement in this study.

Chapter Six

Results 1: Faunalturbation in Farm Mounds

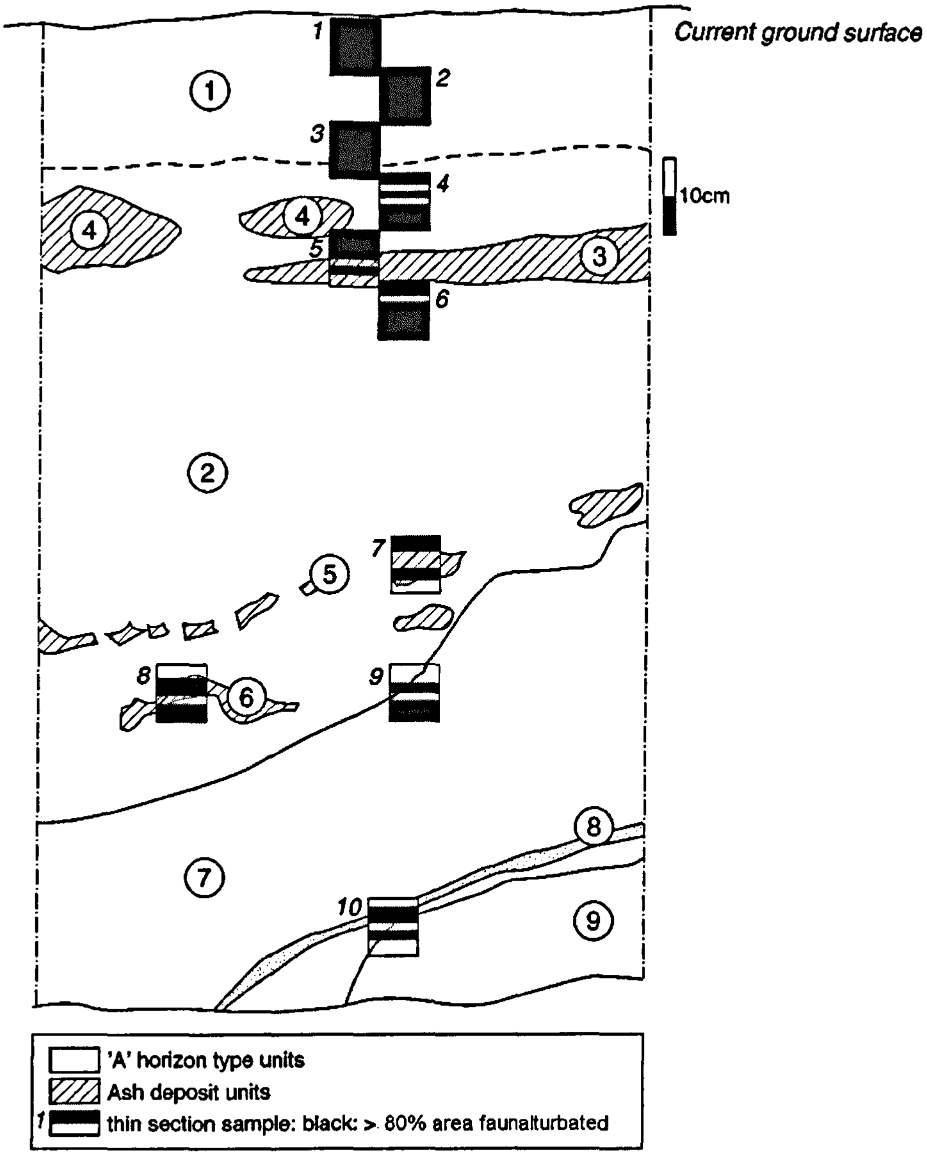
6.1 The Evidence of Faunalturbation on the Archaeological Sites: Introduction

The results presented in this chapter are those concerning the traces of faunalturbation itself. This will establish that faunalturbation is in fact occurring on archaeological sites and has a significant impact on the stratigraphy of a site. These results will also be discussed with regard to the forms and distribution of faunalturbation. This chapter is concerned solely with the evidence of significant effects of faunalturbation on archaeological stratigraphy. As such the samples, and thus data, all relate to the archaeological sites only.

6.2 The Evidence of Faunalturbation on the Archaeological Sites: Field Descriptions.

Field descriptions from the archaeological sites are given in tables 6.1-6.3. The spatial relationships of the different units can be seen in figures 6.1-6.3. Additional descriptions are given in Appendix 4. Based on these descriptions the soils and sediment units of the three sites can be classified into two broad groups. The first group includes the modern 'A' horizons that have developed on the sites. Working from these other units which closely resemble the modern 'A' horizons can be provisionally classified within the same group. They are characterised by a texture that is loamy, a crumb/incipient crumb structure and a fairly homogenous appearance. Colour typically falls in the Munsell range 10 YR 3.5-2/2.5-1, denoted as dark grey brown/dark yellow brown. A feature of all the current 'A' horizons and one of the other units within this

Fig. 6.1 Stratigraphic sequence in the test pit at Beafield, with projection of micromorphology data.



group is that they contain stone lines (see figs. 6.10-6.12), a feature generated by earthworm activity in biologically active soils which are not undergoing any other significant process of pedoturbation (Edwards & Bohlen 1996: 203).

Table 6.1 Description of the soil/sediment units at Beafield, Sanday

Unit No.	Description
1	Slightly sandy silt, colour 10YR2/2. Moderately to heavily rooted to 50-100 mm. Largely clast free in top 100-150 mm. Layer of clasts – 10-20 mm sub-rounded to sub-angular tabular sandstones and limpet shells, conforming to unit boundary. Strongly developed crumb structure. Basal matrix boundary highly diffuse.
2	Slightly sandy silt, colour 10YR3/2. Frequent clasts with an unsorted distribution. Clasts mostly 10-20 mm sub-angular tabular sandstones, with some limpet and cockle shells. Frequent orange mottling, 3-4mm and charcoal flecking, 3-5 mm. Weakly developed crumb structure. Upper and lower boundaries highly diffuse.
3	Slightly sandy silt to silt, base matrix colour 10YR2.5/2, mottle colour 7.5YR9/8. Occasional clasts with an unsorted distribution. Clasts mostly 10-20 mm sub-angular tabular sandstones, with some limpet and cockle shells. Mottles very abundant, 20-30 mm diameter. Upper and lower boundaries moderately diffuse.
4	Slightly sandy silt to silt, base matrix colour 10YR3/2.5, mottle colour 7.5YR9/8. Rare clasts with an unsorted distribution. Clasts mostly 10-20 mm sub-angular tabular sandstones, with some limpet shells. Mottles very abundant, 20-30 mm diameter. Upper and lower boundaries moderately diffuse to moderately defined.
5	Slightly sandy silt to silt, base matrix colour 10YR2.5/2, mottle colour 7.5YR9/8. Occasional clasts with an unsorted distribution. Clasts mostly 10-20 mm sub-angular tabular sandstones, with some limpet shells. Mottles very abundant, 20-30 mm diameter. Upper and lower boundaries highly diffuse.
6	Silt, colour 2.5Y2.5/1. Some black flecking, 1-3 mm. Rare clasts; 10-20 mm sub-angular tabular sandstones. Upper and lower boundaries moderately diffuse to moderately defined.
7	Slightly sandy silt, colour 2.5YR/2.5/1. Largely clast free. Frequent black flecking, 5-10 mm. Occasional orange mottling, c. 3 mm diameter. Upper and lower boundaries moderately diffuse.
8	Pure coarse sand, colour. Structureless. Upper and lower boundaries distinct.
9	Slightly sandy silt, colour 7.5YR4/3. Frequent orange mottles, c. 2-4 mm. Frequent black flecks, c. 2 mm. Largely clast free. Weakly developed crumb structure. Upper boundary distinct.

Given that the stone line forms due to the combined covering of stones by surface casting and their sinking as old earthworm burrows collapse beneath them (Darwin 1881: 72, Edwards & Bohlen 1996: 203), it seems probable that the stone line represents a boundary of the most intensive faunalturbation, or at least the sorting effect associated with intensive earthworm activity. Similarly, where faunalturbation is likely to be the most significant process of pedogenesis, the base of the current 'A' horizon may similarly be regarded as marking the boundary of the area which is currently undergoing the most intensive faunalturbation.

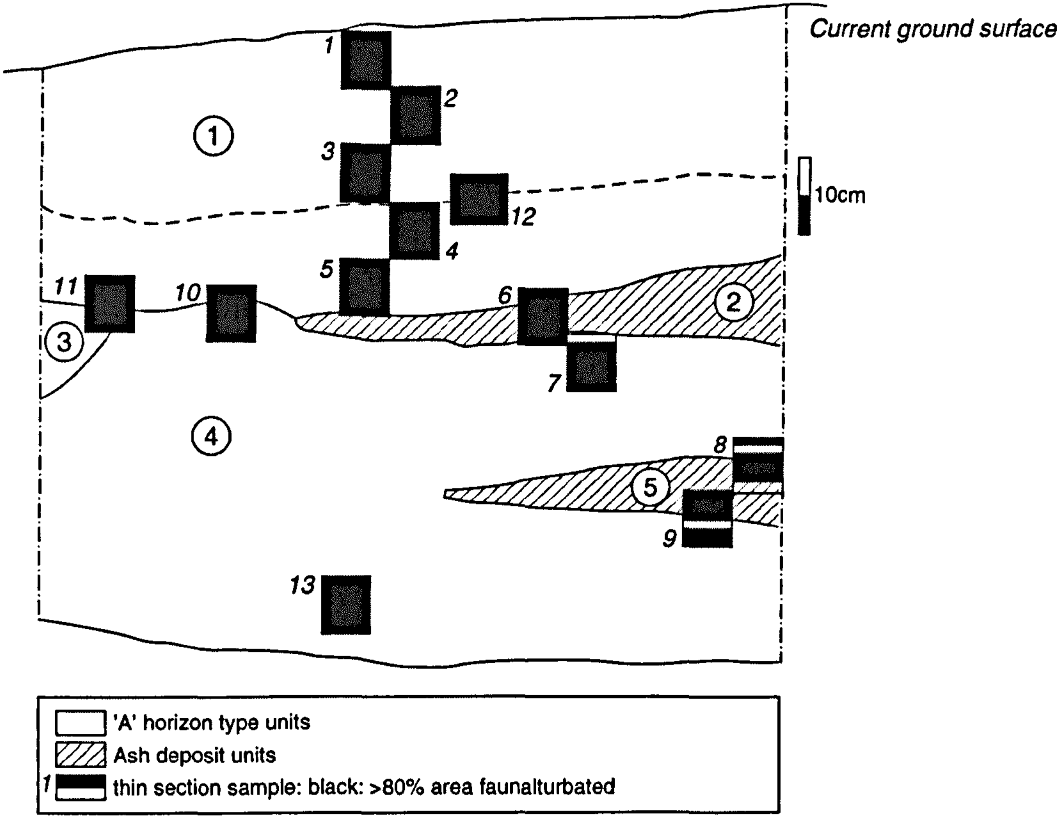
Table 6.2 Description of the soil/sediment units at Tofts, Sanday

Unit No.	Description
1	Silty clay loam, colour 10YR2.5/1. Heavily rooted to 20 mm. Clast free to .21 m. At .21-22 m layer of clasts; predominantly limpet shells, plus occasional tabular sub-rounded sandstone. Below this frequent clasts, compositionally as layer above, but unsorted. Strongly developed crumb structure. Lower boundary highly to moderately indistinct.
2	Silty clay loam, colour 10YR3/2. Occasional clasts; predominantly limpet shells. Abundant black flecks, c. 2-4 mm. Abundant mottles, 10-50 mm diameter, colour 7.5YR4/4. Moderately developed crumb structure. Upper and lower boundaries moderately indistinct to moderately distinct.
3	Silty clay loam, colour 10YR3.5/2. Occasional clasts; predominantly limpet shells. Occasional orange mottles, up to 10 mm diameter. Moderately developed crumb structure. Boundaries highly indistinct to moderately distinct
4	Silty clay loam, colour 10YR3/2. Occasional clasts; stones, 10-100 mm, tabular sub-rounded to sub-angular; limpet shells. Occasional black flecks, 2-5 mm. Weakly developed blocky structure. Upper boundaries moderately indistinct.
5	Silty clay loam, colour 10YR3/2. Occasional clasts; predominantly limpet shells. Abundant grey mottles up to 20 mm, colour 10YR4/2. Abundant black flecks, c. 2-4 mm. Moderately developed sub-angular blocky structure. Upper and lower boundaries moderately distinct.

The 'A' horizon type units therefore can be argued on this basis to be constituted largely or solely of faunalturbated material. Such a conclusion requires further validation, and the additional evidence for this will be discussed below (see 6.3.2). It should be noted that such a conclusion would mean that the 'A' horizon type units are equivalent to part or all of the zone of destruction posited in chapter three (see 3.6). This point is further discussed below (see 9.2).

The other group of units tends to be predominantly or totally composed of grey and/or orange mottles and often exhibit much black flecking. No consistent type of texture is associated with this group, in contrast to the 'A' horizon type of deposit. Where such deposits are substantial, as at Westbrough, a laminated structure is apparent. The units appear to largely conform to the 'law' of original horizonality, that is to say that these units largely resemble the morphology in section that would be expected of dumps of unconsolidated material (Harris 1989: 31).

Fig. 6.2 Stratigraphic sequence in the test pit at Tofts, with projection of micromorphology data.

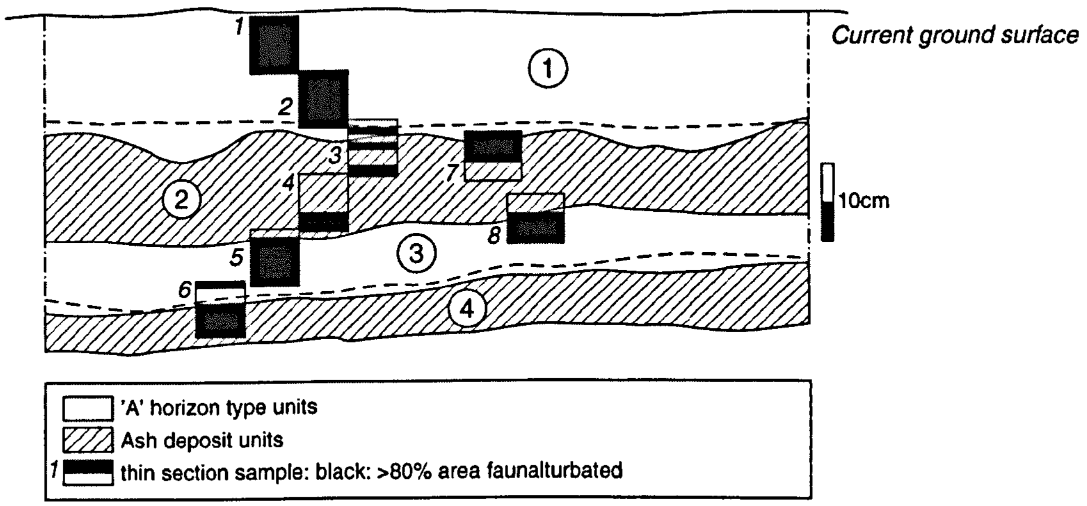


This would be expected of deposits of archaeological material that had not been heavily reworked (Harris 1989: 32). The uppermost of this type of deposit on each site often appears to have been penetrated with material from the 'A' horizon above. Such deposits would probably be interpreted as ash deposits by a field archaeologist. The deposits are thus, in effect, the remaining detectable archaeological stratigraphy.

Table 6.3 Description of the soil/sediment units at Westbrough, Sanday

Unit No.	Descriptions
1	Silty loam, colour 2.5Y2.5/1. Heavily rooted to 60 mm. Generally clast free, except for layer of angular, tabular stones and occasional shell, approximately coterminal with basal boundary. Boundary is moderately distinct to distinct. Boundary very irregular, interdigitating with unit below. Weakly developed sub-angular blocky structure.
2	Sandy silt loam, colour 10YR4/2.5. Occasional clasts; angular cuboidal/tabular sandstones, c. 10-15 mm with an unsorted distribution. Frequent orange flecks, c. 2-4 mm, colour 7.5YR5/8. Upper boundary moderately distinct to distinct. Lower boundary moderaely distinct to moderately indistinct. Structureless.
3	Slightly sandy silt loam, colour 10YR2/2. Occasional clast; sub-angular prismoidal sandstone, 7-10 mm. Sorted – tending to form layer at base of unit. Occasional grey mottle, 10YR5/8, silt texture. Structureless. Upper boundary moderately distinct to indistinct. Lower boundary moderately distinct to moderately indistinct.
4	Clay silt, colour 10YR5/3. Occasional clast; sub-angular prismoidal sandstone, 10-40 mm, unsorted. Abundant mottles, colour 10YR3/1, 10-20 mm diameter and 7.5Y5/8 2-4 mm. Abundant black flecks, 2-4 mm. Structureless. Upper boundary moderately distinct.

Fig. 6.3 Stratigraphic sequence in the test pit at Westbrough, with projection of micromorphology data.



It should be noted that the 'A' horizon type units form the bulk of the recorded sections, with the exception of Westbrough. At Westbrough the lower 'A' horizon type unit (unit 3) is completely stratigraphically isolated from the modern 'A' horizon. This unit also contains a stone line. It would appear that this unit constitutes the 'A' horizon of a buried soil, with the parent material being the archaeological deposits, such as those directly below unit 3. Whether the other deep 'A' horizon type units may be regarded as buried soils is a more complex issue. This issue and the implications proceeding from it for the different models presented in chapter two will be discussed in chapter nine (see 9.2).

6.3 The Evidence of Faunalturbation on the Archaeological Sites: Thin Section Micromorphology.

6.3.1 Introduction.

The technique of soil micromorphology was applied for a specific purpose: to identify and quantify the traces in the soil that would indicate the occurrence of faunalturbation, assess the distribution of faunalturbation in the units, and hence the profile, and where possible identify the specific functional group responsible. Descriptions of the slides are given in Appendix 3.

The significant data produced by the examination of the thin sections is that relating to the traces of faunalturbation. The methods of identification and quantification of these traces, which are largely excrement or derived from excrement, have been discussed earlier (see 5.3). Quantification is given as a percentage coverage of area, based on visual estimates on 1 cm squares (5.3.3). The quantified data is presented in three different ways. Representative micrographs of the micromorphological traces in question are given in figures 6.4-6.12.

Fig 6.4 Total Biological Fabric, Tofts, PPL, frame width 12mm

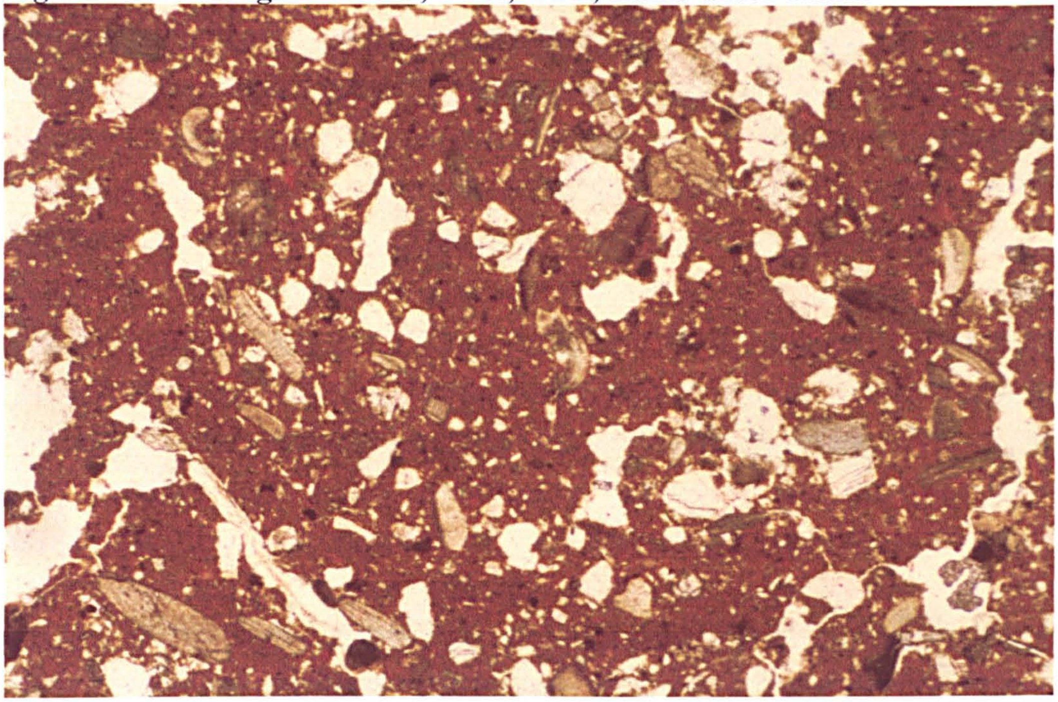


Fig 6.5 Mamillated Excremental Pedofeature, Beafield, PPL, frame width 1mm.

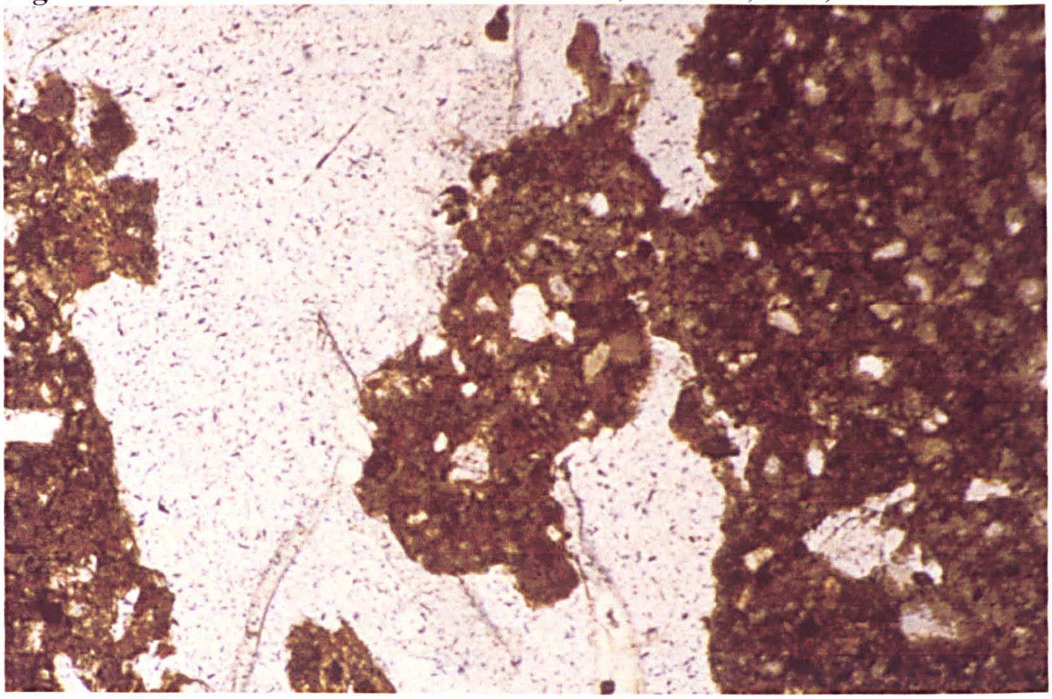


Fig. 6.6 Baccillo-cylindrical Excremental pedofeatures, Beafield, PPL, frame width 1mm.

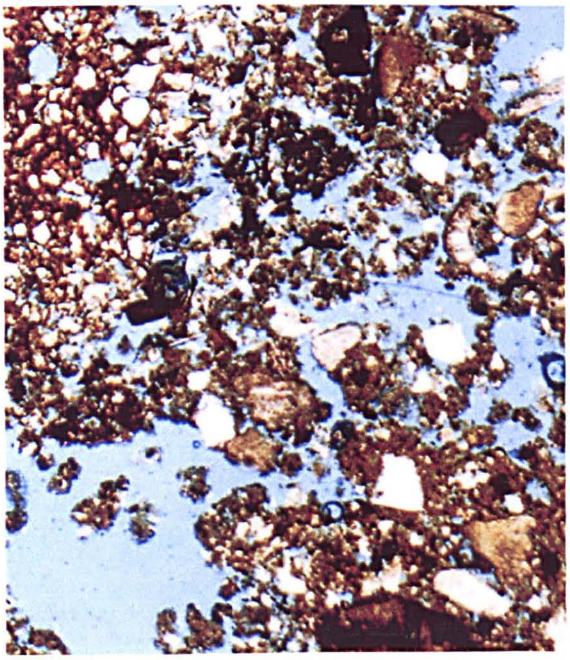


Fig. 6.7 Textural Pedofeature, Tofts, PPL, frame width 4mm.

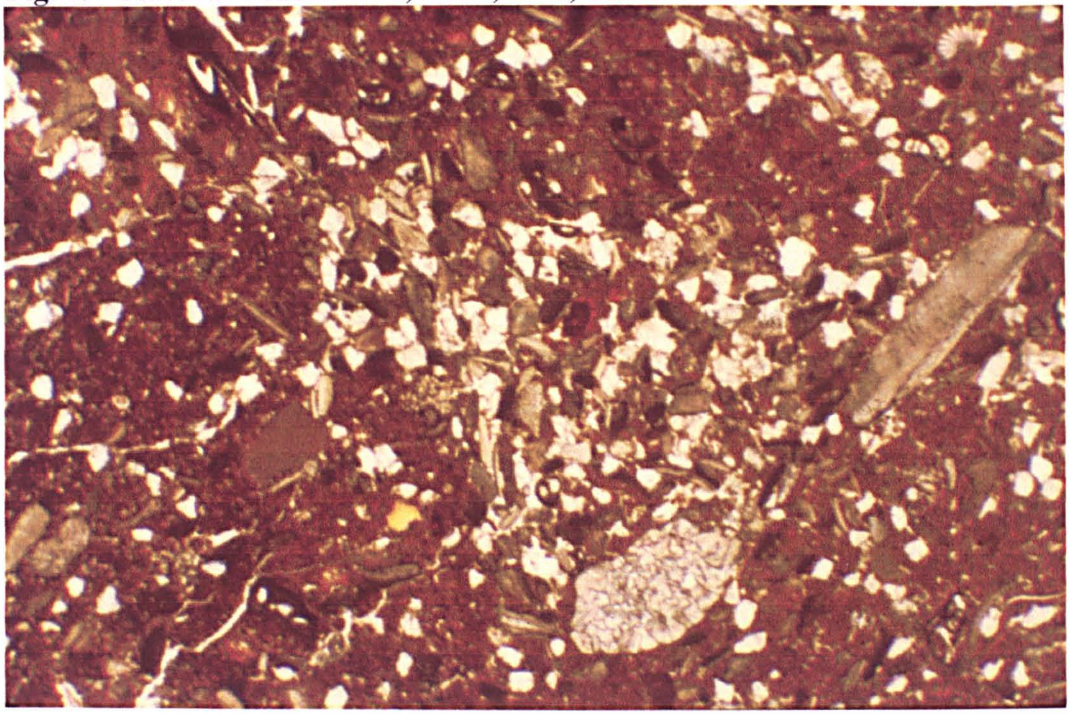


Fig. 6.8 Fabric Pedofeature, Tofts, PPL, frame width 16mm.

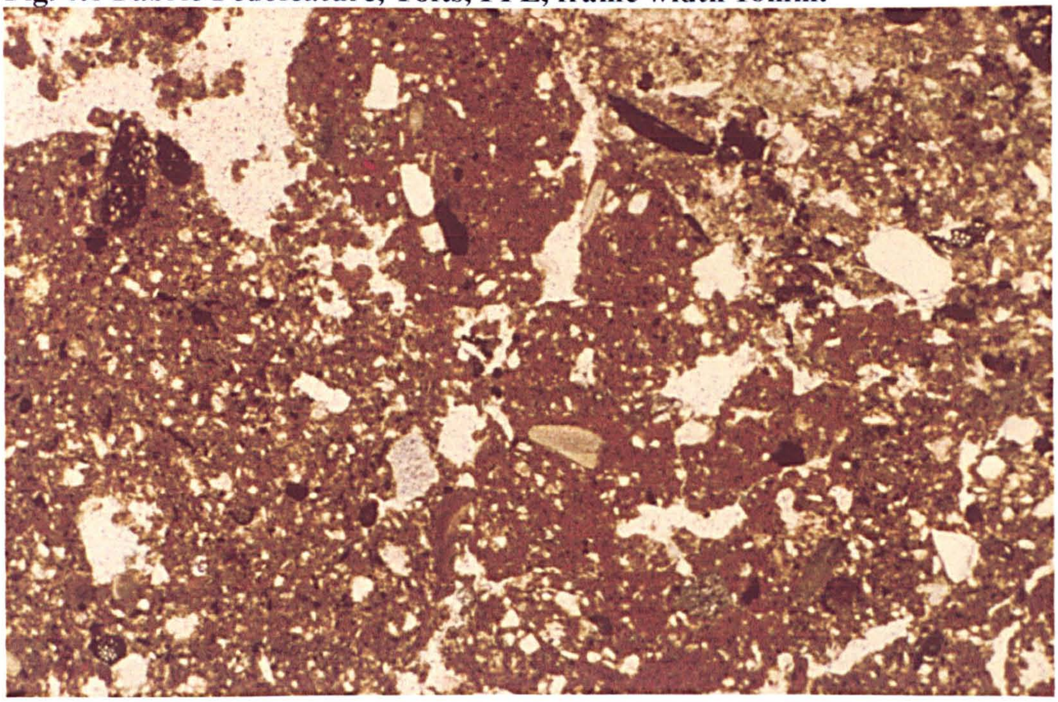


Fig. 6.9 Ellipsoidal Excremental Pedofeature, Westbrough,PPL, frame width 4.2mm.

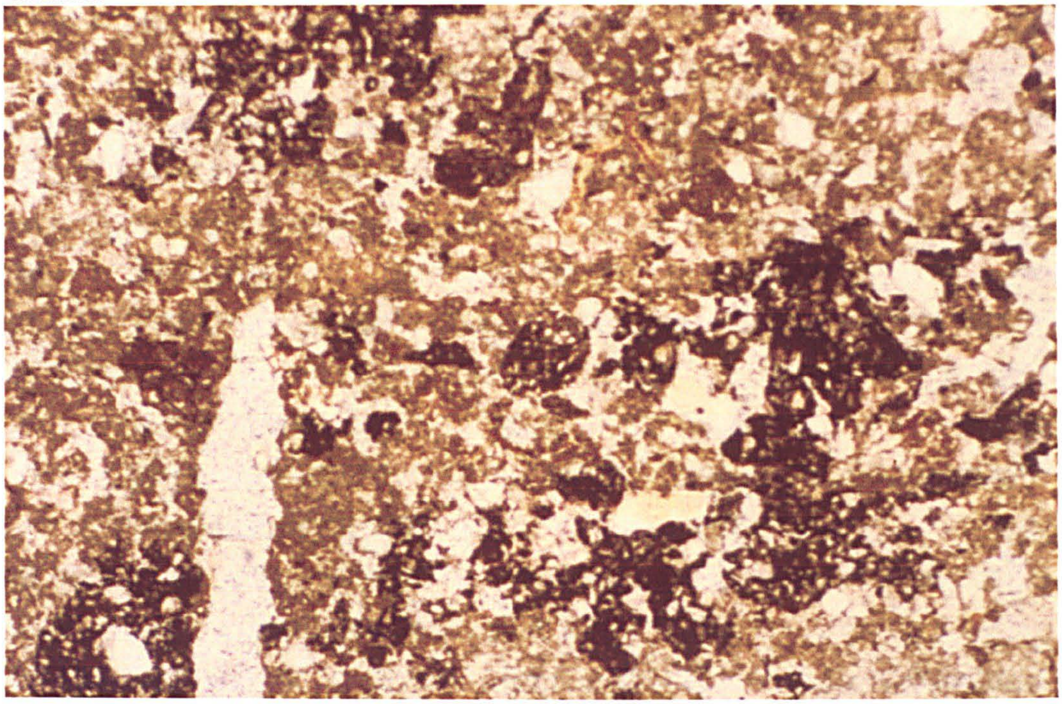


Fig. 6.10 Tailed Conoidal Excremental Pedofeature, Westbrough, PPL, frame width 1.2mm.

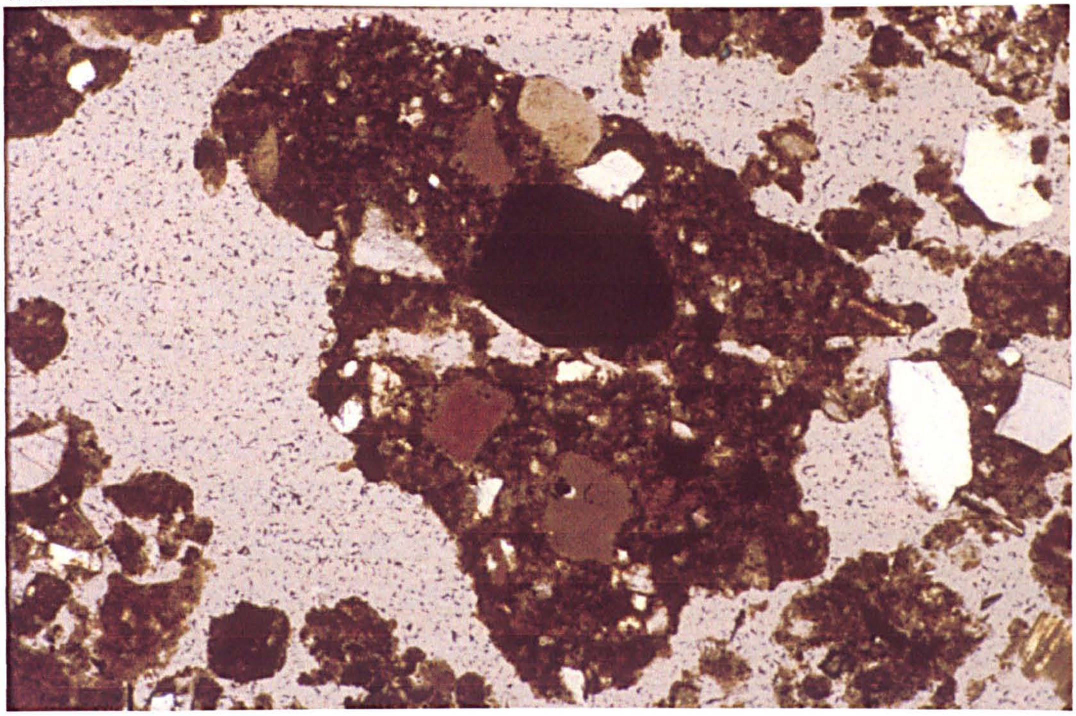


Fig. 6.11 Ellipso-cylindrical Excremental Pedofeature, Westbrough, PPL, frame width 4mm.

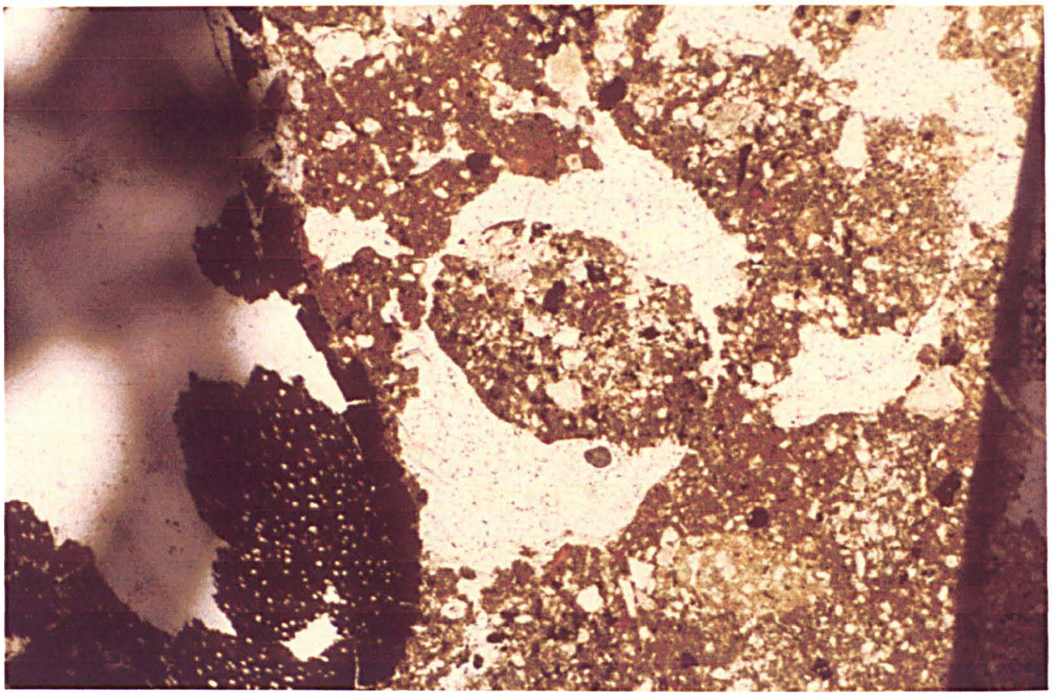
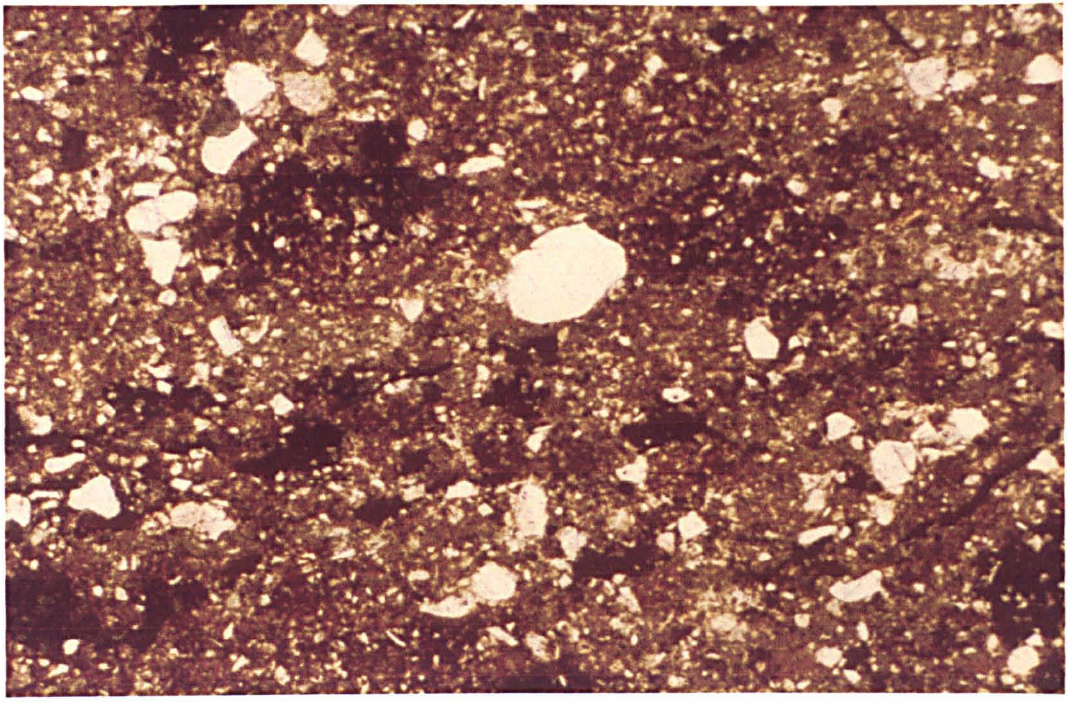


Fig 6.12 Typical Fabric of Ash Deposit Units, Westbrough, PPL, frame width 8mm.



The first presentation of the data is given in figures 6.1 to 6.3. This breakdown takes the form of means of the total traces of faunalturbation, calculated for 1cm layers, projected on to the field section from which the thin section samples were taken. This approach allows the distribution of the micromorphological traces of faunalturbation to be compared with the distribution of the different units recorded in the field. These figures are presented and discussed in below (see 6.3.2).

The second way in which data is presented is given in figures 6.13-6.15 (see 6.3.2). This breakdown takes the form of the standard deviations of the means of the total traces of faunalturbation presented in figures 6.1-6.3, also projected on to the field sections from which the thin section samples were taken. This approach allows the range of variation in the distribution of the micromorphological traces of faunalturbation to be compared with the distribution of the different units recorded in the field. These figures are presented and discussed in below (see 6.3.2).

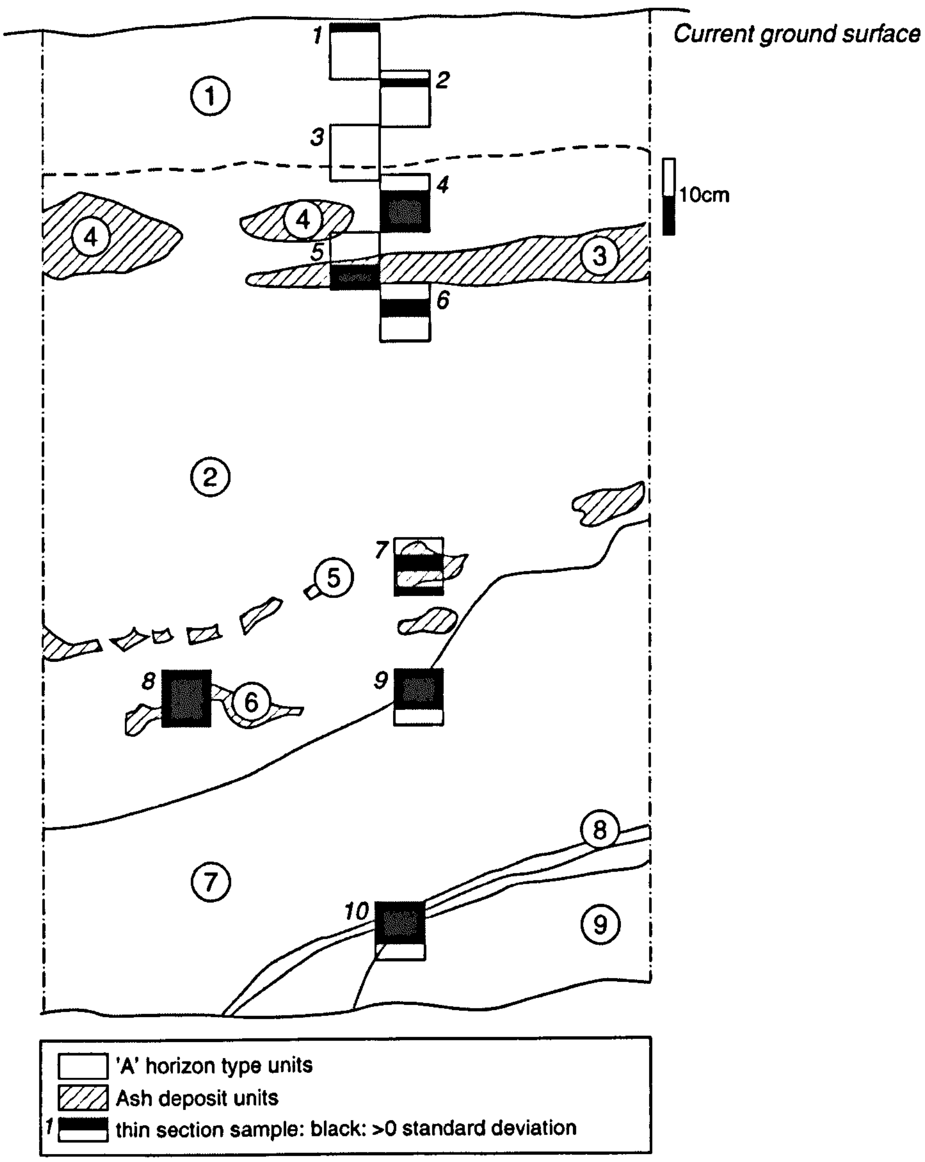
The third breakdown of the data presented in this chapter is a set of averages of the different forms of faunalturbation in the top 40 cm of each site. These averages have been calculated to be comparable with the data produced by the analysis of the soil properties of each site. This will allow statistical analysis of the relationship between the soil properties and the traces of faunalturbation, thus testing some of the relationships posited in the models. These data are presented in table 6.9 (see 6.3.3).

6.3.2 Distribution of the Total Traces of Faunalturbation; 1 cm depth based means and standard deviations.

The data discussed in this section is to be found in two sets of figures, 6.10-6.12 and 6.13-6.15. The data is presented in the form of the means of the total traces of faunalturbation, calculated for 1cm layers, from the constituent 1cm^2 cells examined (see 5.3.3). The total data set may be found in appendix 4. If the mean of the total faunalturbation traces in the1 cm^2 squares quantified in the 1cm layer is greater than 80% this has been coloured black in figures 6.1-6.3. If the mean is less than 80% the slice has been left uncoloured. The results have then been projected on to the field section from which the thin section samples were taken. The 80% coverage by faunalturbation traces has been selected as the threshold in figures 6.1-6.3 because it is the level at which it becomes difficult to distinguish thin sections from the modern 'A' horizon from those sampled across archaeological deposits.

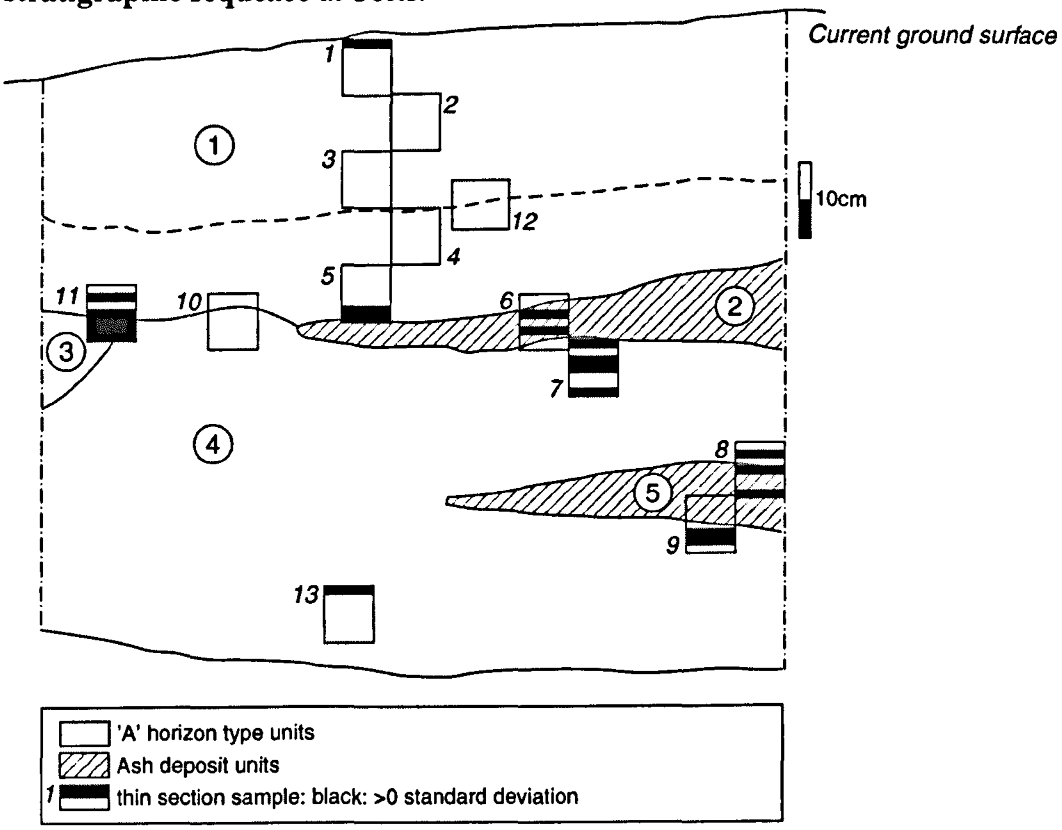
The first point to emerge from the thin section data is the ubiquity of the traces of faunalturbation. There is no single slide that does not include significant traces of the activity of soil fauna. Even with the threshold of identifiability at 80%, the majority of the means of total faunalturbation traces are above that threshold. The majority of samples where there are means of total faunalturbation features less than 80% are in the ash deposit units. Of those areas with less than 80% coverage that fall within the 'A' horizon type deposits, a third lie near the edge of the ash deposit units as depicted in figures 6.1-6.3.

Fig. 6.13 Standard deviation of mean total faunalturbation traces with stratigraphic sequence at Beafield.



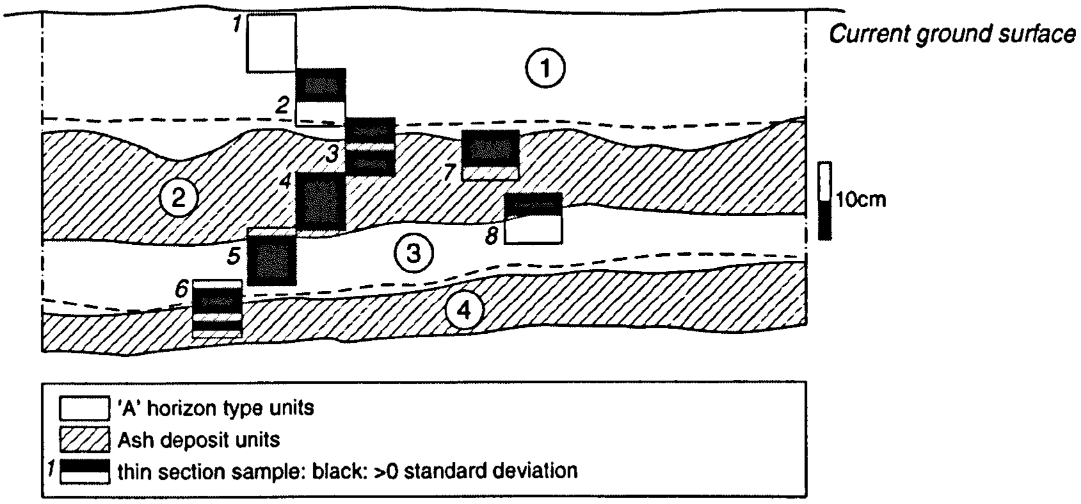
These areas probably represent variation in the position of the unit boundaries in three dimensions: while each field section represents one 'slice' through a site at a given point, the thin sections in fact represent samples from 1-4 cm further back from the face of each of the profiles. As such this third of cases may also have been taken from ash deposit units. In essence the thin sections of the 'A' horizon type units are largely or wholly composed of the traces of faunalturbation. Thus with regard to the 'A' horizon type units the means confirm the points made above (see 6.3.1).

Fig. 6.14 Standard deviation of mean total faunalturbation traces with stratigraphic sequence at Tofts.



By contrast the areas of the thin sections that sample the ash deposit units tend to show lower mean areas covered by the traces of faunalturbation. Even in these units the mean thin section areas covered by faunalturbation traces are often high. While the degree to which the 'A' horizon units does not vary greatly from site to site, the means presented in figures 6.1-6.3 seem to suggest that there is considerable variation in the degree to which ash deposit units are faunalturbated. At Tofts these units are very heavily faunalturbated, those at Westbrough the least. It is worth noting that the deposits that have produced the thin sections with the lowest percentage coverage by faunalturbation traces, as depicted in figures 6.1-6.3, are those units that were the most easily detected in the field, i.e. the archaeological deposits at Westbrough. Thus these units could be argued to have the best preservation of archaeological stratigraphy at the macromorphological scale. That this should be so is the logical outcome of a system where the observed macromorphological characteristics of the different deposits are the result of processes occurring at the microscopic scale.

Fig. 6.15 Standard deviation of mean total faunalturbation traces with stratigraphic sequence at Westbrough.



The second point that emerges from these findings is that an archaeological deposit may have undergone substantial faunalturbation, e.g. over 80% of a micromorphological thin section area covered by faunalturbation traces, and still be identifiable as a discrete archaeological unit at the macromorphological scale, as at Tofts. The issue of why the levels of faunalturbation vary from site to site of course relates to the issue of interactions in the faunalturbation system, which will be further examined in chapter seven.

Variation with depth is particularly noticeable when comparing the slide areas that sample the profiles above the stones lines discussed above (see 6.2) with the slide areas that sample the profile below the stone lines. Most of the 1 cm^2 areas examined from the slides of the samples above the stone lines have 100% values, and a number which do not (e.g. slide 3, fig. 6.1) are due to the presence of stones, rather than areas of ash deposit. This contrasts with the slide areas below the stone line, where a greater range of values is seen, albeit still with a substantial proportion with values of 100 per cent. This seems to confirm the role of the stone line as the boundary of the most heavily faunalturbated area, as posited above (see 6.2).

Figures 6.13-6.15 depict the standard deviations of the 1cm depth means, projected against the stratigraphic profiles from which the samples had been taken. The single most frequent individual value for total faunalturbation is 100%, and a high proportion of the 1cm depth means are composed entirely of 100% values and thus have standard deviations of zero. In fact such values account for all but one of the zero-value standard deviations. Plotting zero-value and non-zero values of standard deviation gives an approximate distribution of variation in coverage by the traces of faunalturbation. As can be seen in figures 6.13-6.15 there is an increased tendency for variation to exist with depth. There is also a greater tendency for variation to occur in the ash deposit type units than in the 'A' horizon type units. The spatially abrupt occurrence/non-occurrence of variation is a reflection of the scale at which the processes of faunalturbation occur, which are in turn determined by the size of the agents. Because of the distribution of the actual individual values of total faunalturbation traces, non-zero values of standard deviation also can be taken as a proxy of some degree of non-faunalturbation, i.e. stratigraphic survival. The abrupt occurrence/non-occurrence of variation and thus of survival/non-survival of stratigraphy emphasises the 'patchy' nature of the preservation of the archaeological units (see 6.2). There are only a few limited areas in the thin sections showing no evidence of faunalturbation, and these are rarely larger than 2 cm^2 (see appendix 4).

6.3.3 Distribution of the Traces of Faunalturbation; 10 cm depth based means.

To allow comparison of the micromorphological evidence for faunalturbation with the data concerning the soil properties a further set of means of the traces of faunalturbation has been calculated. The means have been calculated over 10 cm depth intervals for the slide areas that cover the upper 40 cm of each profile. Whereas the data so far presented has been in the form of the aggregated totals of all the traces of faunalturbation, in this section the contribution of the different forms of faunalturbation traces will be considered. The different categories of faunalturbation trace tend to be associated with different groups of fauna (see 5.3.3 and 6.3.1.) Thus it may be possible to examine the relative impact of the different functional groups. The averaging of the thin section data over 10 cm intervals will also allow statistical analysis of the relationship between the soil properties and the traces of faunalturbation, thus testing some of the relationships posited in the models, which analysis is detailed below (see 8.2). This breakdown of the data is presented in table 6.4.

Table 6.4 Averages of Percentage Slide Area Coverage by Faunalturbation Traces

Site	Depth	T.B.F	Fabric Pattern	Mamillated	Bacillo-Cylinder	Textural	Other
Beafield	10	90	X	4	1	3	X
Beafield	20	89	X	6	1	4	X
Beafield	30	74	X	10	3	X	-
Beafield	40	70	1	8	5	X	-
West-Brough	10	100	X	X	X	X	X
West-Brough	20	73	X	1	2	-	X
West-Brough	30	72	1	1	2	-	-
West-Brough	40	92	X	1	X	-	X
Tofts	10	87	X	7	6	X	X
Tofts	20	93	X	1	5	2	-
Tofts	30	85	X	2	4	-	X
Tofts	40	76	X	1	13	-	X

T.B.F: Total Biological Fabric X: presence of trace type at less than 1% area coverage.

The category of ‘other’ covers a variety of different types of excremental pedofeature, all associated with the larvae of the coleoptera and diptera. The percentages are rounded to the nearest 1%. Where an ‘X’ appears this records the presence of the feature at an average level less than 1%. This allows some insight as to the relative importance of the different functional groups over the depth to which the fauna and soil properties have been jointly sampled. The most noticeable reduction in is the percentage coverage by the total biological fabric category (‘TBF’ in table 6.4). It is known that compression of the soil by livestock trampling may be most significant in the upper part of the soil (White 1997: 40). The apparent reduction in the total biological fabric may be in part be due to less compression of discrete excremental pedofeatures, particularly the mamillated and bacillo-cylindrical forms associated with earthworms and enchytraeids respectively. It is noticeable that these two categories of excremental pedofeatures are often more abundant with depth. Looking at the total percentage area coverage, however, suggests that some of the apparent decrease in faunalturbation traces with depth may be genuine. Such variation may be due to variation in the predominant functional group at different depths (see 8.2).

The greatest changes in the apparent faunalturbation over depth occurs at the site at Westbrough. These changes correspond to changes in the observable vertical distribution of archaeological deposits and soil units. In comparing field and thin section observations it is noticeable that variation in levels and nature of faunalturbation do partly correspond to variation in the unit types delineated above (5.3). The relationship is not, however, uncomplicated, as can be seen by comparing tables 6.1-6.4 and figures 6.1-6.3.

6.4 The Evidence of Faunalturbation on the Archaeological Sites: Caesium 137 Distribution

In figures 6.16 to 6.18 profiles of the distribution of ^{137}Cs activity as a percentage of the total site inventory are given for the different sites. Each is accompanied by a negative exponential curve. The exponential represents a model of the distribution of the ^{137}Cs after initial fixation has occurred. This provides a base line against which the actual ^{137}Cs distribution may be compared. Variation from the exponential curve can be assumed to be largely due to the net effects of adsorbed ^{137}Cs movement due to the mixing of the soil or sediment caused by the activity of the soil fauna (6.2.4) (Tyler *et al.* 2001).

The first point to note with regard to all the sites is that the observed decline in activity concentration with depth is much less abrupt than the exponential form of the initial fixation curve. As such the caesium is distributed in significant quantities at greater depths, and somewhat more evenly, than would be the case if there had been no change from the initial distribution of the ^{137}Cs. It would appear that one effect of faunalturbation is to carry a significant amount of ^{137}Cs to some depth. If the distribution of the radiocaesium is compared with the distribution of other features of the profiles the process of redistribution and thus faunalturbation may be elucidated further.

If the depth of the stone lines and the base of the current 'A' horizons (discussed above in section 6.2) are compared with the distribution of caesium in figs. 6.16 – 6.18, it becomes apparent that the bulk of the caesium activity lies above these two profile features. Given that these features probably represent the boundaries of the majority of ongoing activity by certain functional groups (see 7.2) it is not perhaps surprising that the bulk of the caesium falls above them. It could be argued that the majority of faunalturbation is occurring in the upper levels of the sites. This poses an apparent problem in relation to the micromorphological traces of faunalturbation, which is that high levels of faunalturbation traces are found at all depths throughout the profile, as

Fig. 6.16 Distribution ^{137}Cs Activity as a Percentage of Total Inventory with Depth, Observed and Modelled, Beafield

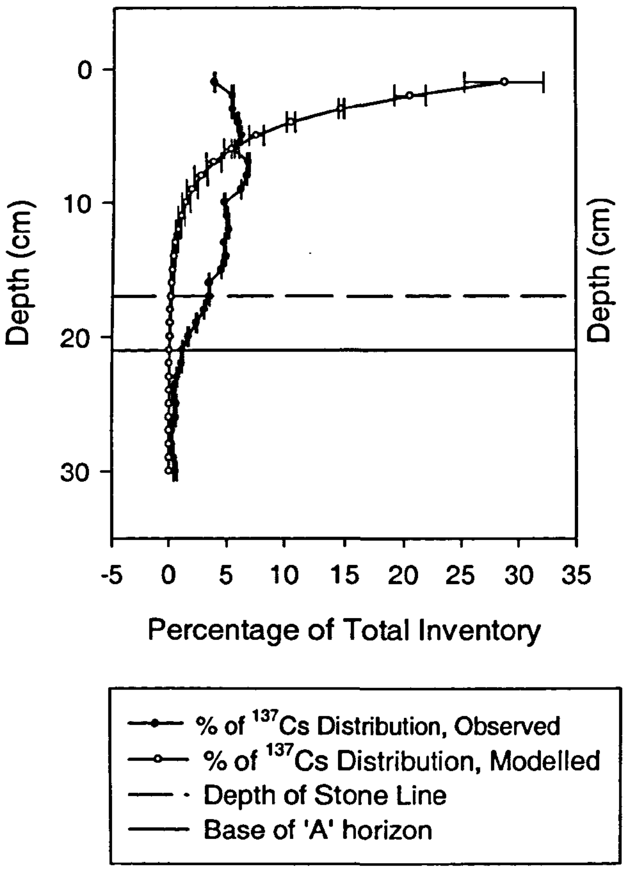


Fig. 6.17 Distribution of ^{137}Cs Activity as a Percentage of Total Inventory with Depth, Observed and Modelled, Westbrough

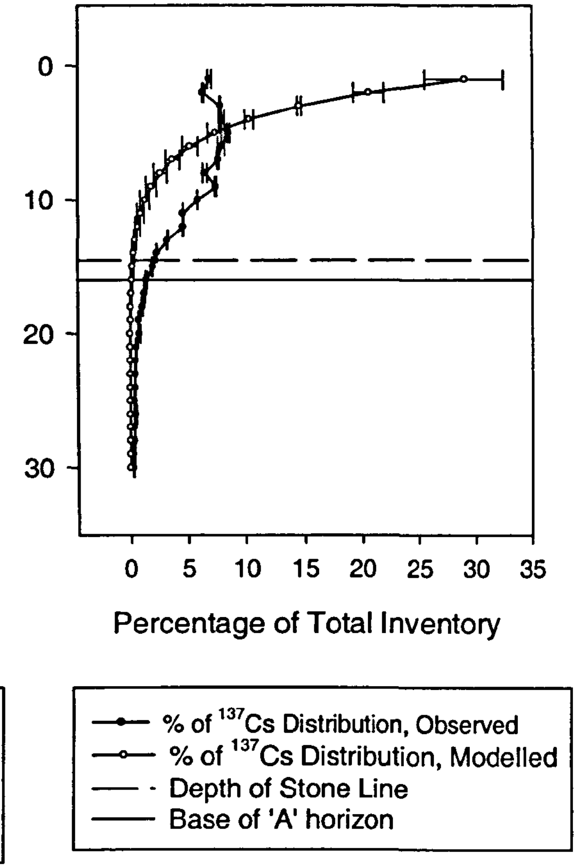
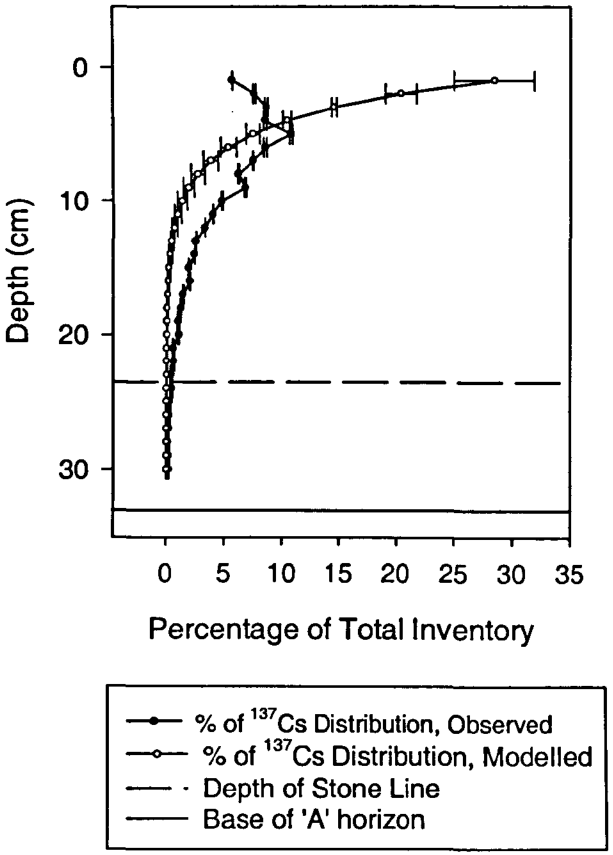


Fig 6.18 Distribution of ^{137}Cs Activity as a Percentage of Total Inventory with Depth, Observed and Modelled, Tofts.



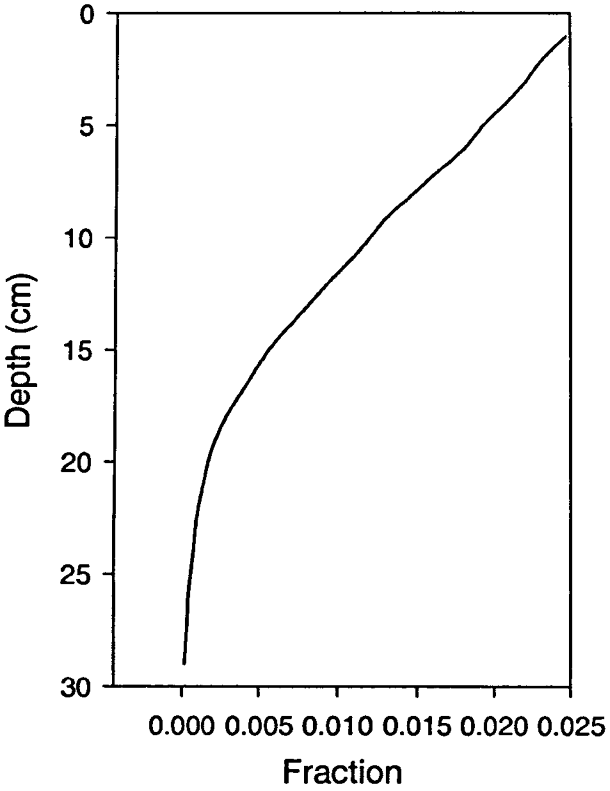


Fig. 6.19 Mean Annual Fraction of Soil Moved, Beafield

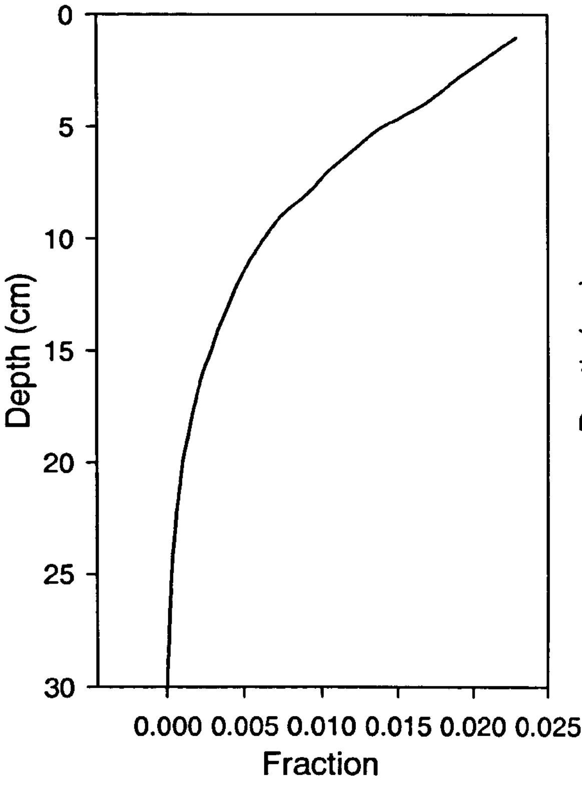


Fig. 6.20 Mean Annual Fraction of Soil Moved, Tofts

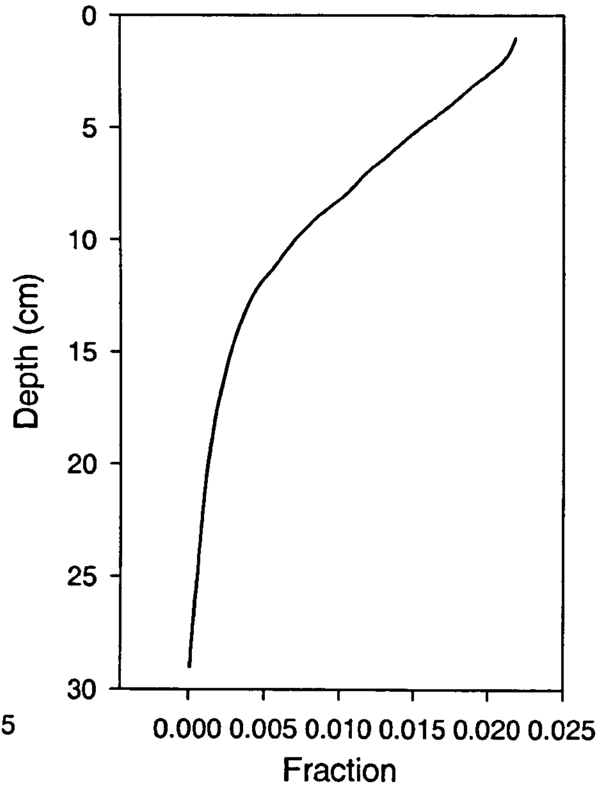


Fig. 6.21 Mean Annual Fraction of Soil Moved, Westbrough

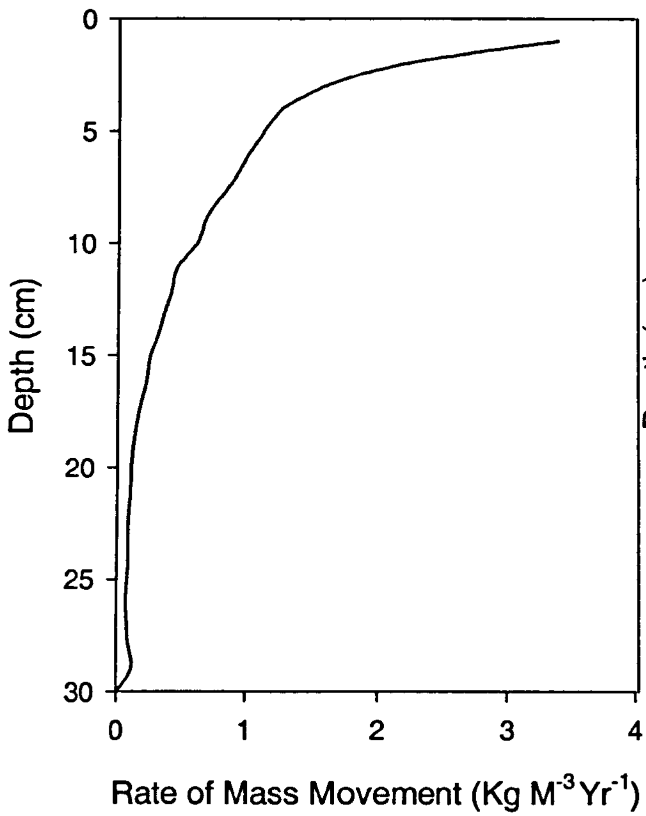


Fig. 6.22 Mean Net Rate of Soil Movement with Depth, Beafield

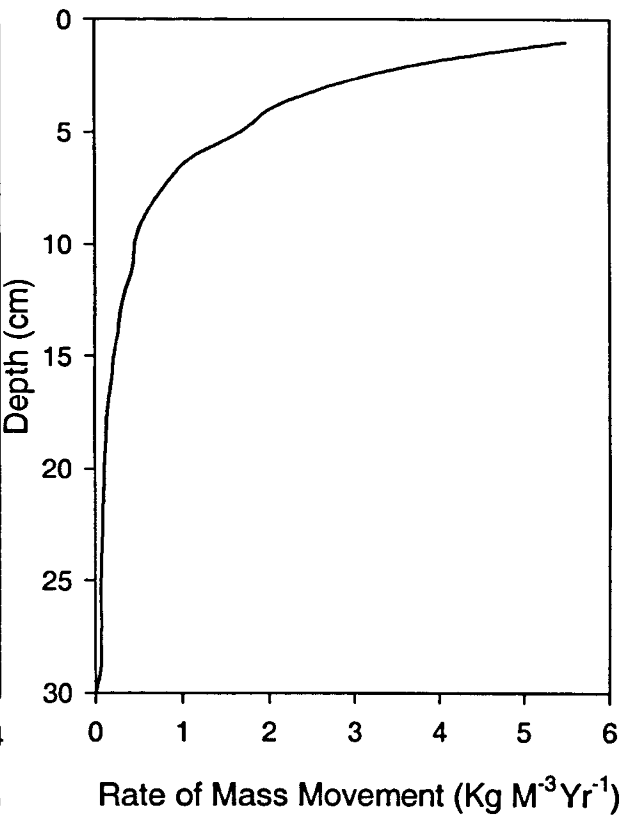


Fig. 6.23 Mean Net Rate of Soil Movement with Depth, Tofts

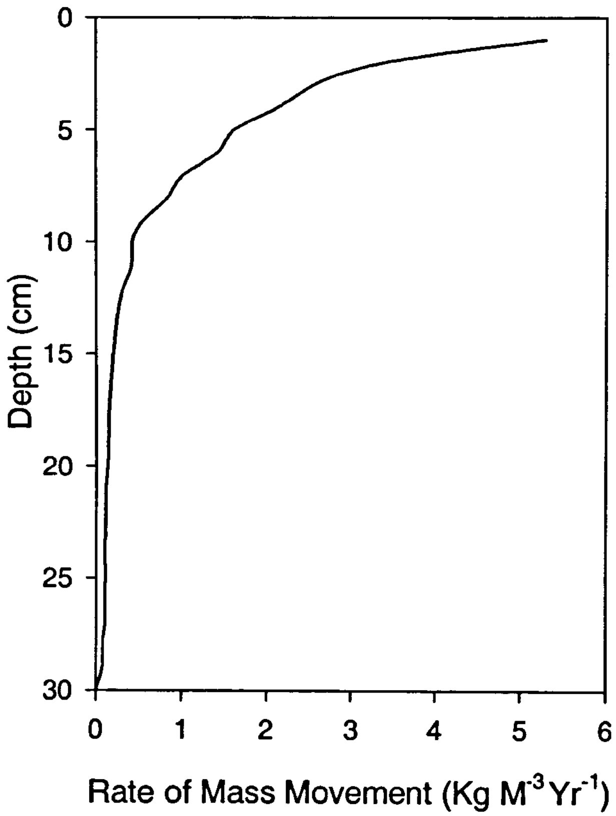


Fig. 6.24 Mean Net Rate of Soil Movement with Depth, Westbrough

Fig 6.25 Variation in Time Required For Complete Soil Mixing With Depth, Beafield

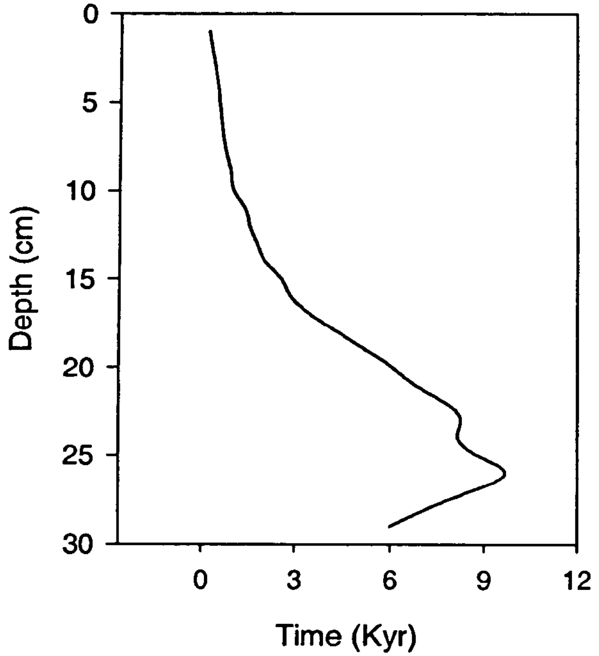


Fig 6.26 Variation in Time Required For Complete Soil Mixing With Depth, Tofts

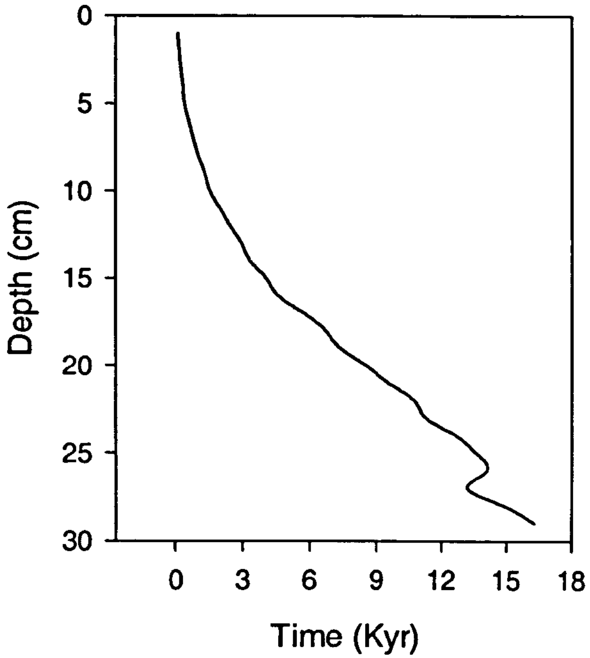
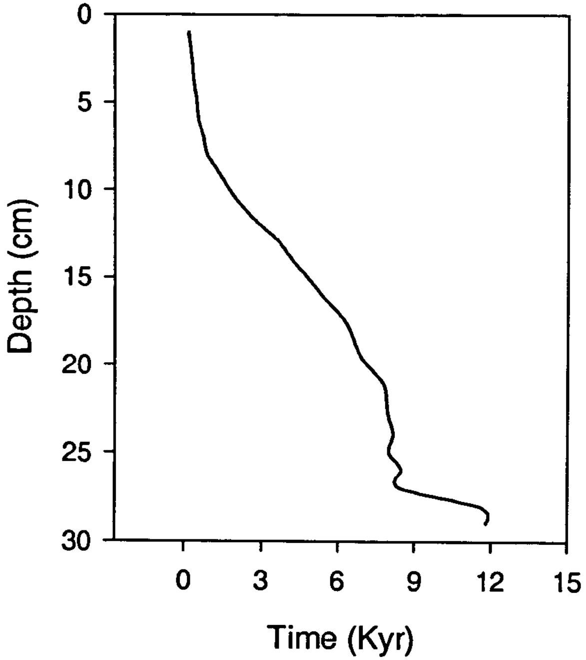


Fig. 6.27 Variation in Time Required For Complete Soil Mixing With Depth, Westbrough



will be discussed in chapter nine. There are, however, still differences between the effects of faunalturbation on the larger and smaller particle size fractions in the soil. Although the measured ^{137}Cs profiles do not have pronounced peaks in them, the highest measurements can be seen, and they all occur at a considerably shallower level than the stone lines. This is probably due to the fact that the fine fractions to which the caesium is adsorbed are ingested by soil fauna, in particular endogeic earthworms, and may be excreted at any depth to which the organism may move. By contrast, the only direction that the larger fraction can move under the influence of invertebrate faunalturbation is down. It seems therefore that the caesium bearing material is reworked quite intensively, but in a bounded area, with a marked reduction in reworking with depth within that area. As such the ^{137}Cs profiles have not yet been completely homogenised over the approximately thirty-five years since deposition.

Below the level of the stone line and the base of the current 'A' horizons the amount of ^{137}Cs falls off markedly. But there is still a detectable amount, and more than in the initial fixation curve. This suggests that there is some fine material being transported down the profile. At the low levels of activity recorded, this may be due to the effects of the deep burrowing anecic earthworms. The fine material may have been transported to depth or by being incorporated into the linings of the burrows that this group produces (Edwards & Bohlen 1996: 114). The implications of this interpretation are discussed in chapter nine. However, given the low levels of ^{137}Cs activity it is also possible that displacement through the profile has been due to material being washed through soil pores (including burrows created by the soil fauna) (Muller-Lemans and van Dorp 1996).

It has already been noted that the ^{137}Cs profiles have not been homogenised over the period since deposition, despite the suggestion that this should occur within 5-20 years (Muller-Lemans and van Dorp 1996). Using the two ^{137}Cs distributions from each site it is possible to calculate the fraction of soil that has moved within each 1cm slice of the profile (see 5.2.5). This the mean net annual fraction of soil is presented in figs. 6.19-6.21. It is noticeable that the annual fraction of soil moved reduces rapidly with depth. Most of the variation in the fraction of soil moved occurs above the stone line, with the fraction of soil moved below the stone line consistently low, generally equivalent to between 5-10% in each 1cm level over the 35 years since ^{137}Cs deposition. The upper-most samples are those in which the highest fraction of the soil has moved, and even in these the proportion that has moved is equivalent to 75-85% over 35 years.

From the fraction of soil moved it possible to calculate the mass of soil moved (see 5.2.5). The mean net rate of soil mass movement by depth is presented for the three archaeological sites in figures 6.22-6.24. From this the net rate of soil movement for the site as a whole may be calculated, as presented in table 6.5.

Table 6.5 Mean Net Rate of Soil Movement

Site	Beafield	Tofts	Westbrough
Rate (kg $m^{-3}yr^{-1}$)	17.1	22.3	22.3

From figs. 6.22 to 6.24 and the above table it can be determined that between 80-95% of the net rate of soil movement occurs above the stone line and 85-100% of the net rate of soil movement occurs above the base of the 'A' horizon. This again ties in with the concept that the upper parts of the site profiles form a particularly biologically active region, that the stone lines and the bases of the current 'A' horizons constitute the boundary of such a region. In considering both the fraction of soil moved and the rate of soil movement, it should be noted that these are net figures, effectively the minimum amount of movement to give the currently observed distribution of ^{137}Cs. Given the precise mechanisms of faunalturbation (see chapter two), in particular the casting patterns of the anecic and endogeic earthworms (2.3 and 2.4 respectively), with the probability of horizontal movement and the movement of material up and down the profile, it must be assumed the actual rate and mass of soil movement must be somewhat greater than the cited net figures. In particular, the apparent complete stop of ^{137}Cs movement toward the bases of the radiocaesium profiles need not indicate that there is no faunalturbation occurring at these depths. The apparent cessation is because ^{137}Cs cannot be reliably detected at the concentrations in which it may be present, and thus there may be no faunalturbation, or simply little faunalturbation.

The figures of mass movement given above may be compared with those calculated by Stein (1983). These vary between 4.4 and 43.4 Kg $M^{-3}Yr^{-1}$. Stein suggests on the basis of her estimate that a mounded archaeological site could be completely reworked in as little as 51 years, although this is acknowledged to be a minimum time period (Stein 1983). The mass movement rates are 2-2.5 times greater than those calculated for the

Orcadian sites. A further comparison could be made with surface casting rates calaculated for a variety of sites n Britain (collated in Edwards & Bohlen 1996: 200). The mean annual rates of soil movement are similar to the lower range of these calculations. Given that the surface casting species are primarily anecic earthworms, which predominantly move vertically through the soil, and that the ^{137}Cs distributions are essentially based on vertical movement, such an apparent agreement is unsurprising.

Stein's estimates are based on data, itself associated with significant uncertainties (Satchell 1958), derived from non-archaeological situations. Further, for the purposes of calculating the rate of movement, the assumption was made that the invertebrate activity can be regarded as effectively as high throughout the archaeological profile as it is in the uppermost part of the profile (Stein 1983). The evidence for the distribution of the traces of faunalturbation throughout this chapter demonstrates that this is not the case, at least in regard to the sites sampled for this study. The change in mass movement rate will effect the time taken before a volume of soil or archaeological stratigraphy is completely mixed. Such time periods have been derived from the ^{137}Cs data, and are given in figs. 6.25-6.27. The time periods are long, and in the case of the uppermost region are probably too long. It seems improbable that it takes over 100 years for the uppermost 1cm to be completely mixed. Two points should be made here. The first is that these time estimates probably do not take sufficient account of horizontal movement, which is probably particularly significant in the upper part of the profile due to the effects of the endogeic earthworms (Edwards & Bohlen 1996: 202). The second point is that movement is shown to occur down to a considerable depth, but that the variation with depth in the relative length of time taken to completely rework the soil or sediment is very considerable.

The ^{137}Cs based rates are based on the actual movement of soil on the sites. While the ^{137}Cs based mass movement rates are net rates, and thus probably underestimate rates of movement, they are probably a more accurate reflection of the sorts of rates of movement due to faunalturbation, and also their relative variation with depth, certainly with regard to archaeological sites in Orkney.

6.4 The Evidence of Faunalturbation on the Archaeological Sites: Summary.

The three strands of evidence discussed above all demonstrate that a significant level of faunalturbation has occurred on all three of the sites. In some respects the pattern of the evidence presents common trends. The evidence suggests that faunalturbation is ongoing on all the sites, but that the majority of current activity is constrained to a relatively shallow layer, corresponding approximately to the current 'A' horizon of the sites. There are also substantial dissimilarities. The depths of the 'A' horizons and the stone lines vary considerably between sites. The micromorphological traces of faunalturbation show considerable variation in area coverage between the sites, particularly below the depth of the current 'A' horizon. These variations have implications for the faunalturbation models that will be discussed in chapter nine.

Chapter Seven

Results 2: Agents and Conditions of Faunalturbation

7.1 Introduction

Models based on a system composed of a number of components have been posited in chapter three. The active components in the faunalturbation system that are of concern to the study are the fauna and the soil properties, that is the agents and conditions of faunalturbation. The results of faunal surveys and investigations into the soil properties are presented in this chapter. This is followed by the analysis required to test the hypotheses presented in 3.10.1, in the following chapter.

7.2 Faunal populations.

7.2.1 Faunal populations: endogeic earthworms.

The main observation to be made with regard to the distribution of the endogeic earthworms is the fact that the majority, both on and off-site, are found in the upper half of the profile, usually with over 50% in the top 10cm. All the sites have endogeic earthworms present, although in the case of the farm mound at Beafield the count is very low. In general there are more endogeic earthworms in the controls than the archaeological material (see figs. 7.1 and 7.2 and Appendix 2).

Fig. 7.1 Distribution of Endogeic Earthworms by Depth, Archaeological Sites.

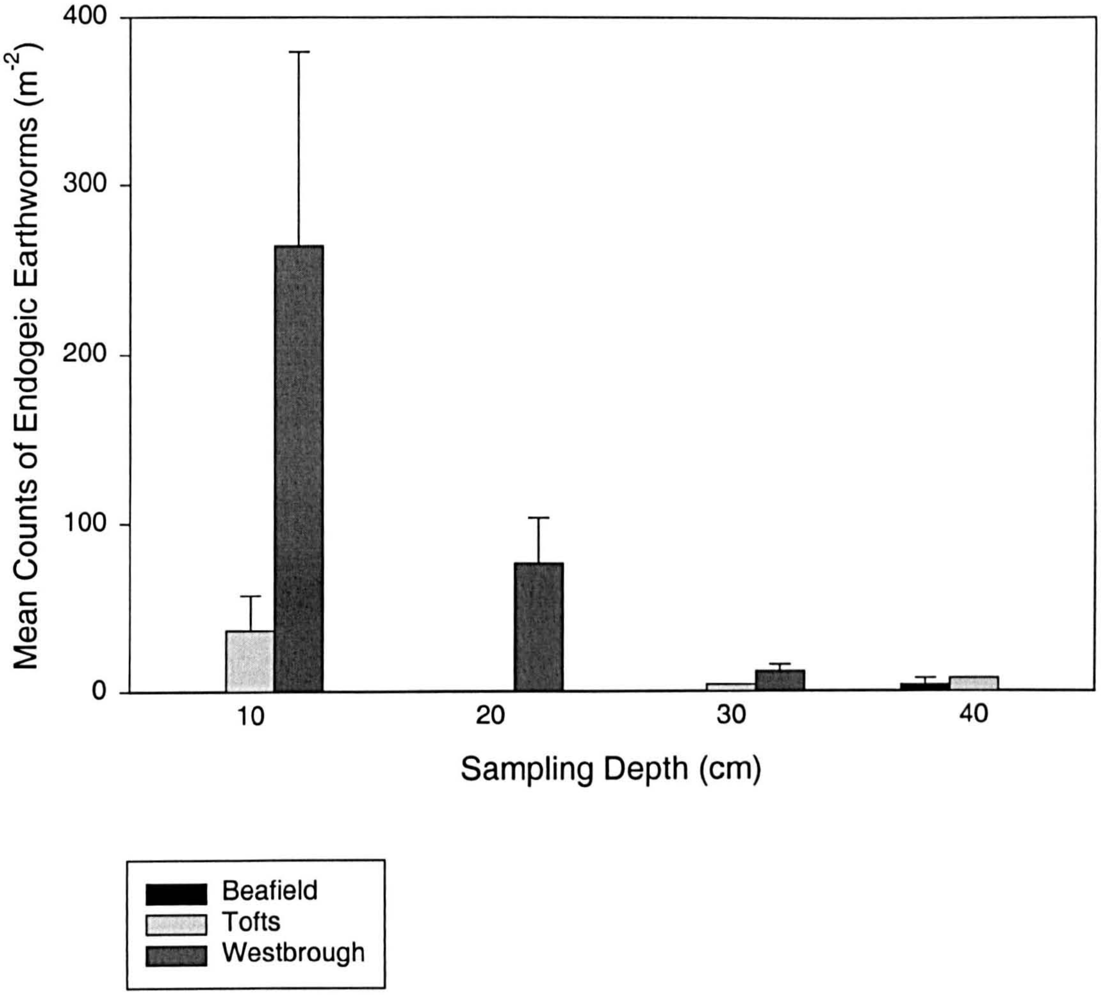
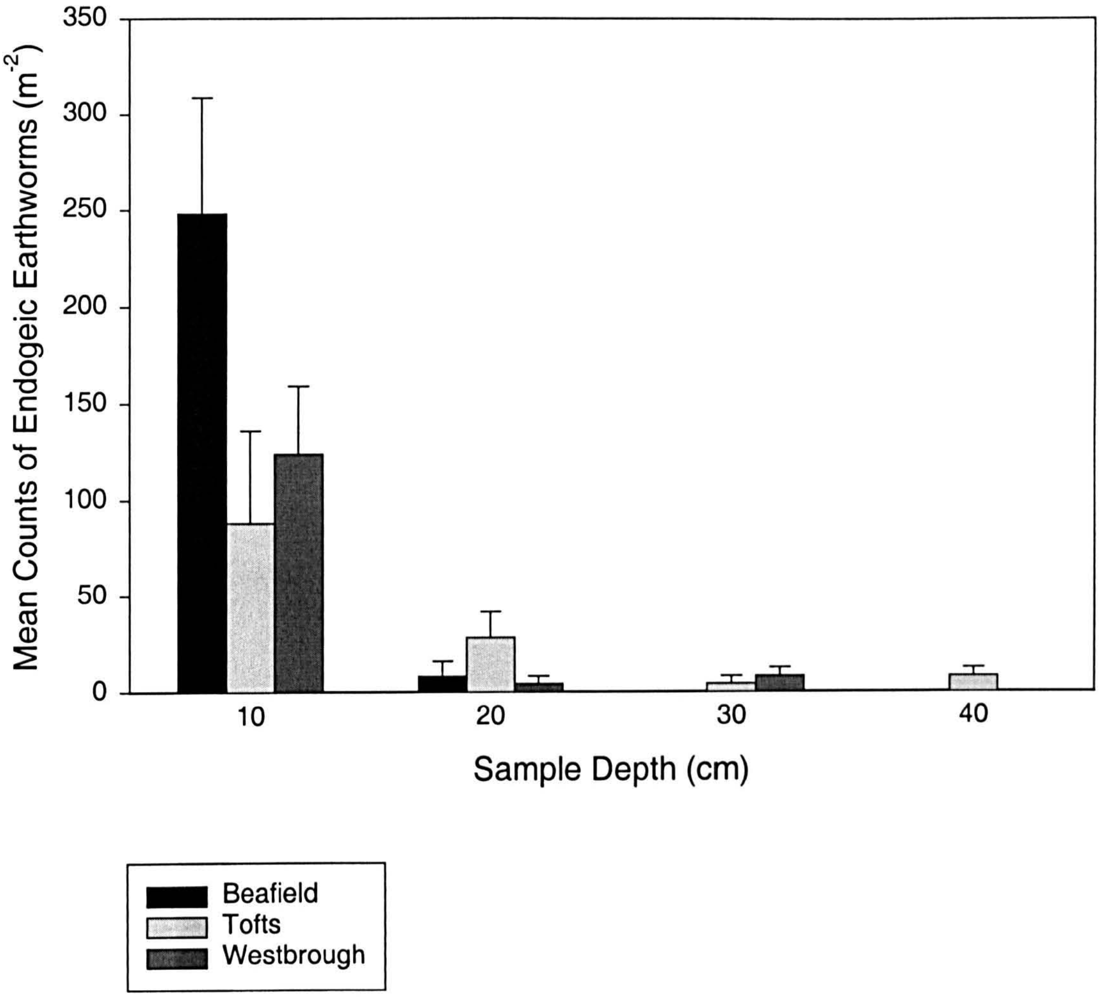


Fig. 7.2 Distribution of Endogeic Earthworms by Depth, Control Sites.



7.2.2 Faunal populations: anecic earthworms.

All the sites sampled yielded anecic earthworms (see fig. 7.3 and 7.4 and Appendix 2). As with the endogeic earthworms the trend was towards the majority of the anecic earthworms being in the upper half of the sampled profile. Although this distribution was not as pronounced among the anecic earthworms, generally at least 50% were in the top 10 cm. One substantial contrast that emerges between the archaeological and control site distributions is the tendency for there to be much higher numbers of anecic earthworms at the archaeological sites than the control sites, in the cases of Beafield and Westbrough amounting to a difference of almost an order of magnitude. This difference may be explicable in terms of the greater depth of the farm mounds and thus the greater availability of suitable habitat. The lower counts of endogeic earthworms on the farm mound sites may reflect the effects of competition.

Fig. 7.3 Distribution of Anecic Earthworms by Depth, Archaeological Sites

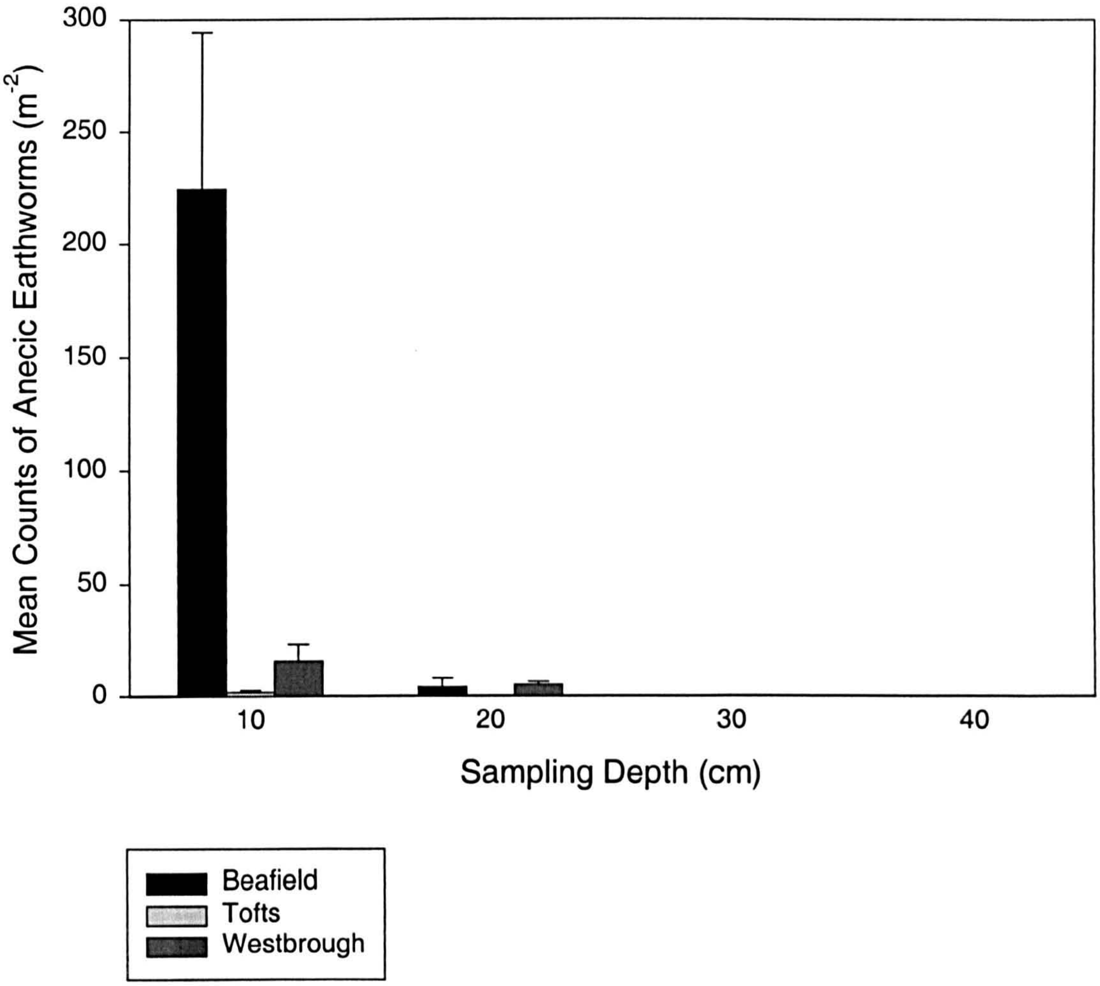
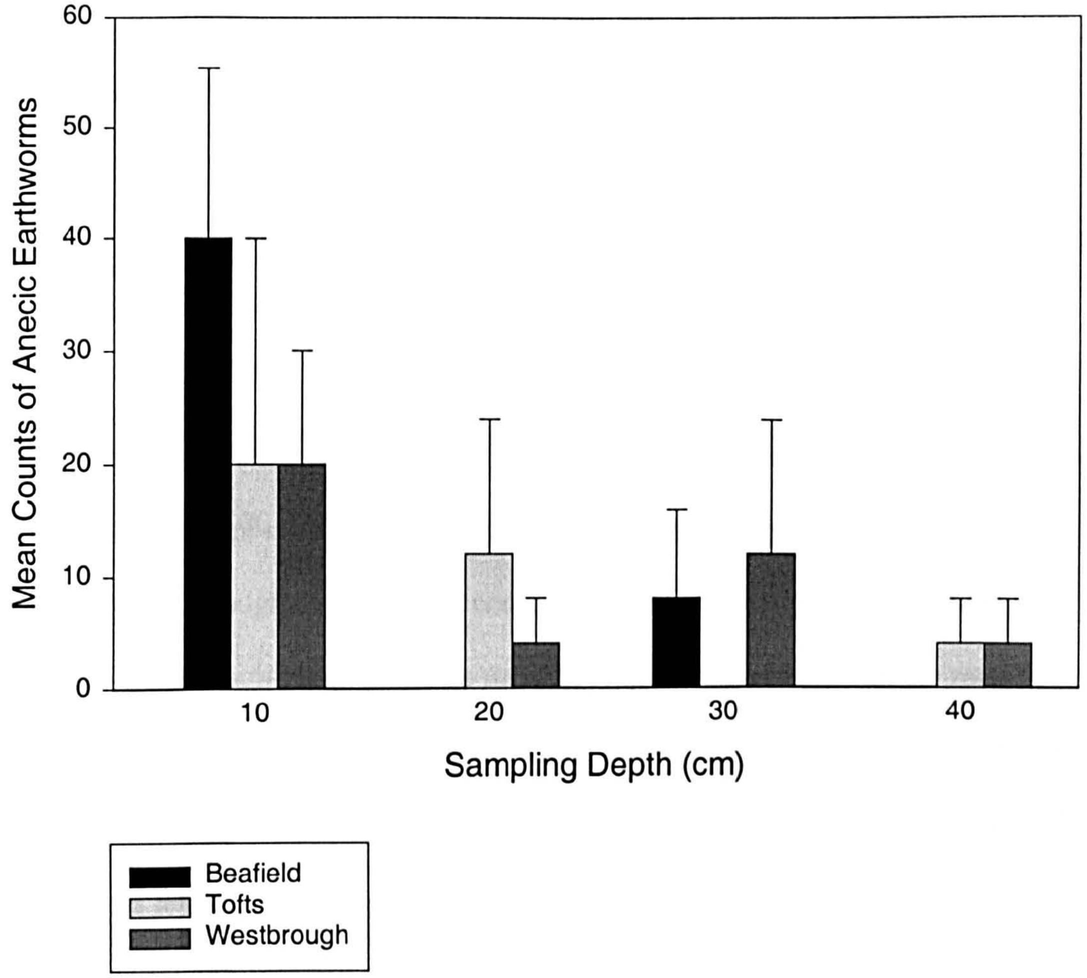


Fig. 7.4 Distribution of Anecic Earthworms by Depth, Control Sites



Two further issues need to be considered in relation to the survey of the earthworm population surveys. The first is the use of counts rather than biomass measures. Biomass measures are often used to supplement counts of individuals, as counts will not differentiate between very small and large individuals (Edwards and Bohlen 1996: 96). Given the nature of the faunalturbation mechanisms associated with both groups of earthworms (see 2.3 and 2.4) variation in size between individuals may equate with variations in rate or magnitude of soil redistribution (Edwards and Bohlen 1996: 96).

Biomass as a measure of earthworm population has certain problems. Measurement of live mass requires weighing soon after collection, which is a problem when large numbers of samples are taken in the field (Edwards and Bohlen 1996: 99). Further, live weight can vary considerably according to gut content, which may form as much as 20% of total live weight, and the state of hydration of the earthworm (Edwards and Bohlen 1996: 83, 100). Due to the logistical problems of live mass weighing during prolonged fieldwork, it was not possible to obtain reliable measures of biomass.

The second issue is the potential implications of species diversity. As has already been noted, the effects of species diversity on soil redistribution can in large part be accounted for through the use of the ecological groups (see 2.3 and 2.4). Species diversity within each group might be thought to have some impact on the rates of faunalturbation, and the possible impact of soil properties and ecological processes have been noted (see tables 2.1 and 2.2). In practice, the species diversity within the two groups tends to be low, with only three species of anecic earthworms being commonly found in Britain, with the samples from all the sites on Sanday being dominated by *L. terrestris.* In the case of the endogeic earthworms there are five species that occur commonly in Britain (see 2.3). In the case of the samples from Sanday, *A. calignosa* was the dominant species. Such a narrow range of diversity, especially the seemingly impauperate *Apporectodea* assemblage, is to be expected in small island settings such as Sanday (Begon *et al.* 1990: 873). There is unlikely to be a significant degree in variation in soil distribution attributable to intra-group species diversity given the low actual level of such diversity.

7.2.3 Faunal population: enchytraeid worms.

The pattern of distribution of the enchytraeid worms is quite complex (see fig. 7.5 and fig. 7.6 and Appendix 2). Generally the majority are distributed within the upper half of the sampled profile. In contrast to the other organisms so far discussed, every site has some enchytraeids in at least one of the lower two of the sampling depths.

Fig. 7.5 Distribution of Enchytraeidae by Depth, Archaeological Sites

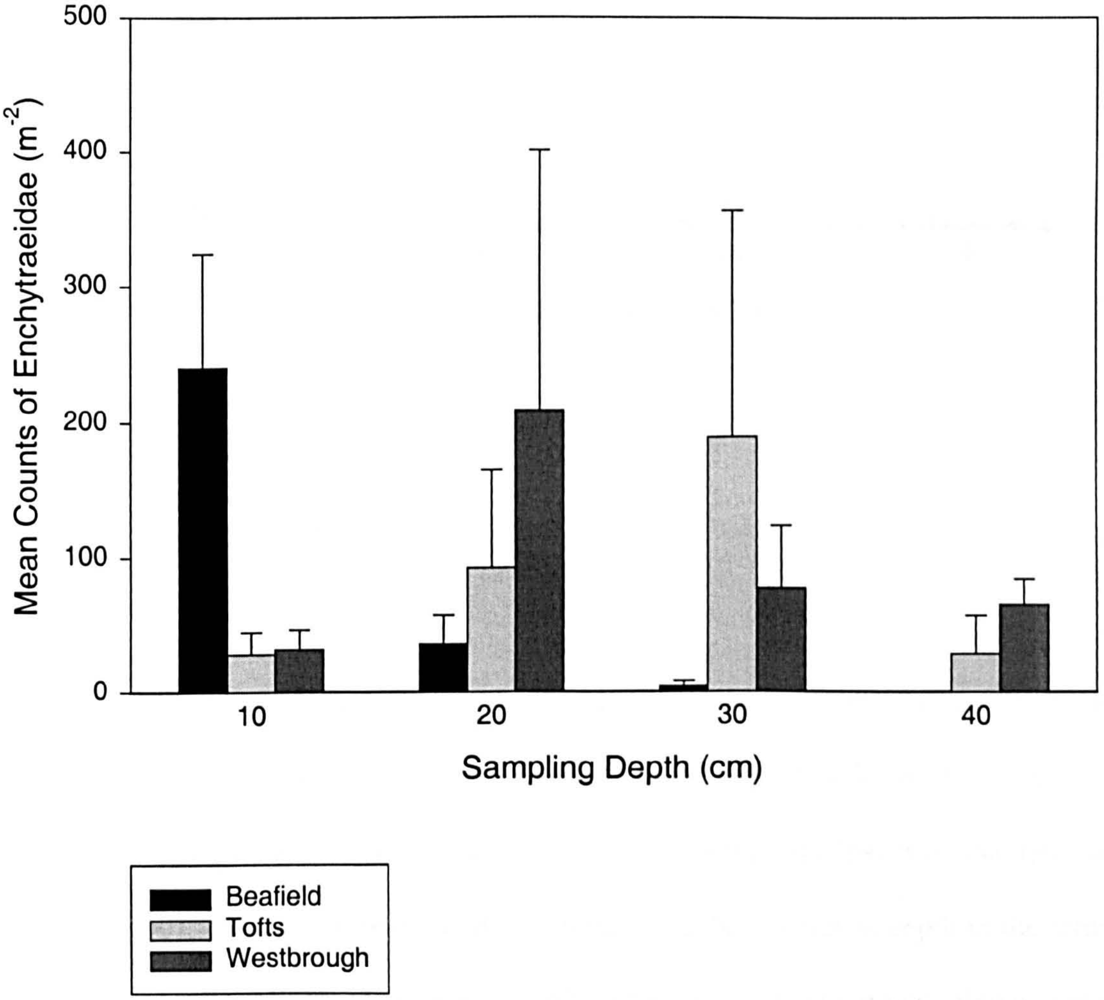
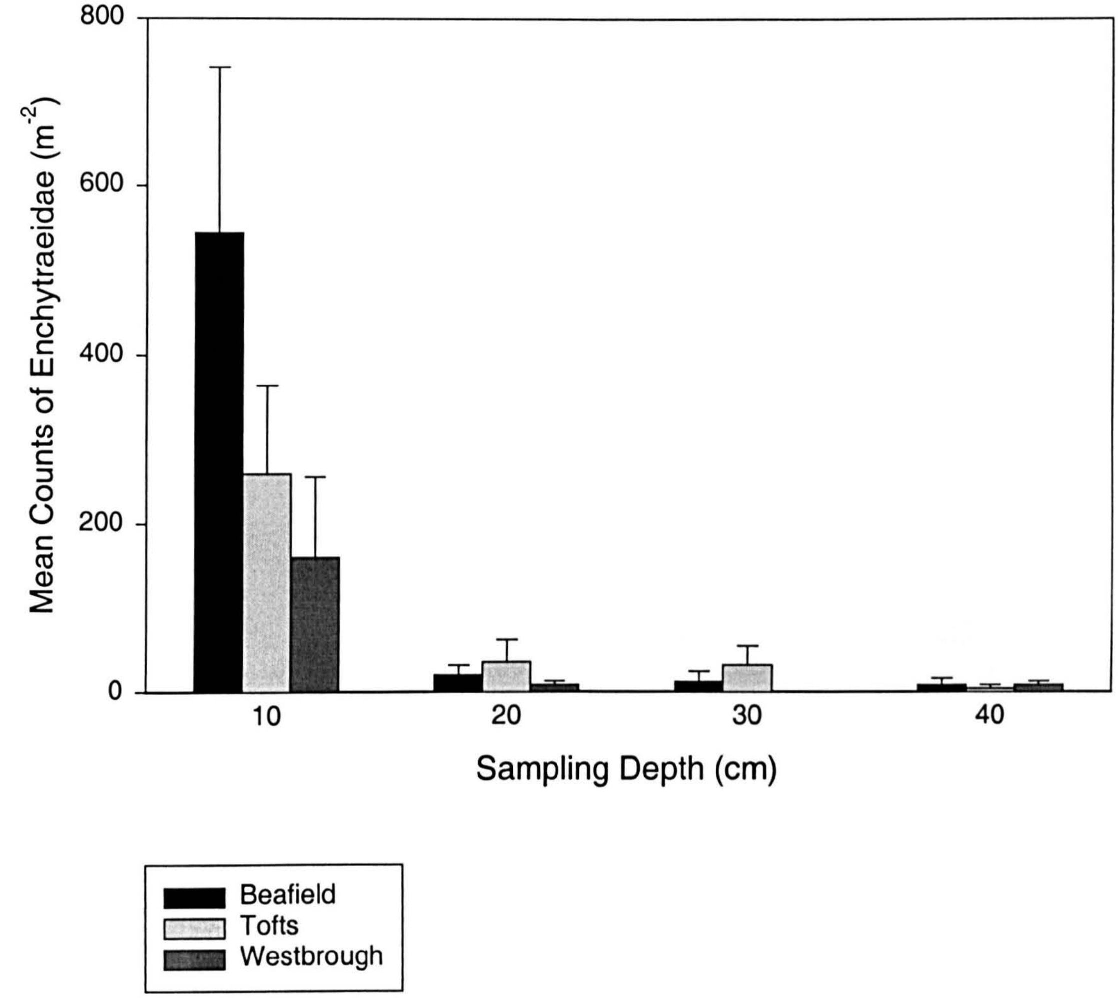
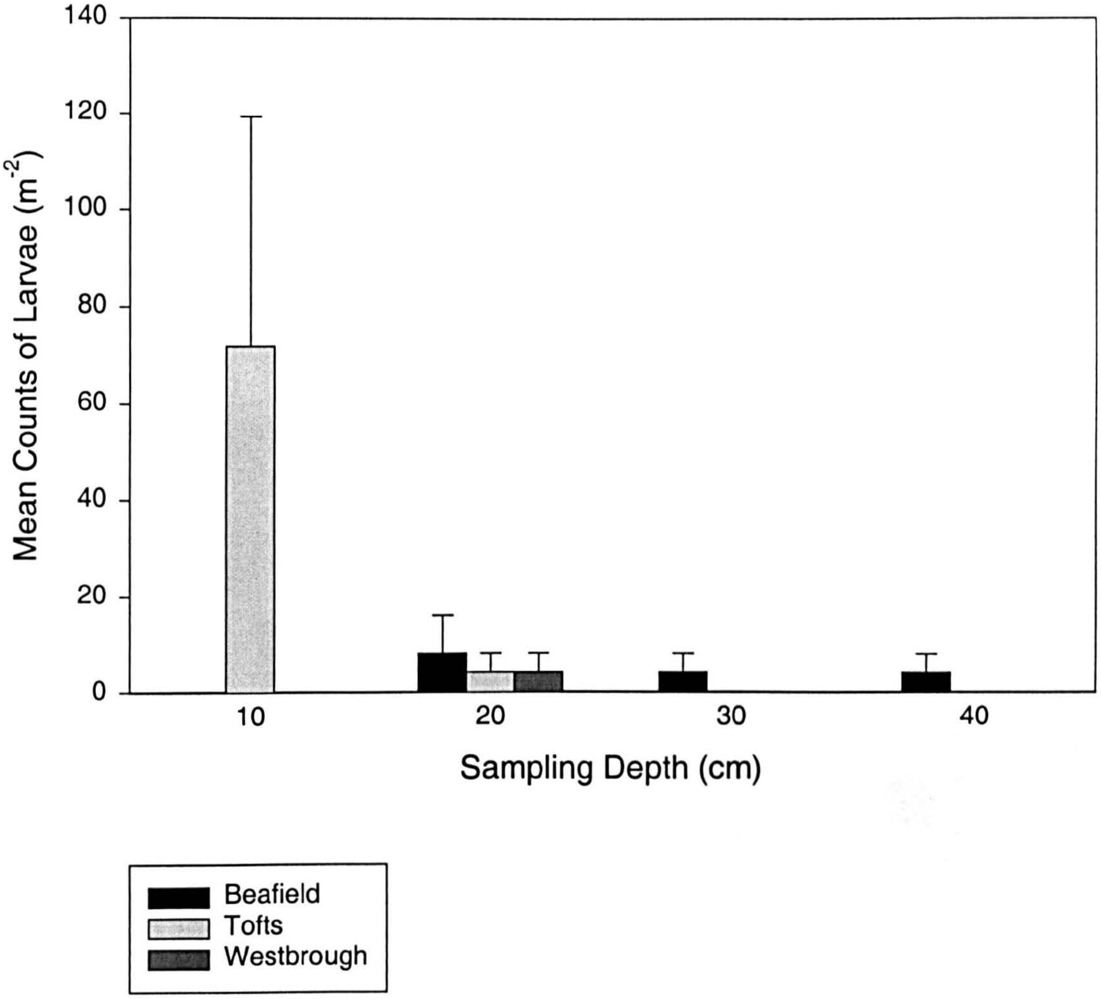


Fig. 7.6 Distribution of Enchytraeidae by Depth, Control Sites



The control sites tend to have more enchytraeids overall and in particular in the top 10 cm. However the onsite samples tend to produce larger counts in the deeper samples. A possible explanation of this may lie in the use of existing pore spaces by enchytraeids (Didden 1990). There may be in greater abundance of these pores at depth in the farm mounds due to the activity of the anecic earthworms, which are in greater abundance on the farm mound sites (see above, 7.2.2).

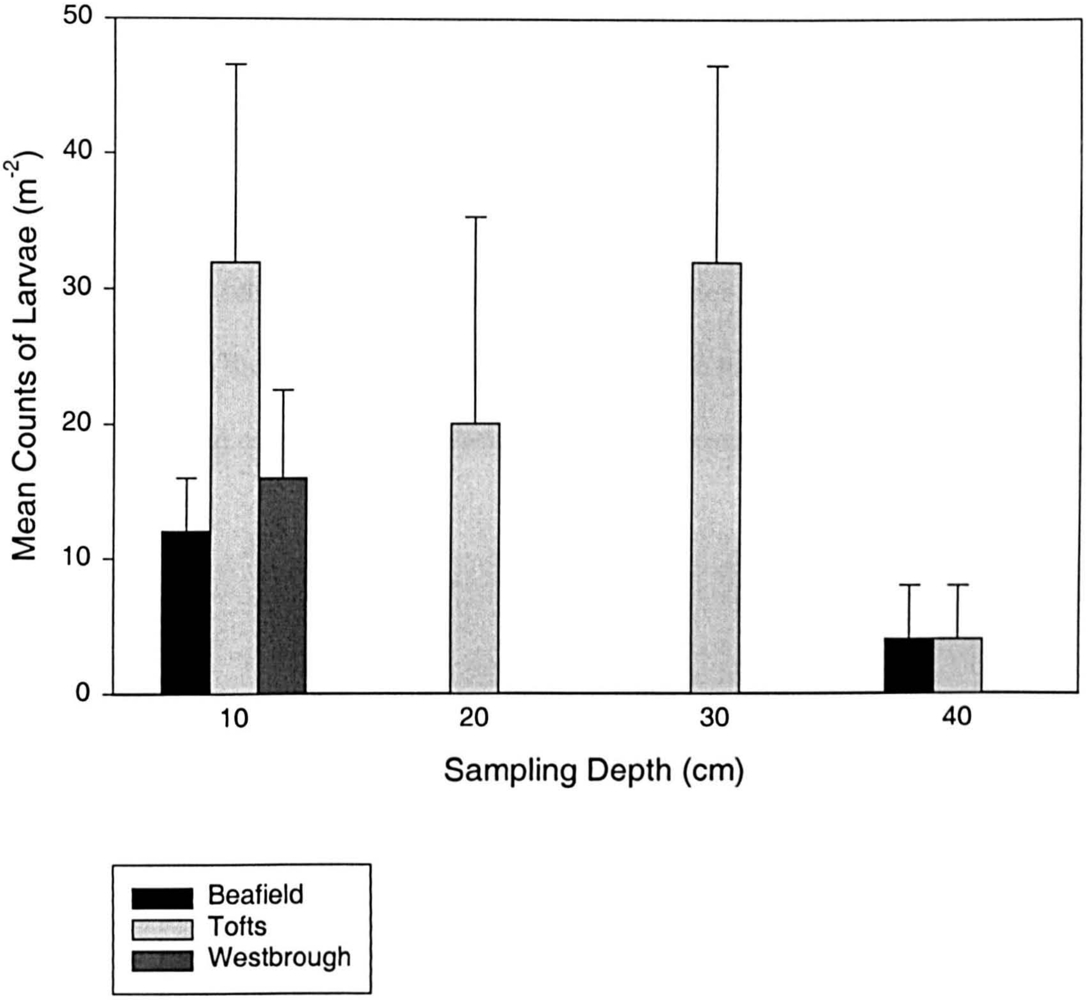
Fig. 7.7 Distribution of Coleoptera and Diptera Larvae by Depth, Archaeological Sites



7.2.4 Faunal populations: Diptera and Coleoptera.

The two remaining functional groups of fauna, dipteran and coleopteran larvae and adult coleoptera will be dealt with together in this section. With regard to the adult Coleoptera, a single example has been recovered from the Tofts control site. Such a small count would suggest that burrowing adult coleoptera are an insignificant group with regard to the faunalturbation of archaeological sites, and as such no further consideration of this group will be made.

Fig. 7.8 Distribution of Coleoptera and Diptera Larvae by Depth, Control Sites



The larval fauna is distinguished by the small mean size of the counts on most of the sites (see fig. 7.7 and 7.8 and Appendix 2). The fauna seem to be distributed towards the top of the soil profiles, but the small counts make it difficult to be fully confident of this. There also seems to be no great difference between archaeological and control samples in terms of numbers or patterns of distribution.

7.2.5 Faunal populations: summary and analysis.

Two sets of charts combining the mean faunal counts are presented below. In the first set of charts (fig. 7.9 and fig. 7.10) the mean combined counts of the anecic and endogeic earthworms and the larvae. This aggregate has been drawn together to see if there are any trends that seem to apply to all fauna. Enchytraeids are excluded from this aggregate as when they do occur, they tend to be in numbers of a different order of magnitude to the other fauna, thus perhaps giving greater significance to trends that are largely related to the enchytraeids. A second aggregate has been calculated which also includes the mean counts of enchytraeids, for the purposes of comparison (see fig 7.11 and 7.12).

Fig 7.9 Distribution of All Non-Enchytraeid Fauna by Depth, Archaeological Sites

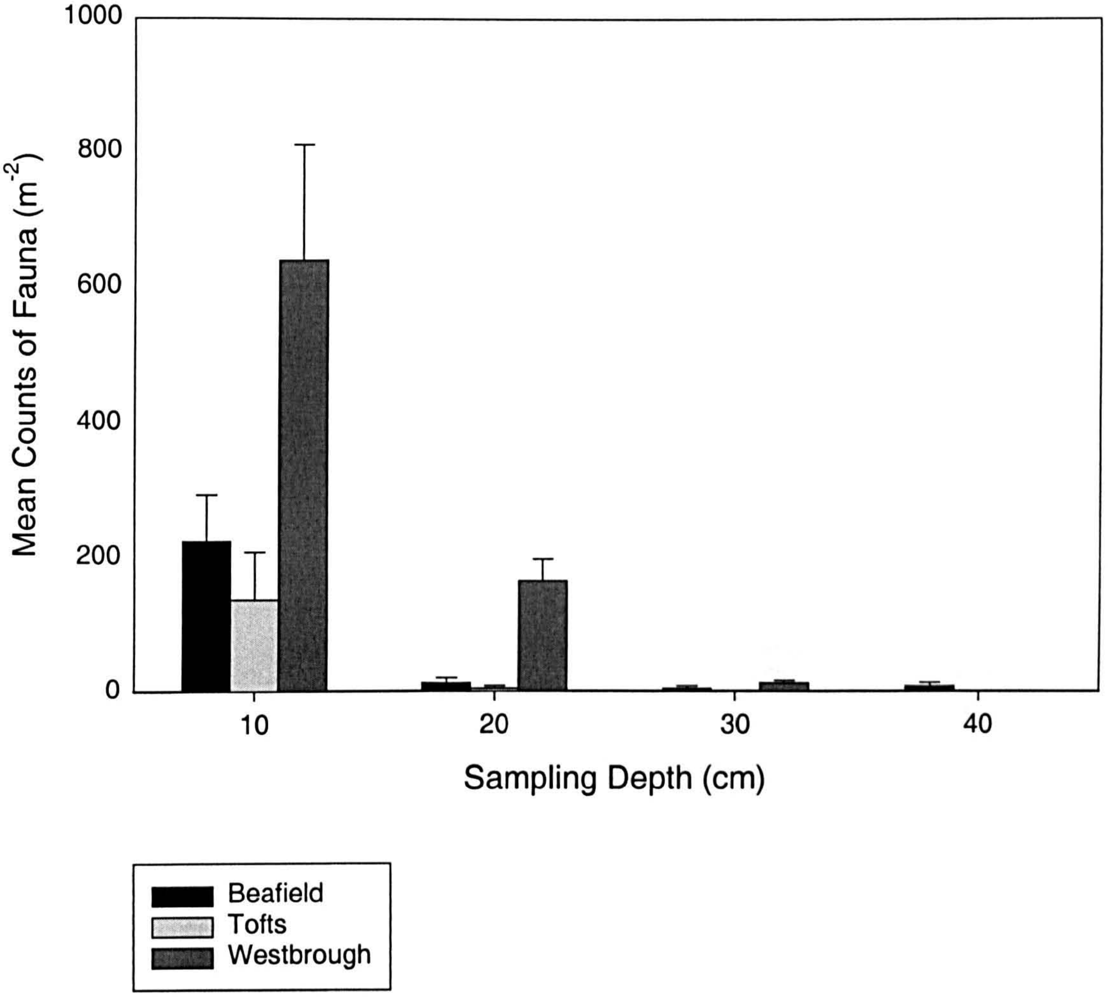
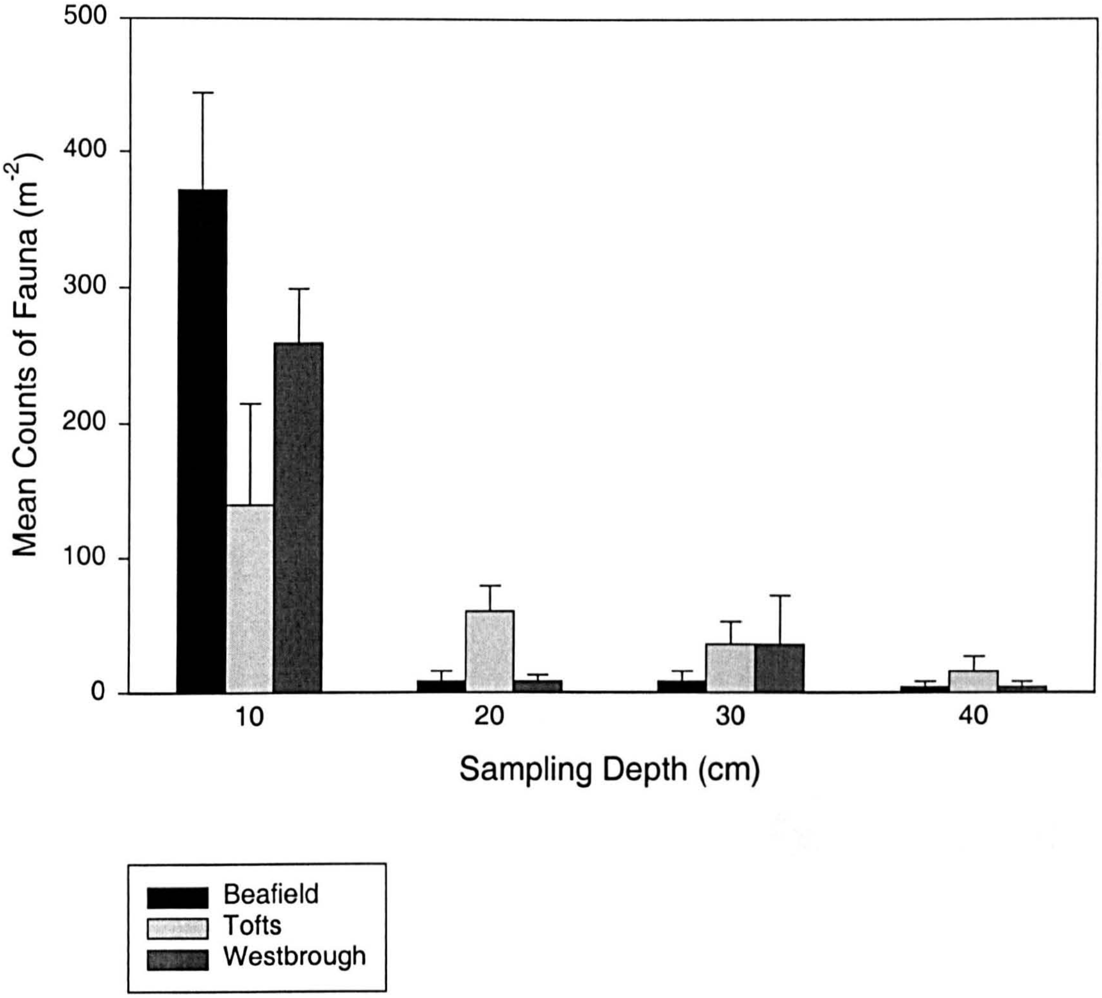
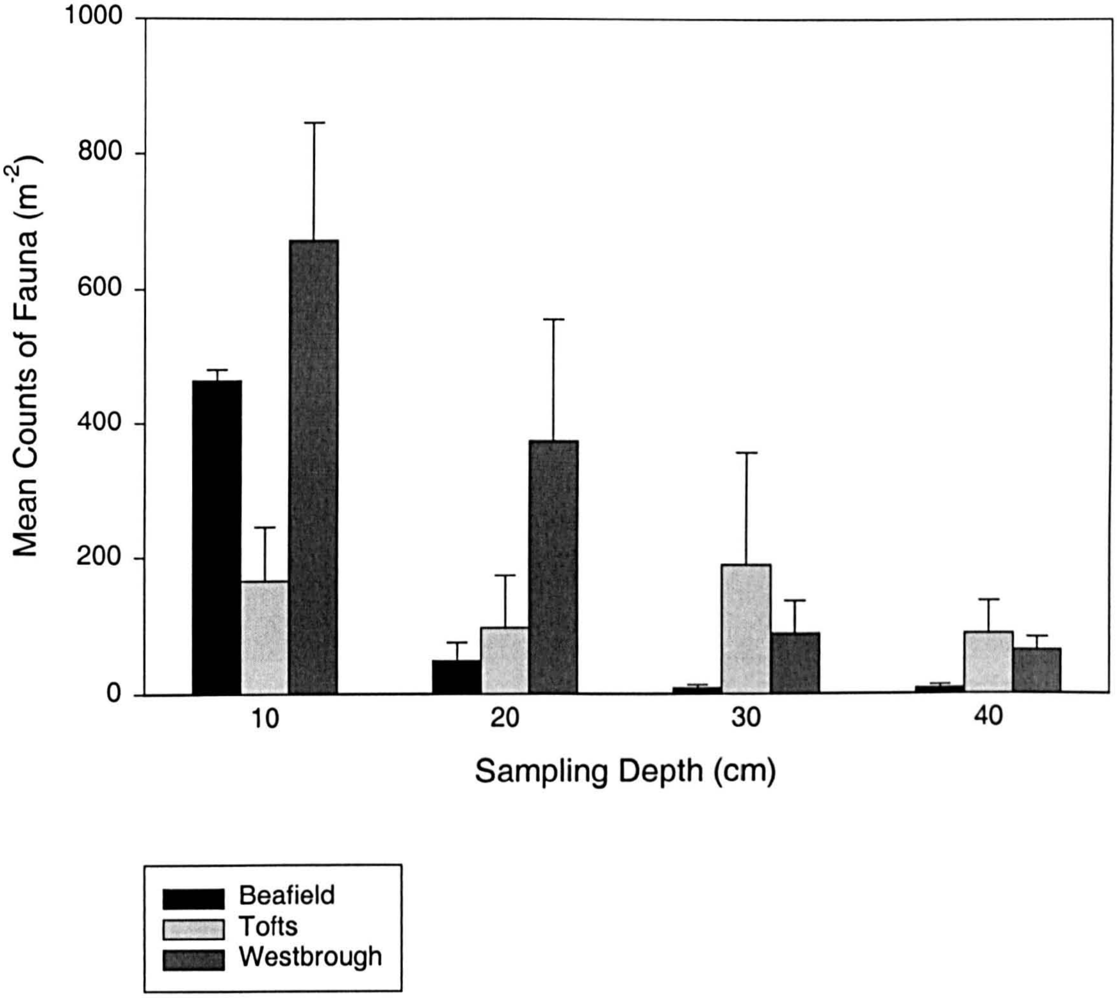


Fig. 7.10 Distribution of All Non-Enchytraeid Fauna by Depth, Control Sites



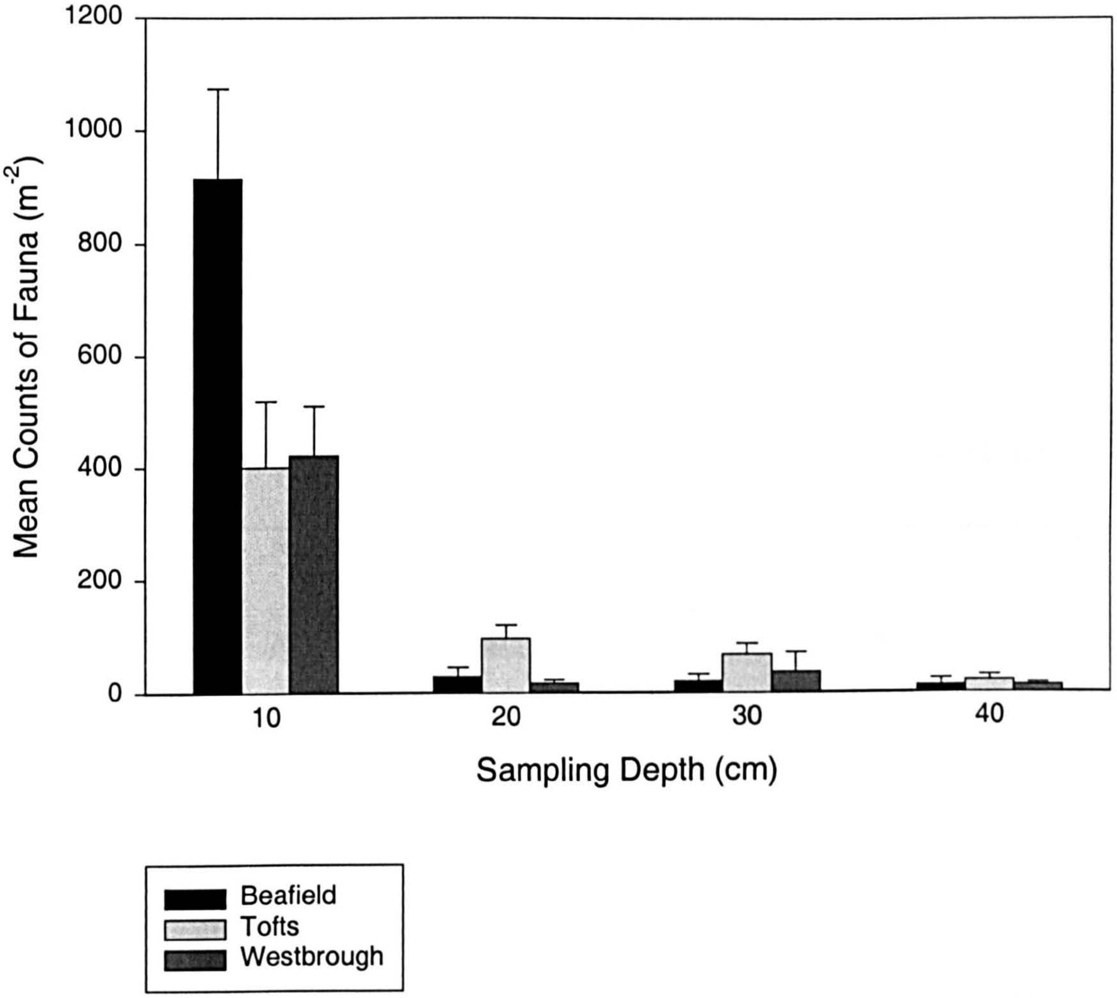
From examining the first of the aggregate charts it is apparent that the difference between the upper most part of the profile, particularly the top 10 cm, and the lower part of the sampled profile becomes even greater when the functional groups are aggregated: there is a strong tendency for the fauna to 'cluster' in the upper part of the profiles, particularly in the top 10 cm. While this effect is found at both the control and archaeological sites, it is more pronounced on the control sites, further suggesting that the greater depth of unconsolidated soil/sediment in the farm mound sites provides more habitat space, at least for functional groups which are able to utilise the deeper regions.

Fig. 7.11 Distribution of All Fauna by Depth, Archaeological Sites



Given this strong apparent relation between depth and faunal population it is necessary to consider the issue of whether depth itself constitutes a soil property, its relationship to the other properties and the role it plays in the faunalturbation system. This issue is discussed with the relevant statistical procedures (8.2.2), with the emergent implications for the survival of stratigraphy in deep sites such as the farm mounds discussed in chapter nine.

Fig. 7.12 Distribution of All Fauna by Depth, Control Sites



The issue of the difference or similarity between the faunal populations between the archaeological and control sites must now be addressed. As it is possible that there may be factors influencing the faunal populations that are unique to archaeological sites it is necessary to compare the populations of the different functional groups between the archaeological and control sites. To do this the sets of population counts for each of the functional groups have been combined into two sets of data, one for the archaeological sites and one for the control. Because this data is not normally distributed, the Wilcoxon-Mann-Whitney 'U' test has been selected as the most suitable (Pett 1997: 177). This is a test that allows the distributions to be compared and thus estimate whether the different data sets are likely to come from different populations or from one population. If there is a significant impact from some unknown factor on the archaeological site populations, these populations should be statistically distinguishable from the control site populations. The null hypothesis of the tests is that there is no significant difference in the distribution of the data, and thus the two samples can be regarded as coming from the same population.

Table 7.1 Outcomes of Mann-Whitney 'U' Tests on Archaeological and Control Populations.

Functional Group	N	Mean Rank		Z	P
		Archaeological Sites	Control Sites		
Endogeic Earthworms	96	45.05	51.95	-1.408	.159
Anecic Earthworms	96	50.93	46.07	-1.040	.298
Enchytraeids	96	50.73	46.27	-.815	.415
Coleopteran and Dipteran Larvae	96	44.54	52.46	-1.837	.066
Non-Enchytraeid Fauna	96	48.02	48.98	-.178	.859
Total Fauna	96	49.42	47.58	-.326	.744

Z= standardised test statistic P= significance level

As can be seen from the results of this analysis, the null hypothesis holds in all cases with $\alpha = .05$, i.e. the 95% confidence level. Thus the populations of the archaeological and control sites cannot be regarded as significantly different.

7.3 Soil properties

7.3.1 Soil properties: pH.

The range of pH across the archaeological and paired control sites and by depth is summarised in table 7.2. Raw data is given in Appendix 2.

Table 7.2 Mean pH and standard error of the mean of soils at all sites (n=8)

Depth (cm)	Beafield	Beafield Control	Westbrough	Westbrough Control	Tofts	Tofts Control
10	7.5± .16	7.3± .05	5.4± .07	4.4± .27	6.7± .27	6.9± .10
20	8.0± .10	7.3± .03	6.1± .14	4.4± .09	7.5± .17	7.5± .09
30	7.8± .20	7.7± .11	6.9± .04	4.9± .13	7.8± .10	7.7± .15
40	8.1± .11	7.6± .14	7.1± .09	4.8± .34	8.1± .21	7.5± .10

A number of patterns can be observed in the data. The first is that the paired onsite and off-site results are generally similar to each another. The results from Beafield and Tofts, both onsite and control, are similar, while the values from Westbrough are considerably more acidic. This contrast reflects the fact that Beafield and Tofts lie on shell sands (see fig. 4.1). The control site pH determinations are typical of the different soil series to which they belong (Futty & Dry 1977: 127). As has been discussed above (see 3.4.1) some of the materials of which farm mounds are composed include cut turves, burnt or unburnt, with ash material being predominant. The similarity between onsite and off-site pH would suggest that such materials are likely to be derived from somewhere in the vicinity of the farm mound. However, the higher pH of the samples from Westbrough in comparison with the Westbrough control site could be taken as evidence that some of the material has been transported from a greater distance i.e. from the more base-rich shell sand areas which are over a kilometre away from the site. This interpretation will be considered further in the context of the particle size distribution results below (see 7.3.3).

Perhaps the most significant pattern is the generally lower pH of the uppermost sample relative to the other samples in each profile. The greater acidity of the upper part of a soil profile, particularly mineral soils in the temperate zone, is often due to the greater proportion of organic matter incorporated in that level of the soil and its subsequent decomposition (Brady 1984: 268). Leaching may also have an effect (White 1997: 135). It is also noticeable that the difference between the mean pH in the top 10cm and the mean pH of the lower samples tends to be greater in the samples from the archaeological sites than the control site samples. The significance of this pattern with regard the distribution of the fauna is discussed below (see 8.2.3).

7.3.2 Soil properties: loss on ignition.

The most notable pattern in the mean percentage mass loss on ignition is the generally much higher values for the top 10 or 20 cm of each profile. The implications of this pattern for the distribution of the soil fauna are discussed below (see 8.2.3).

Table 7.3 Mean mass loss on ignition of soils and standard error on the mean as a percentage at all sites (n=8).

Depth (cm)	Beafield	Beafield, Control	Westbrough	Westbrough Control	Tofts	Tofts Control
10	13.5± .4	27.2± .3	17.7± .6	21.8± 1.0	21.8± .5	13.9± .6
20	13.9± 2.9	16.8± .2	7.5± .9	13.9± .6	15.2± .9	13.4± 1.1
30	5.8± .6	9.1± .6	6.6± .2	11.4± .9	9.8± .6	6.3± .6
40	9.1± 3.	9.7± .3	6.2± .3	15.6± 2.2	7.4± .8	6.7± .4

The raw data is presented in Appendix 2). It is noticeable that there is some variation between the loss on ignition figures of the archaeological and control samples, but that this is not consistent. The main source of variation in organic matter input is variation in current land use (Davies *et al.* 1993). As such the variations between the archaeological and control site pairs of results probably reflects these differences. For example, while at Beafield and Westbrough livestock do graze to some degree on the mounds, the animals are more often in the fields just around them, i.e. the areas in which the control samples would have been taken. As such the higher loss on ignition figures for the off-site profiles in these instances is likely to be due to greater organic input in the form of manure.

7.3.3 Soil Properties: particle size distribution.

In terms of patterns within the sites the most apparent is the broad tendency for the relative clay content of the soil to increase with depth. This is a phenomenon associated with normal illuviation processes typical of the types of soils sampled (White 1997: 173). The raw data is presented in Appendix 2.

Table 7.4 Mean particle size distribution and standard error of the estimate as a percentage, Beafield sites (n=8)

Depth	Beafield			Beafield Control		
(cm)	Clay	Silt	Sand	Clay	Silt	Sand
10	4.4± 1.7	37.5± 9.1	54.4± 11.3	2.2± .3	19.9± 4.1	76.1± 4.0
20	4.5± 1.2	44.7± 4.2	48.1± 4.7	1.8± .3	15.9± 2.6	81.8± 2.8
30	7.8± 1.5	55.0± 5.5	34.4± 6.3	2.6± .3	19.6± 1.0	77.6± 1.4
40	7.0± .9	55.4± 2.8	29.8± 2.2	6.0± 1.6	42.3± 9.9	52.7± 11.5

Table 7.5 Mean particle size distribution and standard error of the estimate as a percentage, Westbrough sites (n=8)

Depth	Westbrough			Westbrough Control		
(cm)	Clay	Silt	Sand	Clay	Silt	Sand
10	3.2± .4	44.6± 1.8	51.0± 2.2	11.3± 1.2	64.9± 3.1	23.6± 4.4
20	6.9± 2.0	55.6± 2.9	34.2± 5.1	8.9± .5	53.7± 1.4	28.2± 1.1
30	5.4± .1	52.3± 1.7	40.7± 1.8	12.3± .6	62.0± 1.2	25.1± 1.4
40	5.3± .3	48.1± 4.0	34.9± 4.2	13.4± .7	62.9± .7	23.1± .8

Comparing the results from the archaeological sites and control sites may throw further light on the issue of the source of the materials of which the farm mounds are constructed, as discussed above with regard to pH determinations. The range of sand contents across the archaeological sites is less than the range across the control sites. It is possible to infer from this that the soil derived materials that have accumulated during the formation of the sites were a mixture of soils that originally had a variety of particle size distributions that have become 'averaged' through the processes of bioturbation.

Table 7.6 Mean particle size distribution and standard error of the estimate as a percentage, Tofts sites (n=8)

Depth	Tofts			Tofts Control		
(cm)	Clay	Silt	Sand	Clay	Silt	Sand
10	2.5± .4	23.7± 1.6	73.5± 2.1	5.2± 1.8	32.2± 6.2	60.4± 8.7
20	4.1± .5	25.2± 2.2	70.6± 2.4	3.8± .5	31.5± 4.2	63.2± 5.5
30	8.3± 1.8	37.6± 4.7	41.8± 8.3	7.0± 2.2	32.3± 6.3	54.5± 10.1
40	6.7± 2.1	38.8± 5.1	50.6± 6.6	5.6± 2.0	29.4± 2.5	58.3± 11.8

Looking in more detail at the different pairs of archaeological sites and controls this interpretation can be examined in greater detail. At Tofts there is little difference between the onsite and off-site particle size distributions. It is noteworthy that Tofts is fairly centrally located within an area of shell sand deposition. By contrast Beafield is at the edge of such an area of shell sand, and the particle size distribution of the site has a lower sand content than the off-site control. Here materials from the shell sand soils, predominantly of the Fraserburgh series, may have been mixed with less sandy materials, such as the nearby soils of the Bilbster series (Futty & Dry 1977: 166). In contrast, the particle size distribution from the farm mound at Westbrough has a higher proportion of sand than that of the control site, which would be classified as belonging to the Bilbster series. Sandier materials would be available most closely in the form of an area of skeletal Fraserburgh soil to the west of the site (Davidson *et al.* 1986). It would thus appear that the farm mounds are composed of materials derived from across the area in which they are sited and as such may contain soils and sediments of a variety of types.

7.3.4 Soil Properties: bulk density.

Table 7.7 Mean bulk density of soils at all sites (g cm^{-3}) (n=8)

Depth (cm)	Beafield	Beafield, Control	Westbrough	Westbrough Control	Tofts	Tofts, Control
10	.66± .03	.47± .03	.76± .03	.55± .02	.72± .01	1.03± .04
20	.69± .04	.72± .04	.93± .02	.85± .05	.88± .02	1.07± .05
30	.69± .01	.90± .04	.85± .04	.84± .05	.94± .05	1.09± .03
40	.67± .02	.83± .03	.89± .02	.68± .02	.90± .04	1.11± .03

The raw data is presented in Appendix 2. The mean bulk densities of the different sites follow a standard pattern of generally increasing with depth, as the mass of soil above compresses the lower parts of the soil profile (Brady and Weil 1999: 49). The sites, as a whole, tend to have the low bulk densities associated with loamy grassland soils (Brady and Weil 1999: 390). These relatively low values have implications for the usefulness of bulk density as a factor in explaining faunalturbation as will be discussed in the following chapter (8.2.1).

7.3.5 Soil Properties: moisture.

The main trend to note with regard to the percentage moisture content of the soils and sediments is that the archaeological samples generally have a lower moisture content than the associated control sites. The raw data is presented in Appendix 2. The differences are explicable in terms of the difference in relief between the archaeological and control sites.

Table 7.8 Mean percentage moisture content of soils by mass at all sites (n=8).

Depth (cm)	Beafield	Beafield, Control	Westbrough	Westbrough Control	Tofts	Tofts, Control
10	33.3± 0.6	49.4± 3.6	41.2± 1.3	52.2± 4.5	21.4± 12.2	27.5± 2.9
20	33.1± 0.3	39.8± 4.6	29.8± 1.7	37.1± 2.5	22.2± 1.9	26.8± 0.9
30	33.1± 0.3	28.8± 3.7	31.2± 0.3	38.5± .3	17.6± 4.1	21.4± 2.8
40	31.0± 0.4	31.3± 6.3	30.2± 0.9	46.2± 1.6	19.2± 5.7	21.8± 3.5

Chapter Eight

Explaining Faunalturbation on Archaeological Sites

8.1 Introduction

The models and the hypotheses drawn from them (chapter three) have required the collection of a variety of sets of data to test them, which have been presented in the two preceding chapters. In this chapter those hypotheses relating to the systemic relationships in the faunalturbation system will be tested through the application of statistical analysis to the data presented in the preceding chapters.

8.2 Relationships Between Soil Properties and Fauna

8.2.1Relationships between soil properties and fauna: introduction.

As part of the faunalturbation system causal relationships are posited between the soil properties and the population sizes of the different functional groups and thus the structure of the community of soil fauna, and the impact that they are likely to have on archaeological stratigraphy (see fig. 3.1). In order to test whether such relationships exist, it was decided that analysis by multiple linear regression should be used. To generate a regression with the greatest likely resolving power the original soil properties were examined to ensure that it was useful to incorporate them. This was done by calculating Kendall's tau coefficient, a nonparametric test of association (see tables 8.1 and 8.2 below). The test was selected to take account of the sample sizes and the deviations from normality in some of the data. From this it was found that the loss on ignition and pH determinations were most often significantly correlated with the different faunal groups. Particle size distribution was found to be less consistently correlated with the different groups, although it was still deemed to be sufficiently frequently correlated to be included in the initial multiple linear regressions. As has been discussed above, low bulk density values were the norm across all sampling areas. Research has indicated that it requires high levels of compaction, reflected in high bulk density, to cause measurable effects on biological activity (Joschko *et al.* 1989, Langmaack *et al.* 1999). While there is a statistically significant bivariate correlation between bulk density and numbers of endogeic earthworms (τ=.380, n=32), at the level of bulk density found on the sites (see 7.3.4) it is more likely that this reflects the effect of the fauna on the soil, in effect the reverse of the relationship originally posited. As such bulk density has not been included as a term in any of the multiple linear regressions that are subsequently presented.

Multiple linear regression was selected as the means of analysing the relationships between a given faunal population and the soil properties discussed above. Multiple linear regression is a parametric technique. The technique allows the effects of independent variables on a dependent variable to be estimated, while taking account of possible interactions between the independent variables (Lindeman *et al.* 1980: 193, Polit 1996: 287). Although there are some deviations from the normal distribution in some of the data sets, it was decided to proceed with this technique on two grounds. The first of these was that multiple linear regression is relatively robust with regard to deviations from the normal distribution. The second is a variation of the first: the assumption of normality on which the test is based is one of multivariate normality. As such combinations of variables may be normal in multidimensional terms even if there are deviations from univariable normality (Polit 1996: 284). The conformity of the variables to the assumptions of the tests was assessed by checking plots of standardized predicted values versus standardized residual values.

Two initial regressions were performed. One was undertaken using data from two of the archaeological sites, Beafield and Westbrough. The second was undertaken using data from the control sites associated with Beafield and Westbrough. Data from Tofts and the associated control site were reserved for testing any apparently significant model that emerged. Examination of the residual plots from these initial regressions revealed that both regressions in fact significantly violated assumptions of linearity and homoscedasity and to a lesser degree that of normal distribution. Use of dummy data sets revealed that these violations were largely due to the presence of a large number of zero values for the different faunal populations. These zero values effectively skewed the distributions. Where data has a skewed distribution it is normal to use a mathematical transformation, in this case a logarithm or square root (Pett 1997: 53). However, these transformations do not work where the skewing is due to a high number of zero values. As such alternatives to the original approach had to be sought.

Two approaches were selected. The first was to return to the results of the series of separate bivariate correlations that had already been calculated. This approach would allow the relationships between individual independent and dependent variable to be tested. Such an approach would not be able to take account interactions between the independent variables, but would allow all the data collected to be used thus including the full range of population counts, which would test the effects of the soil properties on both the abundance and distribution of the different faunal populations. The second approach would be to restate the hypothesis under consideration, to allow multiple linear regressions to be calculated, and to combine this with a chi-squared approach to allow issues relating to presence/absence of fauna to be addressed.

8.2.2 Relationships between soil properties and fauna: the bivariate correlations.

The results of the correlations given below are all for Kendall's Tau Coefficient. This test was selected for reasons stated above (8.2.1), being the most appropriate test for most of the correlations and used for all the tests to maintain consistency and thus comparability. The correlations were performed using the statistical package SPSS (versions 9 and 10).

Table 8.1 Summary of Calculations of Kendall's Tau Coefficient Between Functional Groups and Soil Properties for samples derived from archaeological sites.

Functional Group	Soil Property		
	Loss on Ignition	pH (aq.)	% of total sand
Anecic Earthworms	.415**	-.402**	.290*
Endogeic Earthworms	.146	-.663	.109
Enchytraeids	.244*	-.474**	.315**
Larvae	-.105	.099	-.013
Non-Enchy. Fauna	.427**	-.419**	.331**
Total Fauna	.359**	-.577**	.289*

In the table above n=32. The '*' indicates a correlation at the .05 confidence level, '**' a correlation at the .01 confidence level.

It was decided to use total sand content as a means of quantifying particle size distribution for a number of reasons. The first was the necessity of an interval data set, rather than the categorical classification that is derived from the percentages of the three main mineral fractions. Of the three fractions, clay sized particles form a small proportion of the overall percentage, with a limited range. Percentage sand content gave the greatest range. As the figures were percentages, and the clay fraction is insignificant, variations in sand content would largely be mirrored in variations in silt content.

An additional observation with regard to the test for a correlation between numbers of endogeic earthworms and percentage loss on ignition is that although the there is no correlation at 95% significance, the calculated Tau coefficient is .146, the Tau coefficient to be exceeded to achieve 95% significance is .147, meaning that there is a correlation equivalent to greater than the 90% level.

Table 8.2 Summary of Kendall's Tau Coefficient Between Functional Groups and Soil Properties for samples derived from control sites.

Functional Group	Soil Property		
	Loss on Ignition	pH (aq.)	% of total sand
Anecic Earthworms	.423**	-.120	.005
Endogeic Earthworms	.533**	-.155	.062
Enchytraeids	.681**	-.007	.115
Larvae	.513**	-.123	.123
Non-Enchy. Fauna	.438**	-.115	.048
Total Fauna	.444**	-.083	.079

In the table above n=32. The '*' indicates a correlation at the .05 confidence level, '**' a correlation at the .01 confidence level.

Comparison of the two sets of correlations reveals an apparent difference between the role of the soil properties on the archaeological sites and on the control sites. Loss on ignition would seem to be broadly significant on both types of site, and will be discussed in greater detail below. The positive correlation of sand content with the numbers of anecic earthworms and enchytraeids at the archaeological sites contrasts with the lack of such correlations at the control sites. It should be noted that the control sites present a bimodal distribution of sand content, with the modes representing the two control sites. From this it may be inferred that while the total sand content has some influence on the populations of some of the functional group populations, this influence is less important than other variations in properties between sites. This is reflected in the relatively low coefficients calculated.

The pH determinations show a contrast between the complete set of negative correlations between the populations counts of all the functional groups and pH on archaeological sites and the complete lack of correlations between the population counts and pH on the control sites. This contrast is probably a product of the particular distribution of pH measurements and the non-linear relationship between pH and population counts. Most work on the relationship between populations of soil organisms and pH in temperate Europe has concentrated on the pH range from 7 downwards (Edwards & Bohlen 1996: 298, Didden 1993). The result of this work has suggested that when pH falls below 6-6.5 populations of organisms tends to fall as acidity increases. The small amount of work on soil organisms in higher pH soils tends to indicate that if pH should be higher than 7.5-8, populations are likely be smaller with increasing pH. The modes of the distribution of pH determinations for the control sites fall above and below the probable optimum ranges for the majority of soil organisms, rather than from optimum to sub-optimum conditions, as with the archaeological samples. This has resulted in little contrast between the faunal counts at different pH levels, so that the statistical test has not found any correlation.

Unlike the other soil properties, organic content, as quantified as percentage loss on ignition, is significantly correlated with at least some of the functional group populations on both the archaeological and control sites. The magnitude of the various Tau coefficients associated with the loss on ignition figures could be taken as indicating that organic content is the single most important soil property in terms of determining the populations of soil organisms. Given the significance of soil organic matter as a direct or indirect food source, and the role it plays in moisture retention in the soil, which will be important given the low clay content of the soils, it is to be expected that percentage loss on ignition should correlate with numbers of organisms (see chapter three).

As has been noted above (see 7.2.5), depth seems to play a significant role in the population levels of the fauna. While depth is not an intrinsic property of a soil or sediment, being rather a spatial dimension, the role of depth in the faunalturbation system requires examination. Kendall's tau coefficients were calculated between depth and functional group populations (see table 8.3). The correlations confirm the findings from the graphs, with there being a strong inverse relationship between depth and faunal population.

Table 8.3 Summary of Kendall's Tau Coefficients Between Functional Groups and Depth, Archaeological and Control Sites

Functional Group	Archaeological Sites	Control Sites
Anecic Earthworms	-.649**	-.336**
Endogeic Earthworms	-.353**	-.583**
Enchytraeids	-.367**	-.520**
Larvae	-.198	-.333**
Non-Enchy. Fauna	-.635**	-.524**
Total Fauna	-.562**	-.577**

In the table above n=32. The '*' indicates a correlation at the .05 confidence level, '**' a correlation at the .01 confidence level.

As depth is not an intrinsic property of soil or sediment, the effect being seen must be due to the depth distributed variability of soil properties that do affect the soil fauna. Bivariate correlations of depth with soil properties confirm that such variations do occur (see table 8.4).

Table 8.4 Summary of Kendall's Tau Coefficients Between Soil Properties and Depth, Archaeological and Control Sites

Soil Property	Archaeological Sites	Control Sites
pH	.400**	.286*
Loss on Ignition	-.559**	-.557**
Percentage Sand	-.407**	-.160

In the table above n=32. The '*' indicates a correlation at the .05 confidence level, '**' a correlation at the .01 confidence level.

This would tend to suggest that depth per se is not significant, but that depth related distribution of soil/sediment properties are significant. Another matter, which may be considered here, is that there may be other soil properties that have not been measured that affect the faunal populations. Comparing the amount of variation that the tau coefficients for depth and fauna account for with that accounted for by the Tau values of the soil properties and fauna shows that similar levels of variation are accounted for.

This suggests that no such unmeasured properties that have significant depth distributed variability exist.

Although the Tau coefficients most of the functional groups are highest with loss on ignition, and are in some cases highly statistically significant, i.e. the 0.01 significance level, the Tau coefficients are not particularly high in absolute terms. Given the complexly interacting nature of the soil environment this is unexceptionable. The models advanced in chapter two posit a range of ecological processes that would have a role in determining the size and distribution of soil fauna populations. Given that the other soil properties have also produced at least some significant correlations, no single Tau coefficient is likely to give a very high degree of correlation. The coefficients calculated for the different soil properties may also include effects that effectively 'overlap', that is some of the correlation between pH and anecic earthworms may be shared with the correlation between the loss on ignition and anecic earthworm numbers. This is because the soil properties are not independent of each other – to follow the above example through the organic content of a soil is a factor in the pH of that soil. This interaction between variables can be controlled for statistically using multiple linear regression, as will be discussed in the succeeding section.

8.2.3 Relationships between soil properties and fauna: multiple linear regressions.

As has been stated above, the initial multiple linear regressions calculated were found to violate the basic assumptions of the procedure, and as such had to be discarded. To circumvent these problems it was decided to restate the hypothesis under consideration to allow the effective sub-sampling of the data to produce sets of data more amenable to a multiple linear regression approach. The restatement of the hypothesis was that the soil properties affect the abundance of each functional group if they are actually present. This allowed a multiple linear regression to be performed for each functional group on archaeological sites and on control sites. This restatement has meant that the hypothesis was partially tested using multiple linear regression. Other techniques were employed to complement and thus more fully test the hypothesis (discussed in 8.2.3).

Table 8.5 Stepwise Multiple Regressions for Abundance of Functional Group Populations on Soil Properties on Archaeological Sites (Beafield and Westbrough)

Dependent Variable	N	Predictors Selected	Predictor Coefficient	Adjusted R^2	Predictor Sigs.	Overall Sig.
Anecic Worms	13	–	–	–	–	–
Endogeic Worms	12	Loss on Ignition	.655	.372	.021	.021
Enchytraeids	23	pH	-.467	.181	.025	.025
Larvae	4	–	–	–	–	–
Non-Enchytraeid Fauna	21	pH	-.633	.369	.002	.002
Non-Enchytraeid Fauna	21	pH & Loss on Ignition	-.549 .419	.521	.003 .016	.001
Total Fauna	28	pH	-.705	.477	.000	.000
Total Fauna	28	pH & Loss on Ignition	-.584 .441	.650	.000 .001	.000

The cases used for each of the regressions were selected from the overall data set on the basis of the presence of a least one member of the functional group under consideration. The regressions are all stepwise regressions, that is the independent (predictor) variables are entered one at a time, until adding an additional predictor will make no significant impact on the final outcome of the regression. There are other limits to the number of variables that can be input into a multiple linear regression. To prevent 'over-explanation' the number of cases must be at least five times the number of predictor variable (Polit 1996: 284). Because of the smaller sizes of the data sets used in these regressions, a selection of two independent variables to be entered into the regression had to be made. On the basis of the outcome of the previous bivariate correlations it was decided to use the percentage loss on ignition and pH as the independent variables. The essential statistics from the two sets of regressions are given in tables 8.5 and 8.6.

In tables 8.5 and 8.6 'N' is the number of cases in the sample, 'predictor selected' refers the independent variable(s) selected by the stepwise regression, 'predictor coefficient' refers to the Pearson correlation coefficient between each selected predictor and the dependent variable. 'Adjusted R^{2}' is the overall amount of variation in the dependent variable that the regression accounts for, adjusted for the sample size. 'Predictor significances' refers to the statistical likelihood that the bivariate correlations between independent and dependent variables has occurred by chance. 'Overall significance' refers to the likelihood that the null hypothesis of the whole regression is correct, that is that the correlations have occurred by chance. Where a single predictor variable has been selected the predictor significance will be the same as the overall significance. The first observation is that the data sets for the anecic earthworms and larvae functional groups were rejected for running regressions by the statistical package used, SPSS, on grounds of insufficient sample size in respect to variability of fauna counts. The degree of variation in the different population sizes for which the regressions account is variable. The lowest level is for the enchytraeids on archaeological sites is .181, that is slightly greater than 18% of variation.

Table 8.6 Stepwise Multiple Regressions for Abundance of Functional Group Populations on Soil Properties on Control Sites (Beafield and Westbrough)

Dependent Variable	N	Predictor Selected	Predictor Coefficient	Adjusted R^2	Predictor Sigs.	Overall Sig.
Anecic Worms	11	–	–	–	–	–
Endogeic Worms	12	Loss on Ignition	.726	.479	.008	.008
Enchytraeids	15	Loss on Ignition	.703	.455	.003	.003
Larvae	7	–	–	–	–	–
Non-Enchytraeid Fauna	15	Loss on Ignition	.761	.546	.001	.001
Total Fauna	20	Loss on Ignition	.835	.680	.000	.000

The highest level is .680, i.e. 68%, for total fauna on the control sites. The bulk of the R^2 calculations fall between .350 and .550. Thus while the general level of explanation of variation in the different populations by the regressions is useful, it is by no means exhaustive. Given that adjusted R^2 takes sample size into account, the higher level of explanation of the aggregate categories, that is non-enchytraeid fauna and total fauna, is perhaps unsurprising. However sample size is not the only consideration in determining the overall level of explanation produced by the regressions. The R^2 calculations associated with the archaeological samples are generally lower than those of the control samples. This may be due to a slightly varying degree of importance between the soil properties and ecological processes between the archaeological and control sites. One specific cause of the lower R^2 determinations on the archaeological samples may be the effect of the larger anecic populations associated with these samples. The larger anecic populations would have a greater competitive impact on the other groups. Although there are no multiple linear regressions on the anecic populations in either the archaeological or control samples which might assist in examining this proposition, the aggregate R^2 calculations allow inferences to be made. The aggregate population counts contain the counts of anecic earthworms. The bivariate regressions discussed above (8.2.3) demonstrate that the anecic populations are influenced by soil properties. While the multiple linear regressions calculated for the different functional groups must be influenced by the impact of ecological processes on the functional groups, the R^2 calculated on the aggregate groups will not be influenced by the ecological interactions between the functional groups included in the aggregate groups. At the same time the effect of the soil properties on the anecic populations is included in the calculation of the multiple linear regressions associated with the aggregate groups. This being the case, the effective removal of the impact of anecic earthworms on the other functional groups from these multiple linear regressions should result in the R^2 figures for the aggregate groups being similar between the archaeological and control samples, which is broadly the case.

As has been argued above (see 8.2.2), the high degree of correlation of the different functional groups of fauna and depth is a function of the depth distributed variability of soil properties. It has also been argued that there is little evidence to be found in the bivariate correlations, or the independence testing between archaeological and control populations (7.2.5), to suggest that other depth distributed soil properties that have not been measured have a significant effect on the soil fauna at the archaeological and control sites sampled. Multiple linear regressions may be applied to further test this position. If there are other depth distributed properties that have a significant impact on the population sizes of the functional groups, this effect can be detected by using depth as a factor in a stepwise multiple linear regression along side the known properties. If the impact of the putative unknown properties is significant, then depth will be selected as a predictor variable in the course of the regression. All the multiple linear regressions run for the different functional groups and aggregates of the functional groups were repeated. In all cases the regression results were identical to those produced with the inclusion of depth amongst the potential predictor variables. This further confirms that with regard to properties with depth distributed variability on the sites that have been sampled there are no significant factors not accounted for in the original selection of predictors.

The use of stepwise linear regressions theoretically allows the selection of the presumed predictor variable or variables with the greatest contribution to the variation in the dependent variable. In the case of the regressions performed for this study, loss on ignition has tended to be selected more often than pH or the two variables in tandem. While it might be expected that different predictors or a combination of predictors might be selected for different functional groups, the main difference seems to be between the archaeological samples, where all three possible outcomes are spread across the different functional groups and their aggregates, and the control sites, where loss in ignition has emerged as the sole selected predictor. The reason for the exclusive selection of loss on ignition as a predictor for the control sites may be due to the bimodal distribution of the pH determinations, as discussed above (8.2.2), which may have effectively masked the effect of pH.

The models generated by the multiple linear regressions do explain a significant level of variation. However the influence of ecological processes, and perhaps other soil properties, mean that it would be difficult to use the regression equations that describe the statistical models in a predictive role (see appendix 1). Furthermore, the size of the standard errors of the estimate associated with each regression would make the range of any predictive estimate so large as to be of doubtful value (see table 8.7).

Table 8.7 Standard errors of the estimate for multiple linear regressions of faunal populations on soil properties.

Functional/Aggregate Group	Archaeological Sites	Control Sites
Endogeic Earthworms	8.20	5.49
Enchytraeids	9.03	13.82
Non-Enchytraeid Fauna	13.58 11.83	7.17
Total Fauna	13.21 10.80	13.54

In explanatory terms, the statistical models appear to be broadly correct in principle, although insufficiently precise to be used in a predictive manner. The relative imprecision of the models may be a result of the sample size from which the regressions are calculated. The standard procedure with models derived from multiple linear regression is to test the model against a new set of data (Lindeman *et al.* 1980: 176, Polit 1996: 293). The data sets reserved for such a test, derived from the samples taken at the archaeological and control sites at Tofts, are unfortunately too small to use rigorously when zero counts are taken into consideration. However, a less rigorous test is possible. If the models are correct in principle, running the regressions again, incorporating the new data with the previously used data should render broadly similar results, in terms of selection of predictors and the production of statistically significant regression coefficients. At the same time each new regression should have a reduced standard error of the estimate for each regression. The basic statistics of the second set of regressions is presented below (see tables 8.8 and 8.9).

Table 8.8 Stepwise multiple regressions for abundance of functional group populations on soil properties on archaeological sites (all sites).

Dependent Variable	N	Predictor Selected	Predictor Coefficient	Adjusted R^2	Predictor Sigs.	Overall Sig.
Anecic Worms	16	–	–	–	–	–
Endogeic Worms	14	pH	-.617	.329	.019	.019
Enchytraeids	32	–	–	–	–	–
Larvae	8	–	–	–	–	–
Non-Enchytraeid Fauna	25	pH	-.624	.362	.001	.001
Total Fauna	39	pH	-.567	.303	.000	.000

Table 8.9 Stepwise multiple regressions for abundance of functional group populations on soil properties on control sites (all sites).

Dependent Variable	N	Predictor Selected	Predictor Coefficient	Adjusted R^2	Predictor Sigs.	Overall Sig.
Anecic Worms	14	–	–	–	–	–
Endogeic Worms	21	Loss on Ignition	.719	.491	.000	.000
Enchytraeids	25	Loss on Ignition	.605	.338	.001	.001
Larvae	16	–	–	–	–	–
Non-Enchytraeid Fauna	27	Loss on Ignition	.747	.540	.000	.000
Total Fauna	35	Loss on Ignition	.761	.567	.000	.000
Total Fauna	35	Loss on Ignition & pH	.847 .291	.635	.000 .012	.000

The second set of regressions associated with the control sites is essentially unproblematic in the implications it bears for both of the conceptual models presented in chapter two and the statistical models presented above. It was argued above that if the models are correct in principle then it was likely that a similar statistical model should emerge, in conjunction with a reduction in the standard error of the estimate. This is precisely what has happened with the control site regressions. Loss on ignition has been selected as a predictor variable for all the regressions and in all cases there is a reduction in the standard estimate of error (see table 8.10). That the effects of pH may have been suppressed by the bimodal form of the distribution of this variable must again be noted, even though the bimodal nature of the distribution is less pronounced.

Table 8.10 Standard errors of the estimate for multiple linear regressions of faunal populations on soil properties (all sites).

Functional/Aggregate Group	Archaeological Sites	Control Sites
Endogeic Earthworms	7.85	4.75
Enchytraeids	-	12.86
Non-Enchytraeid Fauna	12.78	6.26
Total Fauna	14.07	13.13
		12.05

It should be noted that there has been a slight reduction in the R^2 figures calculated for each functional group. This would suggest that for this particular set of regressions R^2 is not greatly influenced by sample size. It could be argued that this is confirmed by the R^2 calculated for the aggregate groups. These are again larger than those calculated for the individual functional groups, but almost comparable in size between sets of regressions. As has been argued above this would suggest that by aggregating the population counts the effects of interactions between the functional groups in the aggregate are controlled for. The most likely interactions between the members of the different groups would be competitive ones, leading to the conclusion that at least one of the sets of ecological processes included in the conceptual models in chapter three has a significant effect on the population sizes of the different functional groups.

By way of contrast with the control sites, the results of the second set of regressions for the archaeological sites are more complicated. The first point to note is that despite an increased sample size, the data set for the enchytraeids was rejected. Of the remaining regressions, the standard error of the estimate is smaller for two of the three regressions. The role of loss on ignition as a predictor appears to have been 'reduced'. Whereas it was selected as sole predictor for the endogeic earthworms it has been replaced by pH. The two aggregate categories did have two regressions calculated each, one with pH as sole predictor and one with pH as most important predictor, along with loss on ignition as a secondary predictor. In the new set of regressions for these categories there are only regressions selecting pH as sole predictor. Given that the range of pH values added to the data set run from optimal to those that are sub-optimal due to high pH, it is likely that the effect of pH has been enhanced to the point that loss on ignition offers no significant increase in explanation of variation. Both pH and loss on ignition generally produced significant bivariate correlations with population counts on archaeological sites. Given this point, and the probable overlap of the influence of the two variables on the faunal counts, the change in the role of pH vis-à-vis loss on ignition in the successive regressions probably represents minor changes in the distribution of variation within each variable as sample size has increased, rather than grounds for rejecting the basic conceptual model.

The estimates of R^2 for the second set of regressions are noticeably lower than the first sets of regressions. The R^2 estimates for both sets of regressions on the archaeological data sets are generally lower than the R^2 estimates for the control data sets. Given that for the second set of regressions on the archaeological data there is not a large increase in R^2 from the individual functional groups to the aggregate groups, the explanation advanced for the control sites data either does not hold or is insignificant in comparison to some further factor. This would suggest that the variations in abundance of the different functional groups are influenced by some additional factor. Whether this might be a soil property not considered by the statistical model or an ecological process is unclear. The likelihood of a soil property with depth distributed variability has been effectively discounted (see above). A soil property where variability is not depth distributed could still be having an impact on the functional group populations and their distributions. The independence testing of the populations of the control and archaeological sites (7.2.5) indicates that whatever the source of this lower level of explanation of variation, it does not mean that the archaeological and control populations are statistically distinguishable. As such it is possible to argue that the effect is insignificant in terms of population sizes.

8.2.3 Relationships between soil properties and fauna: Chi-squared testing of faunal distributions.

While the multiple linear regressions have tackled the relationship of soil properties to the abundance of the members of the different functional groups, they do not deal with the other part of hypothesis one, the issue of the role of soil properties in determining the distribution of fauna. The distribution of the fauna has implications for the distribution of the effects of faunalturbation, and thus the pattern of survival and destruction of archaeological stratigraphy. While the overall magnitudes of soil properties may in general terms determine numbers of fauna, the role of soil properties in determining distribution within a site at the basic level of presence or absence is slightly different.

Within a given area it is unlikely that soil fauna will encounter the full range that a soil property can vary through. There will be variations, however, and it is possible that these may affect the distribution of fauna, if the fauna select locations on the basis of preferences amongst the range of variation in a soil property that is immediately available. There is some evidence that at least some of the functional groups will do this with regard to certain soil properties (Cook & Linden 1996, Edwards & Bohlen 1996: 104).

The distribution of fauna revealed through the sampling of the archaeological and control sites might not reflect long term distribution, as some of the possible determinants of distribution might themselves vary considerably over time. Such variation may mean that the observed distribution of the fauna is also unstable over time. The issue of the permanency of the faunal distribution is one that has implications for discriminating between the models presented in chapter three. To investigate this possibility the effect of soil moisture on the distribution of the fauna was investigated in addition to the other soil properties already investigated. Soil moisture was selected as a soil property that was likely to vary rapidly and significantly over time, at the same time as being potentially significant for the distribution of the soil fauna, as discussed above (see 2.3 to 2.7) (Brady 1984: 231).

It is possible that the fauna will select locations according to the interaction of different soil property preferences. As such it would be preferable for any statistical technique to use a multivariate approach. This would need to be combined with a test that could allow the broad ranking of soil property values by preference. By ranking the data sets the effects of widely different absolute values in the soil properties between sites could be controlled for. Given that the distribution of the fauna was most easily approached as a presence/absence problem an approach based on categorical data was required. The first attempt was made using a log-linear approach. Examination of the data set found that basic assumptions of the technique were being violated, so that any log-linear analysis produced would be invalid (Knoke & Burke 1980).

The other approach that was available was to use χ^2 tests of the different functional groups with all the soil properties. The soil property values were recoded into preferred/non-preferred categories, using the following criteria. The loss on ignition determinations for each site were ranked by magnitude, with the top half of the figures on each site assigned to the preferred category and the bottom half on each site assigned to the non-preferred category. The recoding of moisture was slightly more complex due to the wide range of values over the three sets of sites. The moisture determinations form the archaeological and control sites at Beafield and Tofts were ranked and the half of the samples from each site with the highest moisture were coded as preferred. Because the samples from the sites at Westbrough were so moist, and given that in terms of broad preference most of the soil fauna tend to move out of very wet conditions, the coding of the samples was reversed with the driest half of the samples being coded as preferred (Edwards & Bohlen 1996: 135). To recode pH it was assumed, based on the literature (see chapter three) that the pH range 6.5-7 was the optimum, so that the cases that were closest to that range were coded as preferred. Texture was coded in two different ways to take account of two possible effects. The first was texture as a factor in drainage. For this the cases were categorised on the basis of their overall texture classification, with those presenting the greatest likely water retention on the Beafield and Tofts sites being classified as preferred. On the sites at Westbrough this categorisation was reversed to take account of the greater moisture content of the soil. Texture was also classified on the basis of the potential for irritancy, an effect that has been suggested in the literature with particular regard to earthworm species (Edwards & Bohlen 1996: 146-7). For this set of tests the samples were ranked according to sand content, with the half of the samples on each site with the lowest sand content being coded as preferred.

The outcomes of the χ^2 tests are presented in tables 8.11 to 8.12 below. The tests were undertaken using the statistical package SPSS, versions 9 and 10. Where consideration of sample size has had to be taken account of the relevant procedures have been undertaken and are indicated where appropriate.

Table 8.11 Outcomes of soil properties vs. functional group χ^2 tests for archaeological sites.

Functional Group	P Moisture	P pH	P Loss on Ignition	P Texture (moisture)	P Texture (irritancy)
Anecic Earthworms	NS	NS	.001	NS	.012
Endogeic Earthworms	NS	NS	NS	NS	.011
Enchytraeids	NS	NS	NS	NS	NS
Larvae	NS	NS	NS	NS	NS
Non-Enchytraeid Fauna	NS	NS	.001	NS	NS
Total Fauna	NS	NS	NS	NS	NS

Table 8.12 Outcomes of soil properties vs. functional group χ^2 tests for control sites.

Functional Group	P Moisture	P pH	P Loss on Ignition	P Texture (moisture)	P Texture (irritancy)
Anecic Earthworms	NS	NS	.013	NS	NS
Endogeic Earthworms	NS	NS	.002	NS	NS
Enchytraeids	NS	NS	.005	NS	NS
Larvae	NS	NS	NS	NS	NS
Non-Enchytraeid Fauna	NS	NS	.001	NS	NS
Total Fauna	NS	NS	NS	NS	NS

For all tests n=48, df=1, NS= not statistically significant.

Table 8.13 Summary of statistically significant χ^2 tests for archaeological sites.

Functional Group	Soil Property	χ^2	P	ϕ
Anecic Earthworms	Loss on Ignition	11.344a	.001	.530
Anecic Earthworms	Texture (irritancy)	3.787a	.012	-.325
Endogeic Earthworms	Texture (irritancy)	3.862a	.025	-.330
Non-Enchytraeid Fauna	Loss on Ignition	10.101	.001	.459

a = Yate's Continuity Correction has been applied to this test.

Table 8.14 Summary of statistically significant χ^2 tests for control sites.

Functional Group	Soil Property	χ^2	P	ϕ
Anecic Earthworms	Loss on Ignition	4.941a	.013	.367
Endogeic Earthworms	Loss on Ignition	10.243	.001	.462
Enchytraeids	Loss on Ignition	6.762	.005	.375
Non-Enchytraeid Fauna	Loss on Ignition	10.243	.001	.462

a = Yate's Continuity Correction has been applied to this test, χ = chi squared statistic, P = significance level, ϕ = phi co-efficient.

The most striking result of the tests is to indicate that the majority of the tests are non-significant. The exceptions to this are the results of the tests for loss on ignition, particularly those on the control sites. The size of the phi coeffiecient in these cases indicates a low to moderate degree of association (as defined by Pett 1996: 165), suggesting that while the soil fauna may show a preference for higher levels of organic content it by no means determines the distribution of the soil fauna. The apparent discrepancy between the archaeological and control sites in this case may be partially explained in terms of the greater proportion of anecic worms on the archaeological sites than the control sites. The anecic worms may be competitively excluding the endogeic earthworms on these sites.

The possible irritant effect of the coarser sand fraction as an influence on the distribution of the earthworm functional groups seems to be borne out by the test results presented above. It is noticeable that the test results are only significant on the archaeological sites. This probably relates to the overall range of variation in particle size distribution, particularly with regard to the coarse sand fraction, on each of the archaeological sites in comparison with the control sites. While the overall variation of the control sites, when considered as a group, is greater, the variation by site is greater on the archaeological sites individually. The lack of significant results for the control sites may be as a result of there being insufficient variation on each control site for it to be possible for the various earthworms to find locations with an appreciable difference in the sand content. Moisture variation of the scale recorded on each of the sites appears to have no effect on the distribution of the fauna.

8.2.4 Relationships between soil properties and fauna: summary.

The main points to emerge from the results and analysis presented in this chapter can be summarised as follows. The role of some of the selected soil properties as at least partial factors in the overall size of the populations of the functional groups and of the soil mesofauna as a whole has been demonstrated. That in some circumstances a soil property may be more influenced by the soil fauna and in other circumstances the opposite may be true of the same soil property has been demonstrated by combined results of this study and others cited in the discussions of the bulk density results.

The results of the analysis suggest that some of the soil properties do have a role to play in the distribution of the fauna. Loss on ignition is the property most often found to be significantly associated with the presence of fauna. Variations in loss on ignition show fairly consistent patterns of variation with depth on the archaeological and control sites in this study, and such variations are widely accepted in the literature (e.g. Brady 1984: 227, White 1997: 43). The frequency of such statistically significant associations between the functional groups and loss on ignition may be explained by reference to the role of organic matter in the soil as a source of nutrition for the soil fauna, and to a lesser degree the role it plays in regulating soil moisture (Brady 1984: 227, White 1997: 83).

The models advanced in chapter three proposed a role for a variety of ecological factors. The primary focus of this study is upon the role that the properties of an archaeological site may play in the preservation of its own stratigraphy. As such the role of ecological processes stands outwith the main limits of the study. Nevertheless it is possible to make some inferences about the role of ecological processes. The levels of explanation provided by the multiple linear regressions suggests that such processes may be significant in determining the abundance of the members of the various functional groups. In particular it appears that competition between the functional groups may have a significant role to play in the relative population sizes of the different functional groups.

8.3 Correlating Radiocaesium Distributions With Faunal Populations

The soil fauna population counts used in the preceding analyses are the result of relatively short term interactions. As such they may be prone to short term fluctuations, with the resultant impact on the process of faunalturbation also being short term. The visible traces of faunalturbation are of long term and cumulative formation. Ecological theory suggests that populations of organisms are more heavily affected by 'intrinsic' factors (*sensu* Gee & Giller 1991: 7) in the short term, including the ecological processes, e.g. predation, competition, colonisation, than the 'extrinsic' factors, which would include soil properties. This relationship changes over time, with the 'extrinsic' factors playing a more significant role over longer periods of time (Gee & Giller 1991: 10). As such, direct attempts at statistical correlation between the visible traces of faunalturbation, that is the data from field recording and thin section micromorphology, would be of doubtful validity.

It has been possible to calculate mean annual soil mass movement from the ^{137}Cs distributions (5.2.5), giving short-term proxy measurements of faunalturbation rates. As these rates are annual figures, they are suitable for using in checking for correlations with faunal counts.

The mean annual mass movement rate was calculated for each of the thirty measurements on each of the archaeological sites (6.5). As these measurements were made on samples taken at 1cm intervals, the differences calculated were then summed in 10cm blocks, to match the depth intervals of the fauna samples. The data from all three of the archaeological sites was used as a single data set to perform the correlations. Correlations were sought through the calculation of one-tailed Kendall's Tau coefficients (see table 8.15).

Table 8.15 Kendall's Tau coefficients for mean annual rate of movement versus faunal population.

Functional Group	Endogeic Earthworms	Anecic Earthworms	Enchytreidae	Col. And Dip. Larvae
Tau Coefficient	.364	.730**	.177	.160

*p<.05 **p<.01, n=9

As can be seen from the Tau coefficients cited above, the only statistically significant correlation was with the anecic earthworms. As has been noted above (6.5) radiocaesium profiles of a soil are essentially net measurements of vertical movement of soil and sediment particles. The functional group that is primarily associated with the vertical movement of fine material is that of the anecic earthworms (see 2.4), in contrast with the groups of fauna which have a larger lateral component in their movement (see 2.5-2.7, Edwards and Bohlen 1996: 114). That the anecic earthworm is the functional group which o correlates with rates of mass movement based on ^{137}Cs distribution is to be expected, while the greater lateral component, which the ^{137}Cs based calculation of rate of movement may underestimate, might similarly explain the lack of correlation between the population sizes of the other functional groups and annual mean rate of soil mass movement. With regard to hypothesis two it is fair to state that there is at least some connection between population size and rate of faunalturbation. The distribution of the fauna in comparison with the distribution of fraction (see figs 6.19-6.21) and annual rate of mass movement (figs. 6.22-6.24) is evidence that the distribution of the fauna (see figs. 7.1-712.) also influences the distribution of the traces of faunalturbation, with higher rates of faunalturbation in those parts of the profile where there are higher fauna counts. Simultaneously there are small numbers of soil fauna at greater depth, possible evidence of a slow but continuing rate of soil movement from the ^{137}Cs distributions and the evidence of the effects of faunalturbation in the form of the soil micromorphological data and field observations. These points have implications for the discrimination between the two models, as will be discussed in chapter nine.

8.4 Correlating Soil Properties with the Traces of Faunalturbation

To test hypothesis three (8.1), that is to examine the relationship between the traces of faunalturbation and the soil properties it was decided to run a series of correlation tests. Sample size and data distribution considerations lead to the selection of the non-parametric Kendall's Tau Coefficient, calculated as a one sided test, as the most suitable means of doing this.

The correlations may be grouped into two main sets. The first set is the correlations of the different soil properties against the probable boundaries of the most intensive current faunalturbation. Given the completely faunalturbated nature of the region above these boundaries, which has been demonstrated by the findings of the soil micromorphological work (see 5.2.3), it is necessary to test whether the depth to which this region occurs is determined by the soil properties. This would test the influence of the soil properties on the distribution of faunalturbation. The boundaries selected were the stone line and the current 'A' horizon. Generally the measurements are similar. Both sets of measures were selected, however, as while the 'A' horizon depth probably gives the greatest depth of main activity, it could be difficult to determine the precise boundary, particularly where the current 'A' horizon lay over very similar units. Using the stone line gave an extra set of data to check results against. These correlations were split into two further groups. One set was of the depth of the stone line or 'A' horizon boundary versus the measurements of the soil properties in the complete 10 cm sampling unit directly above the boundary. The other set was of the depth of the boundaries versus the measurements of the soil properties in the complete 10 cm sampling unit directly below the boundary. Correlations using data from both sides of the boundaries were undertaken to check if there was a marked difference, suggesting that the boundaries might occur at threshold values in the soil properties.

Table 8.16 P values for 'A' horizon and stone line depth versus soil properties

	'A' horizon depth, a	'A' horizon depth, b	Stone line depth, a	Stone line Depth, b
PH	.504*	.572*	.500*	.690**
Loss on ignition	-.412	.389	-.250	.375
% Sand	.137	-.167	.532*	.219

*p<.05 **p<.01 n=12

From the above results of analysis it is apparent that the only soil property of those that were investigated which is significantly correlated with the boundary depths is pH. This confirms that the distribution of faunalturbation is influenced by soil properties. Thus it would seem that the models presented in chapter three are partially correct. Other soil properties do not seem to influence distribution, at least of the most intense degree, despite statistical evidence from this study and substantive observations from other published sources that soil properties affect the size and distribution of faunal populations (see chapters 8.2.1and 8.2.2 and 2.4-2.7 respectively).

The correlation of percentage sand content in the sampling level above the stone line with the depth of the stone line is the only other statistically significant correlation.

Given the lack of any other correlation, it is doubtful whether there is any causal connection between these two variables. The correlation more probably reflects a sorting effect on the sand, comparable to, but less complete than, that which has created the stone line itself. The lack of a correlation with the sand content below the stone line would reflect the relative lack of sorting that has occurred in this region of the profile, which can be seen in the field observations (6.3).

The P values calculated contrast with the bivariate correlations calculated for the soil properties and functional group populations (see 8.2.1). This apparent discrepancy between correlations of the short and long term effects of soil properties is discussed below (see 8.5).

The other set of correlations that were undertaken were of the 10cm depth averages of total faunalturbation traces assessed by micromorphology versus the soil properties. Whereas the previous set of correlations was examining the role of the soil properties in determining the extent of the region of what is probably most complete faunalturbation, these correlations were designed to test the relationship between the different soil properties and the overall degree of faunalturbation down the 40 cm profile for which the soil properties had been determined. The test selected was again Kendall's Tau. The results are given below.

Table 8.17 P values for total faunalturbation traces versus soil properties.

Soil Property	pH	Loss on Ignition	% Sand
Tau Coefficient	-.131	.625**	.625**

*p<.05 **p<.01 n=12

The correlations on total faunalturbation traces vary from those on the boundaries. Both loss on ignition and percentage sand content emerge as being significantly correlated with the total faunalturbation traces, whereas pH is not.

The two sets of correlations confirm hypothesis three (see 8.1), with both distribution and degree of faunalturbation being determined by soil properties

The variations in the significant variables between the different assessments of faunalturbation may appear to be problematic for the models proposed in chapter two, with a lack of consistency in the results of the tests. The variations in the significant variables may in fact reflect the differing roles of the individual functional groups, in particular the two groups of earthworms.

The correlations concerning the depth of the boundaries of the region of most activity of earthworms probably largely reflect the effect of the endogeic earthworms. The relative numbers and size of the individuals of the other functional groups in comparison with those of this group, particularly in the upper samples would suggest that the endogeic earthworms are the most significant group in the upper part of the profile with regard to faunalturbation. That the upper part of the profile is generally this functional group's main area of operation is well established (Edwards & Bohlen 1996: 112-113).

The correlation coefficients calculated for total faunalturbation traces include the region of the profile in which the 'A' horizon and stone line lie, but also includes a profile up to 25 cm deeper than those regions. In these correlations the effect of the only functional group which is likely to be significantly active at greater depth becomes important, that of the anecic earthworms. Given the probability of a varying impact of different soil properties on the different functional groups, it is unsurprising that different soil properties should appear to significant when differing measures of faunalturbation incorporating elements from different depths are examined. Further demonstration of this point can be seen in the case of the correlations of radiocaesium distributions with modern fauna counts, discussed in the succeeding section.

8.5 Summary

The analyses presented in this chapter suggest that in models presented in chapter three are essentially correct. The basic relationships posited in the original model have been demonstrated to exist. But what further emerges is that a relatively simple system, such as that described in chapter two may present considerable subtleties in its workings. In particular a more sophisticated view of the inter-relationships between functional group, the distribution of functional groups, the distribution of faunalturbation and the role of time scales becomes necessary. Whereas the original models posited a pre-eminent role to soil properties and ecological processes in determining distribution of fauna and thus faunalturbation, that this position requires modification. While the analyses presented demonstrate that soil properties do have an impact on the population sizes, it is apparent that these properties exhibit depth distributed variation. In addition to this the distribution of the fauna may also contain an 'innate' component. Thus the actual distribution of the fauna, if not the actual numbers, may not vary that greatly from site to site.

Another significant subtlety is that properties on one part of the site may affect faunalturbation on a different part of the site. The correlation of radiocaesium displacement with anecic earthworms demonstrates that this functional group is active at depth, as has been suggested by the literature (see 2.5). But the bivariate correlations in chapter four demonstrate that soil properties higher up the soil profile have an impact on the size of the anecic earthworm population.

The other modification to the model is the variation over time of the significance of the different factors of faunalturbation. Each set of regressions or correlations, presented in the last two chapters, has been of differing outcomes of different parts of the faunalturbation system. Different parts of that system appear to operate over different lengths of time. An example might be relatively short term, perhaps cyclical, variation in the population size of endogeic earthworms caused by variations in the organic matter content of the soil. The variation may be real, and may have an impact on the cumulative faunalturbation of an archaeological site, but within constraints imposed by the pH of the soil/sediment that site is composed of, which may itself change over time.

These modifications to the models proposed, and the other findings of this chapter have implications for the comparison for the two and three zone models. These will be discussed in the full consideration of the two models presented in the succeeding chapter.

Chapter Nine

Two Zones Versus Three Zones: Testing and Selecting Models

9.1 Introduction

In chapter three a pair of opposing models were described (see 3.9). These models share many of their components and structure. The relationships consequent upon these models have been identified and analysed in the preceding chapters. While the analysis of these relationships has allowed the elucidation of some aspects of the distribution of faunalturbation, neither the overall distribution of faunalturbation with regard to the level of gross archaeological preservation, nor whether faunalturbation has a significant effect on archaeological sites have been fully investigated. It was to provide working hypotheses that the two contrasting models, which are based on the published data available, were advanced.

To test the relative validity of the different models a number of pairs of hypotheses were derived from each model. These hypotheses were selected on the basis that they could be compared against the evidence generated by the study, and that they should be fulfilled if the model were correct. The succeeding sections of this chapter will examine these hypotheses and determine whether they are fulfilled as predictions in the light of the evidence presented in chapters six, seven and eight.

9.2 Macromorphological Characteristics

9.2.1 Restating the Hypotheses.

Two of the pairs of hypotheses posited for the competing models concerned the gross morphological and structural effects of faunalturbation. Both pairs of hypotheses will be examined in this section. The first pair (number 4 in table 3.2) may be stated in the following manner; the deposits of the site will bear a macromorphological resemblance to the model, that is having a homogenous upper layer and a bottom layer with identifiable archaeological units. In the case of the three zone model there will be an intermediate level of material, in which faunalturbated but discernible archaeological units may be seen.

To test these hypotheses it is necessary to check whether there is any macromorphological resemblance between the recorded site sections and either of the models, in terms of the distribution of different types of soil/sediment unit. As such each of the sites will be examined in turn, in the light of the expected distribution of faunalturbated and unfaunalturbated material. As the model is based upon the identification of different zones, it is necessary to define macromorphological criteria by which the different units recorded in the field may be classified into the different zones.

9.2.2 Characterising the Zones.

The characteristics of the zone of destruction which form the criteria of classification are as follows. The material of which this zone is formed is the organo-mineral crumb structured soil of the 'A' horizon of a biologically active soil. There should be little or no material that is 'non-A horizon', specifically in the case of this study the 'ash-like' deposits identified in chapter six (see 6.3). The zone should be a single unit, a horizon of roughly uniform thickness.

The characteristics of the zone of partial preservation by which units may be classified are the following. The zone is likely to be in the form of a number of identifiable archaeological units, which should be reflected in the composition and shape of the deposits in section. These will broadly tend to conform to the law of original horizonality, although localised areas of complete faunalturbation would reduce the tendency to completely conform to this principle (Harris 1989: 31-32, see 3.1). The composition of these deposits would be a combination of 'A' horizon type material, produced and incorporated through the process of faunalturbation and other sediment, the original deposit material, in the case of the sites in the study the 'ashy' material identified in chapter six (see 6.4). The process of incorporation of material into the original deposits will make the boundaries of such deposits indistinct.

The characteristics of the zone of preservation will be similar to those of the zone of partial preservation. The zone is likely to be formed of a number of identifiable archaeological deposits, which should be reflected in the composition and shape of the deposits in section, such as spreads, dumps and fills, tending to conform to the law of original horizonality (Harris 1989: 32). The composition of these deposits should be completely or almost completely of material other than 'A' horizon type material. The absence of 'A' horizon type unit material incorporated into the constituent units should make the boundaries sharper than those of the deposits in the zone of partial preservation.

9.2.3 Comparing Characteristics with Field Observations

At Beafield the first point to be noted is that the graded ordering implicit in the move from the zone of destruction to the zone of preservation, by way of the zone of partial preservation in the 3 zone model, is not to be found in the distribution of the different types of deposits (see fig. 9.1). Units 1, 2, 7 and 9 in figure 9.1 are 'A' horizon type deposits, as identified in chapter five, and thus in terms of composition conforming to the criteria of classification the zone of destruction. The material of which these units are composed is notable in the Beafield profile by its ubiquity. Not only is the whole uppermost horizon composed of this material, as could be predicted from the models, there is similar material surrounding all the other non-'A' horizon units. Thus it would appear that in terms of the criteria of classification concerning distribution, only unit 1 could be assigned to the zone of destruction. While the 'A' horizon type of material is ubiquitous, it is not entirely homogenous. As may be seen from figure 9.1 and table 6.1 there were slight variations of colour and clast content on which basis this material could be sub-divided. These variations would suggest that these various deposits developed from slightly different parent materials and thus perhaps at different times. The implications of such an inference are discussed below.

The other units at Beafield are what could be termed as the identifiable archaeological deposits. These are units composed of the ash-like sediment, identified and characterised in chapter 6. As such, they are the material which distinguishes the zones of preservation and partial preservation from the zone of destruction in terms of composition. Within the recorded profile at Beafield these deposits appear to be preserved in an attenuated fashion. Deposit boundaries are indistinct, material similar to that of the 'A' horizon type units surrounding these deposits is incorporated into them, and elements that may have been a single discrete unit are apparently broken up (e.g. unit 5). As such all of the recorded archaeological deposits would be classified as belonging to the zone of partial preservation. None of the units recorded at Beafield could be classified as belonging to the zone of preservation. The apparent absence of a zone of preservation and the manner in which the surviving archaeological units 'float' in completely faunalturbated material appears to contradict both of the models presented in chapter three, both in terms of the level of survival of the majority of the deposits, and more significantly the distribution of the different types of units with regard to their states of preservation as assessed by composition.

At Tofts, as at Beafield, units of 'A' horizon type material are notable in the profile by their ubiquity, in both the size and section area covered (units 1, 3, 4 in figure 6.12). Not only is the whole uppermost horizon composed of this material, as would be expected under both of the models, there is similar material above and below the ash deposit units. As such, while units conform compositionally to the zone of destruction they do not appear to conform to the distribution criteria of that zone. A further parallel with Beafield is that while the 'A' horizon type of material is widely distributed, it is not entirely homogenous. As may be seen from figure 9.2 and table 6.2 there were slight variations of colour and clast content on which basis this material could be subdivided.

Those deposits at Tofts which may be identified as archaeological deposits (see 6.2 and 6.3) appear to be preserved in an attenuated fashion. In a manner similar to that at Beafield, deposit boundaries are indistinct and material similar to that which surrounds these deposits is incorporated into them. Under the criteria proposed above (see 9.1), with regard to composition these units would be classified as belonging to the zone of partial preservation. However, as at Beafield, these units do not form a single coherent region, and so with respect to distribution appear not to conform to the criteria laid down for any of the zone types. None of the recorded units at Tofts could be classified as belonging to the zone of preservation on the basis of the compositional criteria. The apparent absence of a zone of preservation and the manner in which the surviving partially preserved units of archaeological deposits 'float' in completely faunalturbated material is discussed below.

The distribution of the different deposit types at Westbrough is somewhat different from that at Beafield or Tofts. There are two discrete regions of 'A' horizon type units of the sort classified as belonging to the zone of destruction. These are separated by a band of the 'ash like' deposits (see fig 6.3 and Appendix 3). Below the lower region of 'A' horizon type unit there is a further region of units composed of ash deposits. Of the two regions of ash deposit units, the preservation of the upper region is somewhat attenuated, with material from the overlying current 'A' horizon interdigitating with the largest unit of archaeology, in some cases completely cutting through that ash deposit unit. However, the units in this band are still in a better state of preservation than any of those found on the other sites. Aside from areas of interdigitation the boundaries are quite distinct. There is relatively little 'A' horizon type material, detectable at this scale, mixed into these units. Even given this higher level of preservation these units are still to be classified as belonging to the zone of partial preservation.

Towards the base of this region there are smaller, localised deposits (see Appendix 3 for full descriptions and figures) which broadly conform to the compositional criteria of the zone of preservation. These units possess a set of clear boundaries, their forms in section conforming to the law of original horizontality and very little identifiable 'A' horizon type material (see fig. 6.2 and Appendix 3). This sequence of a fully faunalturbated region overlying a region of partially faunalturbated material, itself overlying a region of largely unfaunalturbated archaeological deposits would appear to conform to the three zone model. There are two problems with regard to this. The first is that the deposits that might be ascribed to the putative zone of preservation are small, and rather infrequently found, thus perhaps classifying these units as a zone is somewhat presumptuous on this evidence. The second problem is that there is a region of 'A' horizon type material directly beneath, succeeded by a further group of ash deposit units, thus again violating the basic distributions posited by both the models. The boundaries of this lower region of units of archaeological deposits are in places disrupted or indistinct, and there is in some cases 'A' horizon type material admixed with these deposits. As such, these units are classified as partially preserved. While the distributional order of the different types of deposits apparently violates the basic mechanisms of both of the models, the different levels of preservation do seem to form coherent regions, an apparent contrast with the sections recorded from Beafield and Tofts.

9.2.4 Reconsideration of the Basic Assumptions.

It is the issue of the distribution of the different types of deposits within the various sites that is crucial to the validation or rejection of both of the models. The pattern of deposits does not appear to conform to either of the models posited. The location of deposits that conform in composition to the zone of destruction seems to be at odds with that predicted by the model. There is a near absence of deposits that conform in character to the zone of preservation. There are, however, partially faunalturbated archaeological deposits, conforming to the zone of partial destruction in composition, if not entirely in location. In particular at Westbrough all the units belonging to the two main zone types identified on the basis of composition are grouped into two bands of material for both of the two zone types. It is this repetition of the two zones and the possible trace of a zone of preservation at Westbrough that may provide the means of creating a more sophisticated interpretation of the overall pattern of the deposits in a fashion compatible with the basic parameters laid down in one of the models.

At this point it is necessary to reconsider some of the basic assumptions of the models, to ascertain whether there are any fundamental theoretical issues that bear on the actual dispositions of the units. The first issue to be considered concerns the basic mechanisms that underlie the models. The models are based on the assumption that the current state of preservation of the archaeological stratigraphy depends on the activity of the soil fauna, in particular the mechanisms of soil/sediment movement associated with the endogeic and anecic earthworms (see 2.3 and 2.4). The two models are differentiated on the basis of the importance of the activity of the faunalturbation mechanisms associated with the anecic earthworms, that is on the ingestion of soil and sediment at depth and the subsequent egestion of this material, sometimes on the ground surface, sometimes within pores in the soil (see table 2.2). The possibility that these mechanisms did not play any significant role in the processes that have formed the units that have been recorded, and thus that the entire basis of the two different 'zone' models is wrong, has to be examined. With respect to this possibility the following points should be noted. The first is that the casting behaviour of the two groups is known from the scientific literature (see chapter two), so that this element cannot be considered to be incorrect. Similarly, the role of earthworms as a whole is also known with regard to the formation of the 'A' horizon in temperate zone organo-mineral soils, which zone is known to be entirely reworked (Edwards & Bohlen 1996: 113, also see chapter 2). As the identification of the zone of destruction in macromorphological terms is based upon the similarity of that zone to the 'A' horizon of a biologically active soil, it seems improbable that this assumption is incorrect. This point is reinforced by the lack of other likely, still less observed, processes of pedoturbation on the sites that were used in this study, due to the process of site selection employed (see 4.2). If the results discussed in this chapter and chapter six are considered, in particular with regard to the macromorphological and micromorphological evidence, it is apparent that the processes of faunalturbation have occurred on the sites examined. Furthermore, it is demonstrable that there are at least two identifiable 'endpoints', that is units that are entirely faunalturbated and those that are partially faunalturbated. This further confirms that the assumptions concerning the basic mechanisms of faunalturbation on, which the models are based, are broadly correct. The existence of the partially faunalturbated units suggests that it is the three zone model which may form the basis of a truer picture of the progression of faunalturbation on archaeological sites with regard to the relative significance of the different mechanisms of faunalturbation.

Given that the assumptions concerning the broad significance of the mechanisms of faunalturbation appear to be correct, it is necessary to check a different basic assumption of the model to find the source of the apparent discrepancy between the predicted patterns of the macromorphological evidence and the recorded patterns. Even if the assumptions concerning the mechanisms of faunalturbation and the distribution of the agents of faunalturbation are correct, a further assumption is required to produce the zoned variation in the state of preservation of archaeological stratigraphy. This assumption is that the processes of faunalturbation are working on the strata resulting from a single depositional event, or rapidly occurring, continuous sequence of depositional events. The pattern of zones would be due to the progressive or abrupt reduction in faunal activity with increasing depth. If this assumption is incorrect then a point implicit in this assumption, that is that all the traces of faunalturbation are the result of a single, ongoing, episode of faunalturbation, may also be incorrect. This being so, the pattern of stratigraphic preservation would be somewhat different.

9.2.5 The Multiple Episode Hypothesis.

Studies of the formation of the Orcadian farm mounds have been discussed (see 4.1), but it is valuable to consider the rate and constancy of the aggradation of the sites. In doing so it may be possible to determine whether the evidence of faunalturbation that has been recorded is likely to be the result of a single continuous episode of faunal activity or of a number of such episodes. Studies of the formation of the farm mounds suggest that byre clearance may have been a major factor in producing the material that accumulated to form the mounds (Bertelsen and Lamb 1993: 548 Davidson *et al.* 1984, 1986). In the post-Medieval era the depth of material that accumulated, of which ash was a significant component, in a byre before it was removed could be between 1.2-1.5m deep (Fenton 1978: 280). With animals spending the entire winter in byres, and being byred overnight in the summer, there was a rapid accumulation of material (see chapter four for a discussion of composition), the byres being emptied several times a year (Fenton 1978: 280). On Sanday the contents were left to accumulate around the farms (Fenton 1978: 282). Whether this practice can be inferred in the Norse period, when the mounds were accumulating, is uncertain. However, the survival on Sanday of the feudal service of the cottars of emptying the laird's dung court suggests that the practice of emptying the byre and leaving the manure unused was one with roots in the Norse/Medieval era (Fenton 1978: 281).

The evidence cited above concerning the likely primary processes of accumulation of the farm mounds suggests that their accumulation would have been episodic. In particular the overall area that such an episode of dumping would cover need not be that large. While the probable volume of material could be considerable, perhaps in the region of 39-46m^3, if the depth of manure and bedding given above is applied to the post-Medieval byre at Beafield (c. 3.3m x 9.9m in area). This is small when compared to an overall estimate of the volume of the mound at Beafield, which can be estimated as being in the region of 3000m^3. Thus the prospect arises that over time the precise location of dumping may have ranged around the farm, leaving material to undergo faunalturbation for a period of years prior to the deposition of additional material causing the process to be interrupted.

If such a pattern of multiple episodes of deposition, with periods of non-deposition in which faunalturbation took place is correct, then it should leave evidence in the pattern of the soil and sediment units of which the site is composed, and in the other evidence of faunalturbation. With regard to the evidence of faunalturbation, the hypothesis of multiple episodes logically necessitates the division of the data into two sets: those which cover the entire history of faunalturbation, that is the macromorphological and micromorphological evidence; and those which cover only the ongoing and recent faunalturbation, that is the distribution of the fauna themselves and of ^{137}Cs.

The evidence concerning the current and ongoing faunalturbation of the archaeological sites may be used to test the models in the light of the hypothesis multiple episode of deposition and faunalturbation, and also to elucidate points concerning the processes, that when combined with the other data may be used to explain the situation in the deeper parts of the sites where only the other, 'historical' evidence exists. As such, the faunal and radiocaesium evidence will be examined in the immediately succeeding sections, followed by the data from the thin section micromorphology, which will effectively constitute a final test and means of discrimination between the two models.

9.2.6 Applying the Multiple Episode Hypothesis.

If the two models presented in chapter two are modified in the light of the multiple episode hypothesis, then the logical corollaries outlined in chapter two and the criteria of classification given above will be somewhat different. With regard to the macromorphological characteristics to be expected the main variation is in the ordering of the different zones. Under the modified models additional factors will affect the pattern of succession of zones. These factors are the initial depth of the archaeological depths deposited during each episode, the time elapsed from deposition, particularly with regard to the earlier, buried, sets of units and the size of the faunal populations, particularly the anecic earthworms in the case of the three zone model. As has been demonstrated (see chapter eight) this last factor is in part determined by the soil properties of the site. The essential point of discrimination between the two models is the identification of the presence or absence of the zone of partial preservation in succession to the zone of destruction. That pattern of zoning cannot occur under the two zone model, even if in the earliest stages of faunalturbation the incipient zone of destruction would contain the partially faunalturbated remains of archaeological deposits.

The pattern to be expected in the case of multiple episodes of deposition and accompanying faunalturbation would be in the most simple situation be a repetitive sets of zones, beginning at the current surface with a zone of destruction, and continuing with different zones in the order outlined above, each set having a zone of destruction at the top. More complex arrangements of the different zones are conceivable. Given a shallow initial deposit depth relative to the numbers of fauna, that is the effective level of faunalturbation, it is possible that the entire set of archaeological deposits could be entirely faunalturbated, simply leaving an apparently rather thick zone of destruction overlying the previous set of archaeological units. If the three-zone model is correct, then a slightly thicker initial layer of original archaeological deposits relative to the numbers of fauna, particularly the endogeic and anecic earthworms, could result in the reworking of the archaeological deposits such that the resulting soil and sediment units could be classified as belonging to the zones of destruction and partial preservation, but none as belonging to the zone of preservation.

This last described pattern of distribution of degrees of faunalturbation appears to be essentially that which is recorded on the sites. As has been remarked above, the essential point of discrimination between the two and three-zone models is the presence of the zone of partial preservation and in particular its' succession to the zone of destruction. This pattern occurs because of the effective 'two-speed' faunalturbation that is posited under the three-zone model. That it is possible to define zones of partial preservation, each of which is positioned beneath a zone of destruction, on each of the sites would tend to confirm the three-zone model, modified on the basis of the hypothesis of multiple episodes of deposition and subsequent faunalturbation.

This division of the profile into a series of sets of zones of destruction/partial preservation can be projected on to the recorded profiles, as has been done in figures 9.1-9.3. From this it will be noticed that each zone of destruction conforms to an 'A' horizon type unit, and that each zone of partial preservation conforms to one, or occasionally more, ash deposit units. That each zone of destruction should conform to a separate 'A' horizon unit is unsurprising: such units are formed through the process of complete faunalturbation, and any preceding archaeological units are likely to be incorporated into a single homogenised unit/zone. It is to be expected that the zone of partial preservation should be composed of multiple ash deposit units, and the relatively low numbers of units in each zone is further indication of relatively shallow initial deposition in relatively few discrete deposits.

The other pair of hypotheses concerning the gross morphological/structural properties associated with different models is that concerning the position of the stone lines produced by the sorting effect of earthworm activity (number 6, table 3.1). The hypotheses may be given as follows, modified where applicable to take account of the possibility of multiple episodes of deposition and faunalturbation. If the two-zone model is true then the position of the stone line will be at the base of the zone of destruction. If the three-zone model is true then the stone line will probably not be so positioned, instead being positioned somewhat above the base of the zone of destruction. The basis of this means of discrimination between the two models is that under the two-zone model faunalturbation is essentially restricted to the uppermost part of the profile, and the stone line, a consequence of relatively rapid, repeated reworking through faunalturbation, will thus form at the base of the zone of destruction (Edwards and Bohlen 1996: 201, Muller-Lemans & van Dorp 1996). Under the three-zone model the majority of faunalturbation occurs in the upper part of the profile, in particular the repeated reworking by the soil fauna, especially the endogeic earthworms, but there is significant activity at greater depths, generally due to the activity of anecic earthworms (Edwards and Bohlen 1996: 203). While it may be assumed that there will be stone lines in the uppermost of the zones of destruction on each of the sites sampled, this may not be the case with regard to the other zones of destruction identified. The stone lines take time to form, probably in the region of one to three decades (Darwin 1881: 73, Edwards and Bohlen 1996: 202), the uppermost zones of destruction, or at least the upper regions of such, being approximately equivalent to the current, active, 'A' horizons will have had time to generate such a feature. The other, buried, zones of destruction may have been completely faunalturbated without there having been sufficient time to generate a stone line prior to the disruption of faunalturbation by renewed deposition.

For the purposes of testing this corollary, the base of the zone of destruction is taken to be the base of each soil/sediment unit, or the base of the lowest of a group of units which have been identified as the zone of destruction on the basis of macromorphological evidence. Where other evidence suggests that such an identification requires reassessment, this will be discussed with the relevant evidence.

From the diagrams (figures 9.1-9.3), it can be seen that in all but one case stone lines are only present in the uppermost, current, zones of destruction. The exception to this situation is at Westbrough. Here there are stone lines both in the currently active zone of destruction and in the lower zone of destruction (unit 3, fig. 9.3). The presence of the deeper stone line underlines two points. The first is to corroborate the faunalturbated nature of the unit, confirming the designation as a zone of destruction. The second is that the deeper zones of destruction are effectively buried 'A' horizons, the stone lines being effectively markers of such in pedological terms (White 1997: 190). Thus while these units mark the destruction of archaeological units, they are of archaeological and palaeoenvironmental interest in their own right as buried soils.

A comparison of the presence and absence of stone lines between the buried zones of destruction on the different sites might be used to suggest the relative lengths of time that the zones of faunalturbation were active. Although this may be possible in an approximate manner, strict comparisons are probably not possible. The rate at which a stone line forms from the initial deposition of a set of archaeological deposits will be dependent on the numbers of earthworms (see chapter 8), and this is determined by both ecological factors and soil properties. Given the period of time over which stone lines form and the likely relative importance of ecological factors versus soil properties (see chapter 8), it is possible that ecological factors will be highly significant in determining faunal populations over that period. As such close comparisons even between sites with closely matching soil properties may be inadvisable.

Continuing with the issue of the use of the position of the stone lines with regard to the base of the zones of destruction, it may be noted that these relatively rarely coincide with the bases of the zones of destruction. At Beafield and Tofts the separation between the stone lines and the base of the zone of destruction is considerable. At Westbrough the stone lines are much closer to the bases of the zones of destruction. Even in these cases there is still a clear and measurable distance between the bases of the zones and the respective stone lines. With regard to the hypotheses concerning the position of the stone lines it would seem that the three-zone model is corroborated, and the two-zone model falsified.

9.3 Radiocaesium Distribution

9.3.1 The Multiple Episodes Hypothesis

As has been noted above, the ^{137}Cs data is relevant only to the ongoing faunalturbation associated with the last episode of deposition, that is the upper zone of destruction on any site. As such, the radiocaesium based hypotheses do not require revision with reference to the multiple deposition hypothesis. The pair of hypotheses (number 7, table 3.1) derived from the models with regard to the distribution of ^{137}Cs can be stated as follows. If the two-zone model is correct, the bulk of the radiocaesium activity should be found in the zone of destruction, with a sharp reduction in radiocaesium concentration coinciding with the base of the zone. If the three-zone model is correct the bulk of radiocaesium should be above the base of the zone of destruction, effectively 'perched' somewhat above the base of the zone. The reduction of activity with depth should be gradual. Because the ^{137}Cs profile only pertains to recent faunalturbation, it may also be used to differentiate recent and ancient faunalturbation, which is difficult using macromorphological and micromorphological evidence unaided.

For the purposes of comparing the corollaries the base of the zone of destruction is taken as the depth at which identifiable archaeological deposits are first recorded. This depth is marked on each of the ^{137}Cs profiles (figs. 6.16-6.18). Examination of the ^{137}Cs profiles from each site demonstrates that while there is variation in terms of the distribution of the bulk of ^{137}Cs and the abruptness of the reduction of activity concentration with depth, two main tendencies may be noted. The first is that the bulk of ^{137} Cs inventory is somewhat above the base of the zone of destruction. At Beafield and Westbrough there is a noticeable fall off in radiocaesium inventory contribution below the stone line, towards the base of the zone of destruction and beyond, forming distributions that are 'perched' above the base of the zone of destruction. It is also noticeable that the considerable level of variation is replaced by a steady reduction in activity from the same point (see figs 6.16-6.18). The case at Tofts is more extreme, with all the detectable ^{137}Cs being above the base of the zone of destruction. Examination of the cumulative percentages of total inventory on the different sites reinforces the point, with between 87 and 98% of cumulative total loading being somewhat above the stone line.

The significance of the stone line has been outlined above (see 6.3), but needs to be placed into context with regard to the radiocaesium distribution. The stone line is effectively the base of the zone of destruction under the two-zone model, marking the limits of the region that will be faunalturbated, if anecic earthworms have no significant effect, and thus also the limit to which ^{137}Cs will be distributed. Under the three-zone model the stone line has a somewhat different significance. It marks the limit of rapid, repeated, faunalturbation, largely driven by the endogeic earthworm population. It is the relatively rapid and thorough redistribution of the particles to which ^{137}Cs is adsorbed that causes radiocaesium to be redistributed in a soil profile.

The slower rate of faunalturbation at depth is unlikely to have a major role in the redistribution of ^{137}Cs to over the period since fallout deposition, particularly given the manner in which the upper part of the soil profile tends to be reworked largely within itself (Muller-Lemans & van Dorp 1996). The overall zone of destruction as identified by macromorphological and micromorphological evidence (see 6.3 and 6.7) has formed over a considerably longer period. As such, a pattern in which the majority of radiocaesium is to be found 'retained' above the base of this zone is to be expected. As the hypothesis given for the three-zone model implies, this is not to argue that there is no significant redistribution below the depth at which the majority of the fauna is active, merely that redistribution is likely to be much slower. The manner in which such faunalturbation may have a significant effect on the distribution of radiocaesium is discussed above (see 9.5) and below (see 9.3.2).

9.3.2 Checking the Hypotheses.

As has been noted above, there is a change in the pattern of distribution between the ^{137}Cs above the stone line and that between the stone line and the base of the zone of destruction at Beafield and Westbrough. The change from a trend of a distribution with a high degree of variation to one marked by a steady reduction in ^{137}Cs activity may reflect the different modes of faunalturbation in different parts of the profile. The variability in the upper part of the zone of destruction reflects the relatively rapid turnover and reworking of this region, which will tend to partially disrupt any trend for the ^{137}Cs to be redistributed down the profile. The steady reduction in ^{137}Cs activity below the stone line reflects the largely vertical displacement of material caused by anecic earthworms as they clear their permanent burrows and smooth the burrow walls with nearby fine particles (Edwards & Bohlen 1996: 114).

The second main observation is that the reduction of activity concentration is fairly gradual over depth on each site. This conforms to the logical corollary of the three-zone model. Not only does the distribution of ^{137}Cs conform to the three-zone model, but the rates of mass movement of soil calculated from the radiocaesium distributions exhibit a rapid reduction in rate above the stone line, with no marked change in rate of movement at the depth of the stone line (figs. 6.22-6.24). If the two-zone model were correct, it would be expected that there would be virtually no ^{137}Cs below the stone line, giving a sharp cut off in the distribution curve. As it is there is a small but significant proportion of ^{137}Cs below the stone line, and even a little below the base of the zone of destruction at Beafield and Westbrough. This distribution is to be expected under the three-zone model, and is probably due to the activity of the anecic earthworms.

Reference has already been made to 'two-speed' faunalturbation (9.2.6). Examination of the net mean annual rates of soil mass movement tends to broadly confirm this concept. While faunalturbation is continuing below the depth of the zone of destruction, the rates of soil movement are significantly lower at the greater depths (figs. 6.22-6.24). What the variations in the rates of soil mass movement also demonstrate is that there is considerable reduction with depth in movement of soil, i.e. faunalturbation, even within the different zones of a site profile.

The main variations in the ^{137}Cs distribution between the three sites have been presented and discussed above (see 6.7). While these are insignificant in comparison to the overall apparent conformity to the prediction of the three-zone model, they may provide significant evidence with regard to explaining variations in the overall state of stratigraphic preservation between the three sites, as the ^{137}Cs was deposited on the sites in a broadly synchronous manner: any subsequent variation in distribution is likely to be due to differing rates of the various processes of incorporation, specifically faunalturbation in the case of the archaeological sites. The greater proportion of ^{137}Cs distributed between the stone line and base of the zone of destruction at Beafield could be taken to indicate a higher rate of faunalturbation at depth, i.e. below the stone line. This might in turn indicate a high proportion of anecic earthworms in the soil fauna population over the past thirty years, a trend reflected in the current population counts

The situation at Tofts is somewhat different, with ^{137}Cs becoming undetectable above the base of the zone of destruction. The considerable depth of the zone of destruction would seem to imply a high proportion of anecic earthworms in the soil fauna community of the site at some point. The ^{137}Cs distribution does not, however, support this, suggesting a possible change in the structure of the faunal population, subsequent to the main period of formation of the zone of destruction, but prior to the deposition of ^{137}Cs. Comparison with the current faunal populations indicates that this may have been the case, with anecic earthworms forming a small proportion of the current total population.

The relatively shallow distribution of the bulk of ^{137}Cs at Westbrough conforms to the shallow depths of both the zones of destruction at the site, and the associated stone lines. It could be argued that these perhaps tie in with the apparently relatively well preserved nature of the zone of partial preservation, indicating a lower general impact on the archaeological stratigraphy by faunalturbation.

The examination of the distribution of ^{137}Cs with respect to other features recorded at the sites appears to confirm the basic operation of the three-zone model. Comparison between the profiles from the three sites with other data, using the framework of that model, has suggested more subtle interpretations of the faunalturbation histories of the three sites, pointing up the role of changes or stability in different parameters over time.

9.4 Distribution of Anecic Earthworms

9.4.1 The Multiple Episode Hypothesis.

As has been noted above, the current distribution of the fauna solely relates to the current, active zone of destruction. As such the statement of the concerning the two different models (number 8, table 3.1) need no substantial restatement because of the multiple deposition hypothesis. The corollaries may be stated as follows. Under the two-zone model the majority of anecic earthworms will be found within the zone of destruction, above the stoneline. Under the three-zone model the majority of anecic earthworms will be found below the zone of destruction, and the stoneline.

9.4.2 Checking the Hypotheses.

The distribution of the anecic earthworms with respect to the base of the zone of destruction and the stone line on each site will be discussed on a site by site basis. Figures 7.3 and 6.1-6.3 represent the data under consideration. At Beafield all the anecic earthworms were taken from samples within the zone of destruction and the majority from above the stone line. At Westbrough the majority of anecic earthworms were taken from samples within the zone of destruction and above the stone line. Because the lowermost samples from which anecic earthworms were extracted are bisected by the stone line and the base of the zone of destruction on this site it is possible that all the anecic earthworms came from above these two boundaries, but it is not possible to be certain. At Tofts all the samples from which anecic earthworms were extracted were taken from the zone of destruction and above the stone line.

This evidence would seem to contradict the findings of the previous testing of the different pairs of hypotheses. All three of the sites conform to the pattern expected from the two-zone model. While the hypothesis for the two-zone model implicitly assumes an identity between the base of the zone of destruction and the stone line, and this has already been demonstrated not to be the case on the sites examined, it is still the case that the majority of anecic earthworms were taken from samples above the stone line. If the majority of the anecic earthworms are to be found in this region of the profile it might tend to confirm that this functional group has little or no significant effect on the deeper reaches of a site profile, being instead confined to regions of rapid and repeated turnover of soil. It should also be noted that the distributions of the anecic earthworms in no way resemble those predicted for the three-zone model. To resolve this apparent impasse it is necessary to re-examine the basis of the hypotheses concerning the distribution of the anecic earthworms.

The hypotheses are based on an implicit assumption that the different functional groups of earthworms are always to be found at different depths, an assumption rooted in the ecological taxonomy of the earthworms. The anecics are characterised as deep dwelling species (see chapter two, also Edwards & Bohlen 1996: 113). Despite their designation, it is known that the distribution of the anecic earthworms may vary considerably over the short term due to variations in factors such as soil moisture or temperature, or movement associated with feeding behaviour (Edwards & Bohlen 1996: 161). Such variations do not necessarily reflect the underlying distribution of the mechanisms of faunalturbation through a soil profile. As such the pair of corollaries advanced with regard to the distribution of the anecic earthworms do not provide an adequate means of discrimination between the two models. It seems probable that such a distinction could not be made without multiple sampling of the sites over the course of at least a year. Examining the distribution of the anecic earthworms in the context of the two models has, however, highlighted the fact that the anecic earthworms are also to be found within the upper, rapidly faunalturbated, part of the profile, and some of their activity may occur within this region. This may further account for the slower rate of faunalturbation at depth, and hence the persistence of partially preserved archaeological units.

9.5 Micromorphological Characteristics

9.5.1 The Multiple Episode Hypothesis.

The pair of hypotheses concerning the pattern of micromorphological characteristics (number 5, table 3.1) is in part defined in terms of the pair of hypotheses concerning the macromorphological characteristics. As such little explicit adaptation of the hypotheses is required to take account of the multiple episodes hypothesis. It is expected that the micromorphological characteristics should reflect the macromorphological characteristics. As with the macromorphological evidence, a set of criteria can be derived form the initially stated corollaries, allowing units to be classified as to which of the different zones, if any, they belong.

Whereas the criteria for the macromorphological evidence are based both on the composition and distribution of the different units, those for the micromorphological evidence are based more heavily, though not exclusively, on composition. This is due to the scale of observation: the distribution of whole deposits is obviously impossible to determine at the microscopic scale, and the boundary variations observable may be due to a variety of processes, including both faunalturbation and initial anthropic deposition, which cannot be reliably distinguished at this scale (Carter & Davidson 1998). The criteria are based around the presence and proportion of the traces of faunalturbation, as defined and described in chapter five. The criteria are in this case effectively the same as the hypotheses, which are as follows. The zones of destruction, should be largely composed of material that in their structure and features are entirely faunalturbated, that is the micromorphological traces of faunalturbation defined and described in chapter five. The zones of preservation, should have few, if any of the micromorphological traces associated with faunalturbation. In the two-zone model the transition between the two zones should be fairly abrupt in terms of differences in micromorphological characteristics. In the three-zone model the zones of partial preservation should fall between the two types already defined and combine a significant proportion of features diagnostic of faunalturbation together with the unreworked remains of the original archaeological deposits. In the three-zone model the proportion of faunalturbation traces should broadly diminish with depth within the sequence of a set of zones, that is from the zone of destruction to the zone of preservation. With regard to the multiple episodes hypothesis the transitions between all the zones in a set should be gradual. Transitions between sets of zones may be gradual or abrupt, with a greater likelihood of the latter.

Given the observation made above concerning the linked nature of the macromorphological and micromorphological characteristics the examination of the micromorphology of the sites is very useful in elucidating details of the revised models, and in discriminating between the two models. Even though the balance of evidence so far presented appears to favour the three-zone model, the model may require further adjustment even if it is further confirmed in essentials. Most importantly such an examination will allow the verification of whether the classification of the units in to zones, a fundamental part of the models, has a good basis in evidence. The multiple episode hypothesis may be further tested by the means of the micromorphological evidence as well.

9.5.2 Validating the Concept of Zones of Preservation/Destruction.

The fundamental issue is the identification of zones in the profile of the archaeological sites differentiated on the basis of the apparent state of the preservation of the original archaeological deposits. The method of dividing up a profile in this manner was based on the initial models derived from the published literature on the soil fauna. The first test and revision of the zoned models has been through the examination of the macromorphological evidence. This seems to confirm the basic idea of the zoning of the states of preservation/faunalturbation of a site, and the balance of evidence suggests that the three-zone model is closer to the truth. What needs to be examined is whether the identification of the different zones is justified, using the most pertinent evidence available.

As has been discussed above the various zones of destruction and partial preservation identified are essentially composed of 'A' horizon type units and ash deposit units respectively. The micromorphological characteristics of the two types of units have been discussed above (see 6.4). To recapitulate these characteristics with regard to the fundamental validity of the models, it should be noted that the traces of faunalturbation are ubiquitous. All the units on all the sites contain such traces, regardless of unit type. These traces are definitely identifiable as the products of faunalturbation (see chapter five). The next issue is whether the different types of units and thus zones are differentiable in terms of the traces of faunalturbation. Not withstanding the high levels of coverage of thin section samples from the different types of units, such differentiation is possible. This can be seen in the averages by 1cm depth unit displayed in figures 6.10-6.15. In the thin section samples taken from the units of the 'A' horizon type, area coverage by the micromorphological traces of faunalturbation is very high, often complete, characterised in these sites by low/zero measurements of standard error (e.g. slide 3 fig. 6.13, slides 2 and 3 fig. 6.14, slide 1 fig 6.15). This confirms the classification of such deposits as belonging to the zone of destruction in terms of compositional characteristics.

The ash-deposits, which have been classified as belonging to the zones of partial preservation, do exhibit a reduction in the proportion of each thin section slide covered with the traces of faunalturbation, albeit a slight one. None of the slides which sample areas of ash-deposit unit have complete coverage by faunalturbation traces. A further significant difference in composition between the two types of zones/units is the presence or absence of mineral impregnated material. The detection and identification of this material has already been discussed (see 6.4.1). Suffice it to say that very little such material is found in the 'A' horizon type units, while significant areas of coverage are found on the thin sections sampling the ash-deposit units, as can be seen from figures 9.4-9.6. It should be noted that where such material does occur in a zone of destruction, it is generally found below the stone line, e.g. as at Beafield, further suggesting that the stone line marks the lower boundary of the most intense faunalturbation. This material seems to be a reliable indicator of archaeological units on the sites used in the studies. Thus the two different types of units and thus the zones into which it is proposed the sites develop due to faunalturbation are identifiable using data other than the macromorphological.

9.5.3 Checking the Corollaries.

Having confirmed the empirical validity of using the zoned based models in terms of the basic identification and differentiation of such zones it is possible to move on to discriminating between the two models. The zones of destruction have been unequivocally identified using micromorphological evidence compared to the classificatory criteria given for that zone type. This zone type is, however, common to both models. As has been discussed above (see 9.2) the main point of differentiation between the two models is expressed in the zone of partial preservation. Given the degree of faunalturbation found in the all of the various ash deposit units it is not possible to classify any of them as belonging to the zone of preservation. The finding that no well preserved deposits can be identified in the units sampled for thin section micromorphology confirms the finding from the macromorphological evidence that no zone of preservation can be unequivocally identified in the parts of the sites sampled for this study. The units which are not classified as belonging to the zones of destruction can be classified as belonging to the zones of partial preservation. Thus on the criteria of composition the micromorphological evidence tends to conform to the corollary of the three-zone model.

As may be seen in figures 6.10-6.15 the transition from the 'A' horizon type units (effectively the zones of destruction) and the ash deposit units (the zones of partial preservation) is gradual, being marked, as has been noted above (see 6.4.1) by an increase in the range of values of faunalturbation coverage, through an extension of the range of lower values. This further confirms the corollary of the three-zone model.

The identification of the zone of partial preservation does seem to confirm that the three-zone model is the more valid of the two models presented. As has been discussed above (see 9.2) there is the apparent problem of there only being two identifiable types of zones, the zones of destruction and the zones of partial preservation. The solution presented was the multiple episode hypothesis. It is now necessary to apply the micromorphological data to the further testing of this hypothesis.

The first means of testing this hypothesis is to check the basic composition of the different zones of destruction, to see if there is significant variation within each site. Such variation would suggest that the base materials from which such units had formed were of different types, and thus laid down on different occasions. Further, if the zones of destruction have different compositions it suggests that they are not part of a single region of intense faunalturbation, otherwise they would be homogenised into a single unit. Examination of the descriptions of the thin section slides from the different areas confirms that there are variations in composition between the different zones of destruction on each site (tables 6.4-6.8). These variations are in terms of the proportions of different components in the coarse mineral fraction, variations in the proportion of organic to mineral matter in the fine material fraction, and less often variations in the proportions of the different types of coarse and fine organic material in each slide area which samples one of the zones of destruction.

A possible piece of evidence for faunalturbation occurring at different times, thus suggesting multiple discrete episodes of activity comes from the zones of partial preservation. It has been noted above that one of the means by which the zones of destruction and zones of partial preservation may be differentiated in compositional terms is through the presence or absence of mineral impregnation. Within the ash deposit units this phenomenon includes the impregnation of traces of faunalturbation, in particular fabric patterns and different forms of excremental pedofeatures. Not all such traces in these units are so impregnated. In particular, areas of total biological fabric and mamillated excrements which appear to be intruding from a neighbouring 'A' horizon type unit do not exhibit such impregnation. Given that the impregnation pedofeatures appear to be peculiar to the zones of partial preservation, and that both impregnated and non-impregnated traces of faunalturbation are found in these units, it may be argued that the impregnated faunalturbation traces represent an earlier phase of faunalturbation, the reason for mineral impregnation being that this was a primary characteristic of the deposit which has survived through the first stages of faunalturbation. Another possible explanation is that a process of mineral redistribution that occurred early in the formation process of the sites caused the extant faunalturbation traces to be impregnated. Subsequent faunalturbation traces have either occurred after this process has ceased, or are the product of repeated faunalturbation, which has caused the dissolution of the impregnating mineral. The assumption that the non-impregnated faunalturbation traces are later is based on the fact that this type of material is characteristic of the currently active zones of destruction on the different sites, and that this material often appears to be intrusive in the ash deposit units.

9.6 Summary

The examination of the data gathered from the different archaeological sites with regard to the two models suggests that it is the three-zone model which is the most accurate description of the processes of faunalturbation, once the effect of the sites being formed through a sequence of episodes of deposition and faunalturbation has been taken into account. The distribution of ^{137}Cs, the variation in the rates of soil mass movement calculated from the radiocaesium data, and to a lesser degree the fauna themselves, seems to confirm that 'two-speed' faunalturbation occurs, with the more rapid rate occurring in the upper part of the profile, with a slower rate occurring lower down the profile, in both the lower region of the zones of destruction, as suggested by the occasional small area of impregnated material, and the zones of partial preservation, by their very existence. That there has been a sequence of episodes of deposition and faunalturbation is confirmed by three basic pieces of evidence. These are existence of completely faunalturbated units in the same site with different basic compositions, the presence of impregnated faunalturbation traces and the sealing of one layer of completely faunalturbated material by partially preserved archaeological deposits at Westbrough. How the distribution of this set of processes and their results integrates with the other parts of the model, and the implications of the model for archaeological research is discussed in the following chapter.

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Chapter Ten

Discussion and Conclusion

10.1 Introduction

In this final chapter the conclusions and the consequent recommendations will be presented. Two main models were presented in chapter two. These shared many of their features, particularly with regard to the basic factors influencing the structure and distribution of the soil fauna guild. The various components of the models have been modified in the light of the evidence presented in the study, and a particular model selected on the basis of this evidence. This model is the three-zone model, model 2, modified most significantly by the multiple episode hypothesis (see chapter 9).

10.2 The factors of faunalturbation and hypotheses 1-3.

Model 2, as modified by the evidence presented, explains the pattern of faunalturbation in the following manner. If figure 3.1 is examined it will be seen that the system has an element of feedback in it. The different sediment properties do not necessarily have the same levels of impact on the system, nor are they all equally affected by the feedback from the system.

It was the physico-chemical properties, also referred to as the soil properties, which were hypothesised to have the most significant effect on the guild structure and population distribution of the soil fauna (hypothesis 1). The analyses presented in chapter 8 (see 8.2) suggest that some of the properties, particularly pH and loss on ignition, do affect the sizes of the various functional group populations. Similarly the soil properties of loss on ignition and sand content do affect the basic distribution of the various functional groups in terms of their presence or absence (see 8.2).

These analyses, however, suggest that the degree of variation in the population sizes and distributions are only partially determined by the soil properties of a site. Thus it would seem that over the time span represented by the faunal samples that the ecological processes are as at least as important as the soil properties (8.2). That this should be so probably reflects the significance of time as a factor in this regard. As has been discussed above, ecological theory suggests that 'intrinsic' factors such as ecological processes will have a greater impact over the short term than 'extrinsic' factors such as soil properties (see 8.2, Gee & Giller 1991: 8). Indeed one way of viewing figure 3.1 is as a representation of a single iteration of the faunalturbation system, with the fauna sampled being the outcome of the interaction of the various elements in the ecological sub-system with the sediment properties and feeding back into the sediment properties. A single iteration of the system could be assumed to occur over a period of a year.

From the above discussion it is apparent that while ecological processes are likely to be important determinants of population size and distribution of the different functional groups of soil fauna in the shorter term (see 8.2), ecological theory suggests that the physico-chemical properties will be of greater significance over the longer term. As has been discussed above (see 6.3 and 6.4), the macromorphological and micromorphological effects and traces of faunalturbation are the product of longer term faunalturbation activity, over periods from a few decades to a few centuries.

The annual rates of soil mass movement calculated from the ^{137}Cs distribution were, by comparison, suitably short term measures of faunalturbation with which to test hypothesis 2, with the result that being the distribution of certain of the functional groups, specifically the anecic earthworms, determines the distribution and degree of faunalturbation, at least over the time period (annual cycles) in question.

To test hypothesis 3 soil properties where correlated against the depths of the macromorphological markers of what are argued to be the boundaries of the region of most intense faunalturbation (see 6.3. & 8.3). The soil property that proved to be significant was pH. While the boundaries of the region of most intense faunalturbation are formed in a cumulative manner, they may form over a period corresponding to the shorter part of the time scale mentioned above. If the P values calculated for the correlation of the different depths of the boundary markers are examined (see 8.3), it becomes apparent that approximately half of the variation in boundary depth is accounted for by variation in pH. While it is not possible to precisely compare the different amounts of variation accounted for between different types of statistical tests, the broad similarity of variation accounted for by the multiple linear regressions (8.2) and the correlations (8.3.) is itself suggestive. It could be speculated that, under the theory expounded by Gee & Giller (1991), this means that the boundaries of the most intense region of faunalturbation form sufficiently rapidly to be significantly affected by ecological processes, as well as the soil properties. This interpretation is in agreement with the processes posited in the three-zone model (see 7.3 below). The varying role of the soil properties over time is further demonstrated by the correlations of soil properties against the mean total faunalturbation traces. These traces include areas of faunalturbation from below the region of most intense faunal activity. As such, there is likely to be a component of the faunalturbation traces that have been formed over the longer term. The correlation coefficient for these traces against soil properties accounted for a larger part of variation than the coefficient for the region of most intense faunal activity, as would be expected (see 8.3). Thus faunalturbation is affected by the physico-chemical properties at the various depths at which it occurs.

10.3 Model 2 and hypotheses 4-8.

The relationships between the different components of the model described in chapter two and recapitulated above cover the interaction of the fauna with the physico-chemical properties of a site. But this is only part of the problem under consideration. The question of the overall impact of faunalturbation needs to be addressed. The correlations of the depths of the boundaries of the most intensely faunalturbated regions provides some information on this, but a fuller explanation accounting for all sections of the profile of a site is required.

To this end two competing models were advanced, with the three-zone model 2 being the model adopted as best accounting for the evidence of faunalturbation. Discrimination between the models was based hypotheses 4-8. The model attempts to explain the distribution of faunalturbation in terms of the system outlined above, which is thus integral to the model. The model proposes the division of an archaeological profile in to three possible zones which are regions exhibiting similar levels of faunalturbation or preservation. As such all three zones do not have to be present in every case. The number and disposition of the zones relies on two things:

the point in time that the site is sampled in relation to the rate of faunalturbation, and the fundamental history of the site in terms of rates and continuity of initial deposition. This latter point is embodied in the multiple episode hypothesis (see 9.2.5 and 10.4). Given that the zones are defined and classified in terms of the state of preservation and that such characteristics are cumulative and the factors noted above with regard to the number and disposition of the zones, it is possible to have current faunal activity distributed differentially through a zone.

Thus while the distribution of the differing zones, and thus grades, of preservation is posited in part on the basis of the distribution of the various functional groups of fauna and associated mechanisms of faunalturbation, the cumulative nature of the traces of faunalturbation and the role of time since initial deposition are also important factors, as is discussed below.

The three zones were identified as a possible means of characterising the impact of faunalturbation on the basis of data derived from the literature on the soil fauna (see chapter two). The evidence for the three-zone model comes from a variety of sources. The zone of destruction has the predicted properties of resembling (or in some cases being formed by) the 'A' horizon of a biologically active soil (hypotheses 4and 6, see 3.10), and being wholly or predominantly composed of fabrics and pedofeatures attributable to the activity of fauna (hypotheses 5) (see 3.10, 6.3, 6.4 and 9.5). Zones of preservation could not be unequivocally identified, although there is some limited evidence for their presence (see 9.2.2), and the lack of such zones is probably explicable in terms of depth of initial deposition, under the multiple episode hypothesis (see 9.2, 9.6 and 10.4). The identification of zones of partial preservation has been highly significant, as it is this zone type that characterises the model, even in the absence of zones of preservation (9.2, 9.6).

Having identified the different zone types it is important to maintain the distinction between the zones, as volumes of soil or sediment having exhibiting similar levels of faunalturbation/preservation and the regions between which there is a differentiation in the relative rates and predominant mechanisms of faunalturbation, which may not be immediately apparent from the disposition of the different zones. The fact of the stone lines and the distribution of these features in the site profiles, and the distribution of ^{137}Cs (hypothesis 7) both confirm the differential distribution of activity into different regions that was predicted on the basis of the literature on the fauna. There is greater and probably more repetitive activity occurring in a region bounded by the stone line or base of the 'A' horizon where these may be identified (see 2.10, 6.2 and 6.3). As has been mentioned above, while the region of most intense activity may conform to the zone of destruction over the shorter term, the cumulative nature of faunaltubation means that this is not necessarily the case over the longer term, with this zone potentially being extended by the activity of deeper-dwelling fauna.

10.4 The multiple episodes hypothesis.

As has been noted, the distribution of the different zones depends in part on the rate and continuity of deposition of the archaeological deposits. The multiple episode hypothesis has been advanced to take account of this influence (see 10.2.5). In essence the hypothesis predicts that the profile of a deep site, such as the farm mounds sampled in this study, will exhibit a series of partial or complete sequences of zones of destruction/partial preservation/preservation, reflecting the episodic nature of deposition and subsequent faunalturbation, with each earlier episode of faunalturbation being disrupted by subsequent deposition (see 10.2). This hypothesis would account for the lack of zones of preservation and the presence of multiple zones of destruction and partial preservation. The different composition of the various zones of destruction on each site would seem to confirm the hypothesis (see 10.5). Examination of figs. 9.1-9.3 may give the impression that the results of periodic deposition and faunalturbation will form fairly uniform layers across a site. This impression may be no more than that, caused by the relatively limited lateral coverage concomitant on the use of test-pits rather than larger sampling arrangements. Given the seasonal to annual nature and the likely volume of the deposits on the sites (see 10.2) it is likely that, at least with regard to farm mound sites there may be considerable lateral variation in the distribution pattern of the initial deposits and thus the different zones. It might be speculated that there is in effect a three dimensional mosaic of varying states of faunalturbation/preservation, perhaps in the form of a frame or net of interconnected, or at least touching, zones of destruction, with the other zones in the 'gaps' of the frame.

10.5 Rates of faunalturbation and patterns of preservation

With regard to rates of faunalturbation, it has been demonstrated in the study that faunalturbation may be regarded as operating at two different rates (see 10.6). The more rapid rate of faunalturbation occurs in the upper part of the site profile, usually demarcated by a stone line and being approximately equivalent to the current 'A' horizon. The slower rate of faunalturbation occurs perceptibly at greater depth, thus theoretically even the deeper archaeological stratigraphy of a site may eventually be faunalturbated to the point where all stratigraphic information is lost. To compare the different rates in their most extreme examples, the ^{137}Cs derived rates of faunalturbation at Tofts are 5.49 kg $^{-3}$yr^{-1} in the uppermost sample and .05 kg $^{-3}$yr^{-1} in the lowest. This corresponds to a complete turnover of soil and sediment in 131 and 16,300 years respectively. While these rates are likely to be underestimates (see 6.5) the contrast of rates within the profile is evident. It is difficult to be certain of the period over which complete faunalturbation of archaeological stratigraphy occurs.

The patterns of surviving stratigraphy give some possible indication, with some identifiable stratigraphic units, albeit heavily faunalturbated, surviving after 700-1000 years (based on the radiocarbon determinations tabulated in chapter four). This is before the effect of a site being formed through multiple episodes of deposition and faunalturbation is considered. It should be remembered that stratigraphic units composed of up to 80% faunalturbation traces are still identifiable (see 6.3). Thus it could be argued that, with regard to the basic identification of units so that relatively full stratigraphic analysis can be undertaken, the stratigraphy of the sites sampled has proved moderately durable with regard to the slower forms of faunalturbation associated with the anecic earthworms.

10.6 Archaeological implications of the model

10.6.1 Introduction

The importance of stratigraphy in archaeology has already been established (see 1.1). In this section the practical implications of the model with regard to this fundamental element in archaeology will be discussed. The implications of the model vary according to the broad type of site under consideration. Three broad groups will be considered: farm mounds and related sites, shallow rural sites, urban sites.

10.6.2 Farm Mounds and Related Sites.

The significance of the farm mound and the more closely related sites in terms of the archaeology of the North Atlantic have already been discussed (see 4.2). The comments in this section relate not just to the farm mounds and settlement mound sites, but also to other relatively deeply stratified rural sites. Such sites are fairly common in Orkney, particularly sites formed of midden accumulations (R.C.H.A.M.S 1980: 14).

The main effect that may be predicted from the model is the loss of stratigraphic information identified in chapter one. Collections of stratigraphic units will be mixed into regions of soil with the original units being indistinguishable. This zone of destruction will correspond to the 'A' horizon of the current soil, that is the 'top soil' that is removed prior to excavation proper (Roskams 2001). As such the presence of a zone of destruction on an archaeological site with stratigraphy surviving below it means that there has been a loss of stratigraphic units and that the stratigraphic sequence is incomplete. In the destruction of the uppermost level of a stratigraphic sequence information on the processes of site formation and the initial history of the deposits that have been completely faunaturbated has been lost. This loss creates a hiatus in the sequence from the date of the uppermost surviving archaeological stratigraphy to the present. That a stratigraphic sequence is incomplete does not often appear to be observed by field archaeologists.

Within the zone of partial preservation other effects will occur. Contacts between units may be obscured, making the determination of stratigraphic relationships difficult. The original extent of deposits may be made unclear. Both these types of information are very important in excavation and in the interpretation of stratigraphy (Roskams 2001). Materials used in archaeological analysis and interpretation may be moved from one unit to another, or even from the surface of the site. This may include small biological remains such pollen, seeds and insect remains. Potentially the most problematic movement is not of these materials, which are still relatively large and have to moved in their own right as particles, and thus may form distinctive and recognisable distributions, but with chemical evidence. A variety of compounds and some elements are used as markers for past activity. To be effective these generally must adsorb to the soil or sediment to remain detectable. Some are unlikely to be affected by faunalturbation, such as phosphate, which is likely to remain on a site even if the stratigraphy of the site has been completely faunalturbated, and is generally simply used as an indicator of human activity. Others occur at lower concentrations, such as various biomolecular markers e.g. coprostanol (Bull *et al.* 1997), and are specific to certain processes or materials. This specificity is an important part of the value of such markers. As adsorbed compounds it is possible that they may, through faunalturbation, move, in conjunction with the soil or sediment to which they are adsorbed. They may be moved into deposits that originally did not contain the particular marker and thus cause false positives in any analyses seeking to detect them. That adsorbed materials do move, and may be introduced to some depth even over a relatively short period is demonstrated by the ^{137}Cs profiles presented (see 6.5).

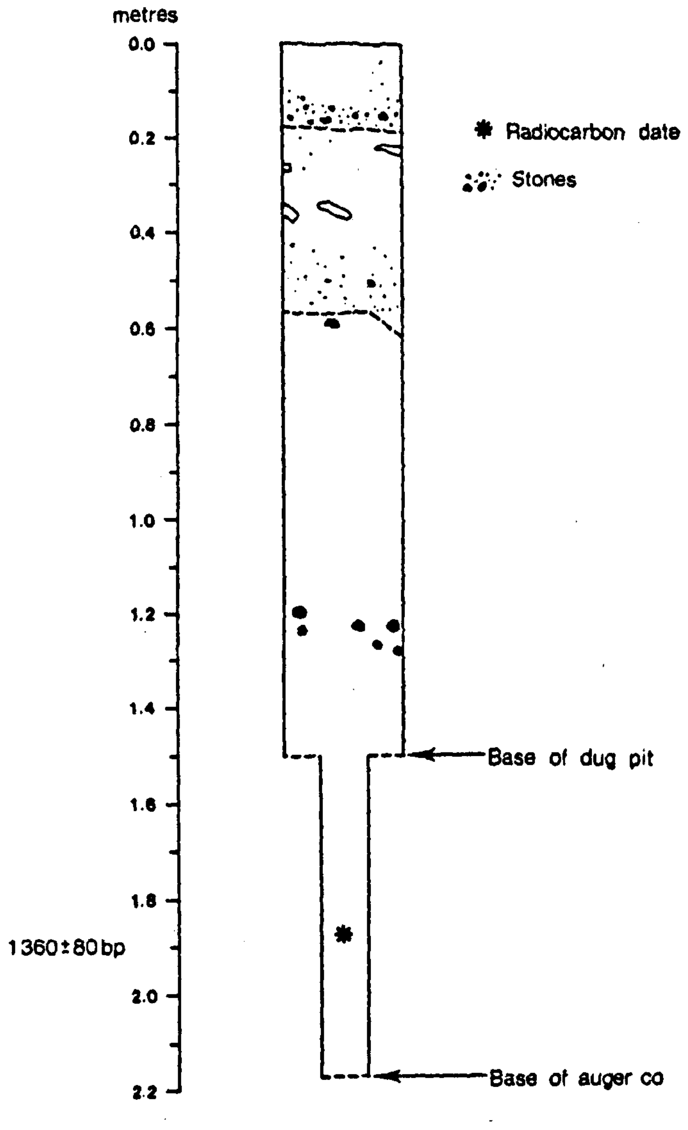
A further issue that is significant with deep sites is the effects of multiple episodes of deposition combined with faunalturbation. This can has to the creation of multiple zones of destruction, as has happened at the sites investigated in this study. In addition to the effect of the uppermost group of stratigraphic units being lost, each deeper zone of destruction constitutes a further hiatus in the sequence of the history of the formation and use of the site. This is a point not frequently considered in the interpretation of archaeological sites.

There is a further point of complexity in regard to the presence of zones of destruction in such situations, which is that the presence of these zones presents more than simply a hiatus in the sedimentary sequence of the site, in the sense of a loss of stratigraphic information. For significant faunalturbation to occur there must have been an actual hiatus in deposition. This in itself is valuable information with regard to the processes of formation of a site, even if a somewhat paradoxical situation. The time scales for the formation of zones of destruction would be useful tools in reconstructing site histories where such zones occur, and the soil movement rates derived from the ^{137}Cs distribution data is a novel and unique approach to provide modern analogue data on this matter.

The zones of destruction can be classified as the 'A' horizons of biologically active soils formed from archaeological sediments. As such, each zone of destruction, other than the current one on each site, is in effect part of a buried soil. This in itself is a possible source of information. While with regard to the farm mounds there is currently no indication that such soils were in use by the contemporaneous site inhabitants, this may not be the case for all sites. Further research on such buried soils may provide insights to soil management in the North Atlantic region, where materials similar to those of which the farm mounds are composed were used in soil emendation (Fenton 1978: 278).

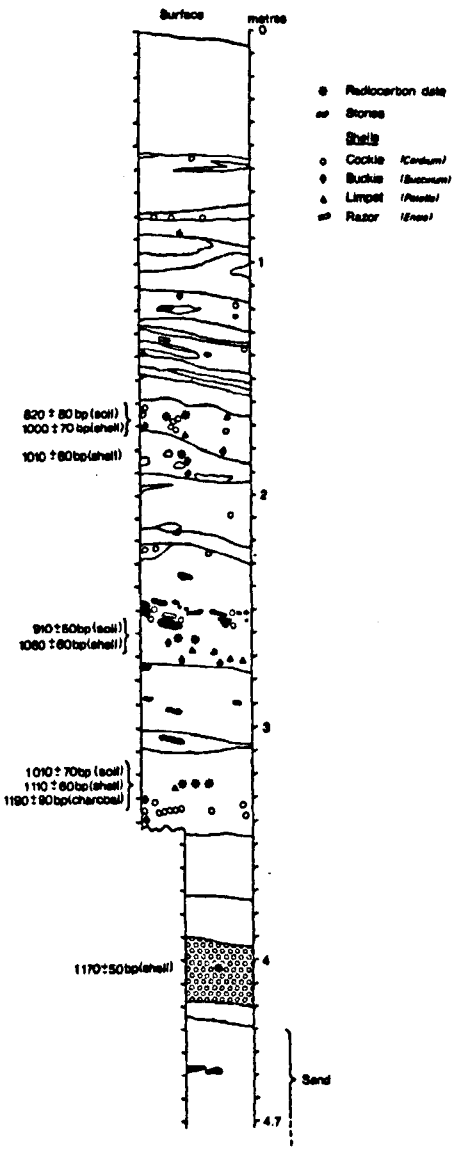
Study of the composition of the zones of destruction using the techniques of geoarchaeology/pedoarchaeology has the potential to provide other data. While the discrete archaeological units have been reworked into a single unit, aspects of the composition of the original units may be recoverable. The comparative variations in the particle size distributions of the samples from the different sites with regard to sourcing has been discussed (see 7.2.3). Micromorphological analysis has demonstrated the presence of large quantities of spherulites at Tofts, contrasting with their absence on the other sites (see Appendix 4). This again may provide evidence for primary formation processes, even in the absence of identifiable stratigraphy. Without such study it is difficult to confidently detect and interpret traces of faunalturbation and this renders reinterpretation of previous research difficult. However, some tentative reinterpretations will be offered in this sectionand in section 10.6.4.

Fig. 10.1 Stratigraphic section from Skelbrae, Sanday (from Davidson *et al.* 1986)



If figures 10.1 and 10.2 are examined it becomes apparent that there are alternating bands of stones and shells. In the case of the Langskail section the layers of stone or shell are associated with the deeper deposits, in contrast to clusters of bands of thinner deposits. At Skelbrae there are no clusters of thinner bands of material.

Fig. 10.2 Stratigraphic section from Langskail, Sanday (from Davidson *et al.* 1986).



The layers of stones could be interpreted as the sort of stone lines formed by earthworm activity. The association with the thicker deposits looks like that found in the case of the heavily faunalturbated deposits in the farm mounds sampled for the study. An examination of the ^{14}C determinations associated with the sites (see table 4.1) shows that soil determinations tend to have a more recent lower age limit than the stratigraphically associated non-soil samples, and slightly larger error ranges, both of which might be expected if one sample type, i.e. soil, was composed of material from a greater range of sources, particularly some of more recent date through top-down mixing processes, as faunalturbation is. This tends to confirm that there may be problems using chemical/biochemical markers in these circumstances.

10.6.3 Shallow Rural Sites

Although rural sites with shallow stratification were not part of the study, the model can easily be extrapolated to this type of site, and the implications of the model in this situation considered. Sites with shallow stratification constitute an important component in the rural archaeology of Britain, possibly forming the majority of archaeological sites (Roskams 2000: 220). One of the reasons that the model can be extrapolated to shallow sites is that shallow and deep sites are not discrete groups, but different points on a spectrum of depth of stratification. Further, the multiple episode hypothesis means that one way of viewing the deep sites with regard to the effects of faunalturbation is simply as a superimposed sequence of relatively shallow sites.

For the purposes of this discussion a shallow site is defined as one having the bulk of its archaeological deposits and other traces of human activity at a depth no greater than 20-30 cm. Comparing such a notional site with the upper 20-30 cm of the sites sampled suggests that the majority of the original archaeological traces, in terms of the stratigraphic ordering of the site would be entirely lost. To refer back to the sedimentalogical-pedological model, all those particles which could be moved by faunalturbation would be. Those that could not, essentially those too large to be substantially affected by faunalturbation would leave some indication of past human activity, but in a form difficult to interpret with any confidence. The best example of this would be the case of the remains of a stone structure, whose largely unmoved stones would 'float' in the zone of destruction, with no means of being linked with other structural remains in the vicinity. Neither would it be possible to tell by traditional archaeological means very much concerning the history of use or occupation of such remains. Moreover, the issue of whether rural sites have had prolonged or multiple phases of occupation is currently an important issue with regard to the settlement patterns and population levels in Iron Age Scotland. The debate concerning the duration of site occupation seems to have taken no account of formation processes of any kind, including faunalturbation (Haliday, undated). What is essentially occurring through the processes of faunalturbation on such sites is the loss of the information required to usefully discriminate between rival interpretations.

10.6.4 Urban Sites.

In this section the possibility of applying the model to urban site is considered. If such an application is valid then the actual implications for the survival and interpretation of stratigraphy will be essentially the same as those for the more deeply stratified rural sites like the farm mounds that have already been discussed (10.6.2). It could be argued that urban sites should be specifically excepted from consideration, and for a variety of reasons. The first reason is that the model has been constructed and tested using both the published literature, which is almost entirely concerned with rural soil fauna populations, and data collected from rural sites. The urban situation might well be likely to be sufficiently different for it to be difficult to extrapolate from a rurally derived model. In current urban settings faunalturbation is likely to be insignificant, with the soil fauna being confined to gardens. It is difficult to be certain, however, due to the lack of surveys concerning urban populations of soil fauna. Pre-modern urban settings are, however, quite different from modern ones, lacking the systematic and heavy coverage of ground by concrete and tarmac (Sjoberg 1960: 169). The pre-modern urban setting has no fully analogous equivalent in modern Europe. Despite having a closer resemblance to rural situations (Mumford 1961: 258), there may have been potentially significant differences with regard to the conditions for the soil fauna and thus possible faunalturbation. The trampling effects associated with higher population density and frequent use of thoroughfares could have excluded or reduced numbers of fauna (Edwards & Bohlen 1996: 222). Craft and industrial processes may have caused substances toxic to some elements of the soil fauna to have been introduced to the soils or sediments of urban areas. For example, various heavy metals are known to adversely affect at least some species of earthworms (Edwards & Bohlen 1996: 222). These include copper and lead, both of which are frequently deposited in the soil as a result of a range of craft/industrial processes, particularly metalworking (Butzer 1982: 97).

While these may appear to constitute reasons for not applying the model to urban sites there are substantial reasons to attempt such an application. As has already been noted, sociologists and historians of urbanism have noted that the main differences between urban and rural situations in pre-industrial cultures is institutional rather than environmental (Sjoberg 1960: 170, Mumford 1961: 257). Work on urban sites has thrown up evidence for environments that are more similar to modern rural environments than modern urban settings, e.g. as at York (Kenward and Hall 1995: 57). Urban sites constitute an extremely important part of the archaeological resource, with the deep stratification providing not just important detailed site histories but also often substantial organic remains, both artefacts and biological remains (Roskams 2001: 247).

At the current level of knowledge it is difficult to fully assess the validity of the model with regard to urban sites. The possible impact of faunalturbation simply has not been investigated, and there is no evidence that field archaeologists working in urban settings have been aware of the possibility. It would be necessary to specifically investigate pre-industrial urban archaeological deposits with a view to detecting the presence of the traces of faunalturbation to evaluate the applicability of the model.

10.7 Conclusions

Through the construction of a conceptual model, based on evidence derived from the literature and testing and subsequent revision of this model, a number of conclusions can be drawn concerning the impact of faunalturbation on archaeological sites. While it has been long been known that faunalturbation might affect the distribution of artefacts on a site e.g. (Atkinson 1957), this study has demonstrated that faunalturbation does occur on archaeological sites, with potentially wide ranging effects. The faunalturbation that occurs is on a scale and is so distributed that it affects the survival of archaeological evidence, particularly in the form of the stratification of a site. The integrated basis of the model, based around the sedimentalogical-pedological framework, which provides a basis for explaining the fate of all archaeological remains is an entirely novel approach, as has been the use of integrated techniques to test and refine the model. The integrated use of these techniques has demonstrated that faunalturbation may detected, and its role as a formation process may be included in forming interpretations of the history of a site.

Testing of the original model has lead to the conclusion that the population levels and distribution of the different functional groups of the soil fauna are determined in part by the physico-chemical properties of the soils and sediments of which sites are formed, with significant influence from other factors, probably mainly ecological processes. This element of the model has been revised to take account of time scales, which probably influence the relative importance of the soil properties and ecological processes as factors of fauna populations (Gee & Giller 1991: 8).

The depth to which archaeologically significant faunalturbation occurs is thus determined in part by the physico-chemical properties of these soils and sediments. Faunalturbation of an archaeological sites proceeds at different rates, with rapid faunalturbation occurring in the upper part of the profile and more slow effects occurring deeper in a site profile. This pattern is in accordance with the distribution of the different functional groups of the soil fauna.

The effects of faunalturbation on the archaeological record of a site may be grouped as follows: the total destruction of stratigraphic units, the movement of artefacts and ecofacts, the movement of small ecofacts, the transport of chemical markers. Given the techniques successfully applied in assessing the extent of faunalturbation, the possibility of false evidence can be guarded against and the loss of information partly compensated for by the application of these and similar techniques.

10.8 Recommendations

10.8.1 Recommendations for Archaeological Practice.

- That suitable techniques are employed to detect evidence of faunalturbation, or other processes of pedogenesis as a part of archaeological excavation/post-excavation analysis to ensure that possible losses of components of stratigraphic sequences can be taken into account.
- That thin section micromorphology be used in parallel with any analysis for specific chemical markers of samples from archaeological sites, as a possible means of detecting possible contamination of a deposit with material originating from other soil/sediment units.
- That a range of geoarchaeological/pedoarchaeological techniques be applied to apparently completely faunalturbated units where such techniques may be applicable to the resolution of specific research questions.

10.8.2 Recommendations for Further Research.

- Further sampling of a wider range of sites to check the validity of the model over a wider range of variation in the physico-chemical properties, particularly pH and loss on ignition.
- Work to improve knowledge of the rate of long term faunalturbation at depth, possibly using a range of dating techniques, including radiocarbon dating and perhaps optically stimulated luminesence.

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Appendix One: Regression Equations for Multiple Linear Regressions

Archaeological Sites, Initial Regressions

endogeic earthworms = -5.71 + 1.25(pH)

enchytraeids = 38.62 – 4.9(pH)

total non-enchytraeid fauna = 86.77- 10.71(pH)

= 61.03- 9.24(pH) + 1.38(% loss on ignition)

total fauna = 109.14 - 13.84(pH)

= 76.05 – 11.48(pH) + 1.62(% loss on ignition)

Control Sites, Initial Regressions

endogeic earthworms = -9.82 + .867(% loss on ignition)

enchytraeids = -23.78 + 1.94(% loss on ignition)

total non-enchytraeid fauna = -10.18 + 1.16(% loss on ignition)

total fauna = -33.53 = 2.97(% loss on ignition)

Archaeological Sites, Final Regressions

endogeic earthworms = 52.392 - 7.28(pH)

total non-enchytraeid fauna = 10.58 - 10.58(pH)

total fauna = 83.36 = 10.92(pH)

Control Sites, Final Regressions

endogeic earthworms = -5.02 + .67((% loss on ignition)

enchytraeids = -11.82 + 1.43((% loss on ignition)

total non-enchytraeid fauna = -5.83 -0.96(% loss on ignition)

total fauna = -18.08 + 2.27(% loss on ignition)

= -49.07 + 2.53(% loss on ignition) + 4.20(pH)

Appendix Two: Lab Data

Beafield, Archaeological Site

Sample Depth/ No.	% Moisture	Bulk Density	pH	% Loss on Ignition
10/1	32.61	.62	7.3	14.02
10/2	34.04	.62	7.5	14.04
10/3	33.03	.73	7.2	12.52
10/4	33.33	.66	7.9	13.41
20/1	33.33	.64	7.9	15.19
20/2	32.98	.63	8.1	21.57
20/3	32.69	.70	7.7	9.22
20/4	33.33	.78	8.1	9.45
30/1	33.33	.68	7.9	5.15
30/2	32.67	.68	8.0	7.23
30/3	33.03	.73	7.2	4.43
30/4	33.33	.68	8.1	6.40
40/1	33.33	.62	8.4	4.91
40/2	33.33	.62	8.0	18.21
40/3	32.69	.70	7.9	7.00
40/4	32.71	.72	8.1	6.12

Westbrough, Archaeological Site

Sample Depth/ No.	% Moisture	Bulk Density	pH	% Loss on Ignition
10/1	42.79	.71	5.5	16.39
10/2	40.53	.75	5.3	18.09
10/3	39.79	.84	5.2	17.33
10/4	41.70	.74	5.4	18.95
20/1	29.57	.88	6.2	6.72
20/2	28.27	.97	6.3	6.42
20/3	32.26	.94	5.7	10.19
20/4	29.05	.92	6.2	6.49
30/1	31.05	.75	7.0	6.37
30/2	30.87	.93	6.9	6.97
30/3	31.21	.83	6.8	6.18
30/4	31.64	.89	6.9	6.75
40/1	28.93	.86	7.1	6.26
40/2	31.10	.84	7.2	6.65
40/3	30.34	.90	7.2	6.57
40/4	30.52	.96	6.8	5.31

Tofts, Archaeological Site

Sample Depth/ No.	% Moisture	Bulk Density	pH	% Loss on Ignition
10/1	21.48	.71	6.6	20.49
10/2	27.15	.71	6.0	22.58
10/3	32.45	.74	6.7	22.20
10/4	4.29	.70	7.3	21.90
20/1	20.83	.91	7.8	17.61
20/2	25.02	.90	7.0	15.15
20/3	21.05	.83	7.4	13.29
20/4	22.02	.86	7.6	14.66
30/1	15.83	.80	7.9	9.89
30/2	22.35	.98	7.6	10.74
30/3	19.35	1.00	8.0	8.23
30/4	12.91	.98	7.6	10.51
40/1	12.99	.89	8.2	7.55
40/2	26.76	.93	8.0	5.29
40/3	19.52	.79	7.6	7.37
40/4	17.71	.99	8.6	9.28

Beafield, Control Site

Sample Depth/ No.	% Moisture	Bulk Density	pH	% Loss on Ignition
10/1	50.59	.42	7.2	26.97
10/2	48.28	.45	7.2	27.21
10/3	53.61	.45	7.4	26.75
10/4	45.10	.56	7.2	27.90
20/1	46.09	.62	7.2	16.30
20/2	35.71	.72	7.3	16.54
20/3	39.85	.80	7.3	17.43
20/4	37.39	.72	7.3	16.76
30/1	27.69	.94	7.7	8.49
30/2	25.00	.96	8.0	7.7
30/3	28.57	.90	7.6	9.7
30/4	33.88	.80	7.5	10.52
40/1	25.00	.87	7.3	9.74
40/2	40.00	.72	8.0	8.92
40/3	28.69	.87	7.6	9.74
40/4	31.50	.87	7.6	10.55

Westbrough, Control Site

Sample Depth/ No.	% Moisture	Bulk Density	pH	% Loss on Ignition
10/1	54.06	.54	4.0	23.08
10/2	46.37	.61	3.9	20.31
10/3	56.93	.50	4.4	19.96
10/4	51.31	.56	5.1	23.81
20/1	35.22	.91	4.4	15.11
20/2	40.25	.80	4.3	12.55
20/3	35.02	.96	4.6	13.31
20/4	37.77	.74	4.2	14.79
30/1	38.54	.85	5.2	12.34
30/2	38.59	.84	5.0	11.75
30/3	38.95	.84	4.9	8.80
30/4	38.16	.83	4.6	12.67
40/1	44.88	.73	4.1	14.37
40/2	46.09	.66	5.3	14.80
40/3	48.42	.67	4.3	21.76
40/4	45.30	.66	5.4	11.45

Tofts, Control Sites

Sample Depth/ No.	% Moisture	Bulk Density	pH	% Loss on Ignition
10/1	29.70	1.07	6.80	14.98
10/2	23.51	1.02	6.90	12.52
10/3	29.50	1.10	7.10	14.92
10/4	27.38	.93	6.60	13.33
20/1	27.16	1.09	7.20	11.34
20/2	25.65	1.16	7.60	16.70
20/3	27.81	1.09	7.50	13.14
20/4	26.74	.95	7.50	12.39
30/1	19.63	1.16	8.00	7.12
30/2	19.62	1.04	7.40	6.21
30/3	25.58	1.10	7.80	4.76
30/4	20.80	1.05	7.40	7.19
40/1	20.44	1.14	7.40	6.32
40/2	24.14	1.06	7.80	8.00
40/3	21.54	1.18	7.40	6.82
40/4	20.86	1.07	7.50	6.72

Particle Size Distribution, Beafield Sites

Sample	Beafield			Beafield Control		
Depth/No	% Clay	% Silt	% Sand	% Clay	% Silt	% Sand
10/1	1.65	23.79	73.28	3.06	32.14	64.73
10/2	3.91	30.80	63.10	2.38	15.02	82.01
10/3	2.79	31.12	59.74	3.03	15.37	76.00
10/4	9.41	64.14	21.95	1.74	16.91	81.65
20/1	2.43	51.40	44.95	.93	9.27	89.56
20/2	4.68	42.83	48.19	2.38	17.18	80.27
20/3	2.92	33.42	60.90	2.72	15.49	80.81
20/4	7.83	51.03	38.32	1.93	21.70	76.35
30/1	5.97	48.26	40.86	1.92	18.15	79.87
30/2	11.99	69.06	18.25	3.36	22.41	74.01
30/3	5.38	44.49	47.39	2.88	19.96	77.14
30/4	7.80	58.04	31.19	2.32	18.01	79.53
40/1	6.07	53.83	30.98	10.21	67.37	22.68
40/2	9.13	62.24	23.36	5.31	34.80	60.01
40/3	7.96	56.68	33.83	7.76	46.81	50.18
40/4	4.91	48.85	31.52	2.00	20.14	77.83

Particle Size Distribution, Westbrough Sites

Sample	Archaeological Site			Control Site		
Depth/No	% Clay	% Silt	% Sand	% Clay	% Silt	% Sand
10/1	3.36	47.83	46.45	13.44	71.07	15.49
10/2	4.16	47.22	48.15	9.33	59.40	31.18
10/3	2.34	40.21	55.34	8.91	59.70	31.07
10/4	2.72	43.27	53.96	13.51	69.22	16.49
20/1	4.65	51.76	41.63	7.7	55.95	30.80
20/2	12.91	64.26	19.67	8.51	49.59	28.84
20/3	4.91	55.12	34.72	9.75	53.76	26.11
20/4	5.00	51.36	40.93	9.95	55.34	26.93
30/1	5.44	52.12	41.20	10.82	60.78	27.36
30/2	5.70	57.73	35.46	12.30	63.81	23.30
30/3	5.13	50.25	43.72	13.59	64.08	21.99
30/4	5.21	51.40	42.31	12.30	59.11	27.63
40/1	5.29	47.60	37.87	12.68	60.80	24.49
40/2	4.77	50.12	42.93	12.37	63.46	24.01
40/3	5.24	56.98	35.60	13.10	64.12	22.73
40/4	6.02	37.58	23.33	15.41	63.34	21.03

Particle Size Distribution, Tofts Sites

Sample	Archaeological Site			Control Site		
Depth/No	% Clay	% Silt	% Sand	% Clay	% Silt	% Sand
10/1	1.70	19.69	78.61	1.70	19.69	72.01
10/2	3.48	27.08	68.64	4.54	30.57	55.30
10/3	2.37	23.36	74.10	10.23	49.14	27.48
10/4	2.59	24.83	72.43	4.37	29.22	54.41
20/1	4.54	30.57	64.82	3.48	27.08	59.51
20/2	2.78	24.68	72.33	2.78	24.68	64.10
20/3	5.19	25.71	69.10	3.57	30.61	57.65
20/4	3.78	19.80	76.05	5.16	43.54	40.61
30/1	10.23	49.14	37.02	2.37	23.36	69.89
30/2	3.57	30.61	64.12	5.19	25.71	59.28
30/3	7.60	29.28	41.64	7.60	29.28	35.91
30/4	11.61	41.51	24.48	12.87	51.01	27.04
40/1	4.37	29.22	61.18	2.59	24.83	63.15
40/2	5.16	43.54	47.64	3.78	19.80	66.41
40/3	12.87	51.01	33.01	11.61	41.51	15.39
40/4	4.55	31.57	60.37	4.55	31.57	55.50

Beafield, Archaeological Site

Sample Depth/No	Endogiec Earthworms	Anecic Earthworms	Indet. Earthworms	Enchytraeid	Coleoptera/ Diptera	Total Non. Enchy. Fauna	Total Fauna
10/1	0	5	0	6	0	5	11
10/2	0	22	0	2	0	22	24
10/3	0	8	0	6	0	21	14
10/4	0	21	0	0	0	21	23
20/1	0	1	0	1	0	1	1
20/2	0	0	2	1	0	2	1
20/3	0	0	0	2	0	0	1
20/4	0	0	0	1	2	2	4
30/1	0	0	0	1	0	0	1
30/2	0	0	0	0	0	0	1
30/3	0	0	0	0	1	1	1
30/4	0	0	0	0	0	1	0
40/1	0	0	0	0	0	0	0
40/2	0	0	0	0	0	0	0
40/3	0	0	0	0	1	1	1
40/4	1	0	0	0	0	0	1

Westbrough, Archaeological Site

Sample Depth/No	Endogiec Earthworms	Anecic Earthworms	Indet. Earthworms	Enchytraeid	Coleoptera/ Diptera	Total Non. Enchy. Fauna	Total Fauna
10/1	8	37	1	4	0	52	49
10/2	11	4	1	49	0	20	64
10/3	38	15	9	13	0	64	66
10/4	9	7	0	2	0	24	18
20/1	2	5	0	3	1	8	11
20/2	6	1	0	2	0	7	9
20/3	9	6	0	1	0	16	16
20/4	2	8	0	6	0	10	16
30/1	1	0	0	1	0	2	2
30/2	1	0	0	0	0	1	1
30/3	1	0	0	4	0	2	5
30/4	0	0	0	2	0	0	2
40/1	0	0	0	0	0	0	0
40/2	0	0	0	1	0	0	1
40/3	0	0	0	1	0	0	1
40/4	0	0	0	6	0	0	6

Tofts, Archaeological Site

Sample Depth/No	Endogiec Earthworms	Anecic Earthworms	Indet. Earthworms	Enchytraeid	Coleoptera/ Diptera	Total Non. Enchy. Fauna	Total Fauna
10/1	0	0	0	3	0	0	3
10/2	4	3	0	0	1	8	8
10/3	5	3	0	4	13	21	25
10/4	0	1	0	0	4	5	5
20/1	0	0	0	19	1	1	20
20/2	0	0	0	4	0	0	4
20/3	0	0	0	0	0	0	0
20/4	0	0	0	0	0	0	0
30/1	0	0	0	43	0	0	43
30/2	0	0	0	2	0	0	2
30/3	0	0	0	1	0	0	1
30/4	0	0	0	1	0	0	1
40/1	0	0	0	7	0	0	7
40/2	0	0	0	0	0	0	0
40/3	0	0	0	0	0	0	0
40/4	0	0	0	0	0	0	0

Beafield, Control Sites

Sample Depth/No	Endogiec Earthworms	Anecic Earthworms	Indet. Earthworms	Enchytraeid	Coleoptera/ Diptera	Total Non. Enchy. Fauna	Total Fauna
10/1	14	3	0	69	0	18	87
10/2	14	1	7	24	1	23	47
10/3	14	5	0	12	1	36	48
10/4	26	1	5	31	1	16	47
20/1	8	0	0	0	0	0	0
20/2	0	0	0	2	0	2	4
20/3	2	0	0	3	0	0	3
20/4	0	0	0	0	0	0	0
30/1	0	0	0	3	0	0	3
30/2	0	2	0	0	0	2	2
30/3	0	0	0	0	0	0	0
30/4	0	0	0	0	0	0	0
40/1	0	0	0	0	0	0	0
40/2	0	0	0	0	0	0	0
40/3	0	0	0	2	0	1	3
40/4	0	0	0	0	0	0	0

Westbrough, Control Sites

Sample Depth/No	Endogiec Earthworms	Anecic Earthworms	Indet. Earthworms	Enchytraeid	Coleoptera/ Diptera	Total Non. Enchy. Fauna	Total Fauna
10/1	3	1	0	10	1	10	20
10/2	5	1	0	0	2	22	22
10/3	12	3	1	3	1	17	20
10/4	11	0	1	27	0	16	43
20/1	1	0	0	0	0	1	1
20/2	0	0	0	0	0	0	0
20/3	0	0	0	1	0	0	1
20/4	0	1	0	1	0	1	2
30/1	1	0	0	0	0	0	0
30/2	0	0	0	0	0	0	0
30/3	1	3	0	0	0	9	9
30/4	0	0	0	0	0	0	0
40/1	0	0	0	1	0	0	1
40/2	0	1	0	0	0	1	1
40/3	0	0	0	0	0	0	0
40/4	0	0	0	1	0	0	1

Tofts, Control Sites

Sample Depth/No	Endogiec Earthworms	Anecic Earthworms	Indet. Earthworms	Enchytraeid	Coleoptera/ Diptera	Total Non. Enchy. Fauna	Total Fauna
10/1	14	5	0	19	3	22	41
10/2	0	0	0	3	0	0	33
10/3	3	0	0	11	4	7	18
10/4	5	0	0	2	1	6	8
20/1	1	0	0	1	1	2	3
20/2	4	3	0	1	0	7	8
20/3	0	0	0	0	4	4	4
20/4	2	0	0	7	0	2	9
30/1	0	0	0	6	0	0	6
30/2	1	0	0	2	3	4	6
30/3	0	0	0	0	4	4	4
30/4	0	0	0	0	1	1	1
40/1	1	1	0	0	1	3	3
40/2	0	0	0	0	0	0	0
40/3	0	0	0	1	0	0	1
40/4	1	0	0	0	0	1	1

Appendix 3
Thin Section Micromorphology Data: Quantification of Faunalturbation

Beafield 1-8cm (1)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	15	90			5	2	5	2	x[1]					
1	17	35												
1	19	100												
1	21	100	x											
1	23	100	x		x									
1	25	100	x		x									
1	27	90	x		10	2	x							
2	29	100	x		x				x[2]					
2	31	100	x						x[3]					
2	33	100	x											
2	35	100	x		x				x[2]					
2	37	100	x											
3	39	100	x											
3	41	60	10	3					30[3]	2				
3	43	100	x											
3	45	100	x						x[6]					
3	47	80	x		20	2								
3	49	100	x						x[3]					
3	51	95	x						5[3]	2				
3	53	90	x		x		x		10[3]	2				
3	55	100	x		x				x[3]					
3	59	100	x											
3	61	100	x		x		x							
3	63	95	x		5	2	x							

Beafield 7-15cm (2)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	16	100	x		x		x							
1	18	75	x		x				25[3]	1				
1	20	25	x		50	2			20[3]	1	5[2]	1		
1	23	45	x		40	2	10	3						
1	25	100	x		x		x							
1	27	100	x		x		x							
1	30	80	x		10	2	10	3						
1	32	100	x		x		x							
1	34	100	x		x		x							
1	36	100	x											
1	38	95	x		5	1								
1	40	100	x		x		x							
1	43	80	x		10	1	10	3						
1	45	90	x		10	1	x		x[4]					
1	47	100	x		x		x							
1	51	85	x		10	1	5	3						
1	53	100	x		x		x							
1	55	90	x		5	1	5	3						
1	58	100	x		x		x							
1	60	100	x		x		x							
1	62	60	x		35	1	10	3						

Beafield 14 – 22cm (3)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	16	100	x				x		x^3					
1	18	65	x						35^3	1				
1	20	60	x		5	1			35^3	1				
1	23	85	x		10	1	x		5^3	1				
1	25	85	x				x		15^3	1				
1	27	90	x		x				10^3	1				
1	30	100	x		x		x		x^3					
1	32	95	x		5	1								
1	34	100	x		x		x		x^2					
2	37	85	x		15	1	x							
2	39	100	x		x		x							
2	41	100	x		x		x		x^3					
2	44	85	x		15	1	x		x^4					
2	46	95	x		5	1	x		x^4					
2	48	100	x		x		x							
2	51	65	x		35	1	x							
2	53	100	x		x		x							
2	55	100	x		x		x							
2	58	40	x		50	1	10	3						
2	60	45	x		30	1	15	3						
2	62	100	x		x									

Beafield 21-29cm (4)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
4	9	100	x		x		x							
4	11	80	x		10	3	10	3						
4	13	95	x		x		5	1						
4	16	90	x		10	1	x							
4	18	90	x		10	1	x							
4	20	100	x		x		x							
4	23	5	x		x		x		5[3]					
4	25	100	x		x									
4	27	20	x		45	1	30	3	x[2]					
4	30	100	x		x		x							
4	32	50	x		30	3	5	1						
3	34	90	10	1	5	1	x							
4	37	10	x		15	1	x							
4	39	15	x		15	1	x							
2	40	35	x		x		x							
1	44	10	x		x		5	1						
4	46	100	x		x		x							
3	48	95	x		5	2	x							
1	52	45	x		5	1	10	1						
4	53	100	x		x									
4	55	80	x		15	1	5	3						

Beafield 28-33 (5)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	2	95	x				5	1						
1	4	70	x		30	1								
1	6	100	x		x		x							
1	8	100	x		x		x							
1	12	70	x		25	1	5	3						
1	14	70	x		30	1	x							
1	16	80	x		15	1	5	3	5[3]	1				
1	18	100	x		x		x							
1	20	100	x		x									
1	22	85			x		x							
1	24	95	x		10	1	5	3						
1	26	70	x		x		5	1						
1	30	90	x		25	1	5	1						
1	32	90	x		5	1	5	1						
1	34	90	x		5	1	5	1						
1	36	95	x				10	1						
1	38	60	x				5	1						
1	40	20	x		5	1	5	1						
2	42	95	x		5	1	10	1						
3	44	95	x		x		5	1						
1	48	95	x		5	1	x		x[3]					
2	50	90	x		x		5	1						
2	52	90			5	1	x							
3	54	85	x		5	1	x							
2	56		20	3	40	1	x							
2	58				10	1	x		x[3]					
2	59				25	2	15	2						
2	61				5	1	10	1						

Beafield 35-41cm (6)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	3	90	x		5	1	5	1						
1	5	100	x		x		x							
1	10	100	x		10	1	x							
1	12	95			5	1	x							
1	14	85	x		15	1	x							
1	16	95	x		5	1	x							
1	18	90	x		10	1	x							
1	20	95	x				5	3						
p	24	65	x		x	x	x							
1	25	70	x		20	1	10	1						
p	27	25	x		15	1	15	1						
p	28	25	x		10	1	5	1						
1	31	95	x		x		x							
1	33	85	x		5	1	10	1						
1	35	60	x		10	1	10	1						
1	37	80	x		15	1	5	3						
1	39	75	x		10	1	15	1						
p	41	10/80					10	1						
1	45	85	x		5	1	10	1						
1	46	80	x		15	1	5	3						
1	48	100	x		x		x							
1	52	90	x		5	1	5	1						
1	54	85	x		5	1	10	2						
1	56	90	x		x		10	1						

Beafield A (7)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	16	100	x		x		x		x^3					
1	18	95	x		x		x		5^3	2				
1	20	90	x		x		x		10^3	2				
1	24	95	x		x		x		5^3	2				
1	26	95	x		x		x		5^3	2				
1	28	95	x		x		x		5^3	2				
1	30	90	x		5	1	5	3	x^3					
1	32		20	1	10	1	15	1	5^3	2	x^1			
1	34	40	x		5	1	5	1						
2	37	10	x		10	1	5	1						
1	40	100	x		x		x							
1	42	95	x		x		x		5^3	2				
1	44				70	1	30	1						
1	46	100	x		x		x							
1	48	100	x		x		x		x^3					
1	52	95	x		x		5	1	x^3					
1	54	85	x		5	1	10	1	x^3					
2	56	10/80	x				10	1						
1	58	100	x		x		x							
2	60		10	1	40	1	30	1						
2	62		x		10	1	5	1	5^1	1				

Beafield B (8)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	2				5	1	x							
2	4	20	x		30	3	20	1	10^5	1				
2	6	10	x		10	1	30	1	x^6		x^2			
1	10				x									
3	12	70	x		10	1			5^3	1	5^6	1		
4	14	75	x		10	1								
4	16	80	x		15	1	5	1						
3	18	80	x		20	1	x				x^1			
3	20	80	x		x		5	1	5^3					
5	23		x		60	1	x							
3	26	95	x		5	1	x							
4	28		x		100	1								
6	30	85	x		10	1	5	1						
6	32	60	x		x		x							
4	34								50^5	1				
6	38	100	x		x		x		x^5					
6	40	85	x		10	1	5	1						
6	42	90	x		5	1	5	1						
6	44	90	x		5	1	5	1						
6	46	100	x		x		x							
6	48	90	x		x		10	1						
6	52	90	x		10	1	x							
6	54	70	x		30	1	x							

Beafield C (9)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	2	100	x											
4	4				30	1								
1	9	30	x		25	2	10	2						
4	11				10	1								
2	13	85	x		x		5	1	10^{3}	2				
4	17				10	1	5	1						
5	19	10	x		10	1	70	1	10^{2}	1				
5	21	10	x		5	1	40	1						
3	23	90	x		x		5	1	5^{3}	1				
5	25				30	1	60	1						
5	27	40	10	1			95	1	5^{2}	1				
3	30	5			10	1	30	1						
5	33				30	1	50	1	5^{5}	1				
5	35				20	1	40	1						
5	37				10	1	75	1						
5	39				20	1	80	1						
5	41	30	x		10	1	70	1						
5	45	5			15	1	40	1						
5	47				10	1	70	1	5^{2}	1				
5	49	45	x	1	10	1	75	1						
5	51				10	1	35	1						
5	53				10	1	80	1	10^{6}	1				
5	56		x		40	1	60	1						

Beafield D (10)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	6	100	x		x									
2	7	60	x		20	1			x^6					
2	9		15	2	45	1	20	1	x^6					
1	11	30	20	2	20	1	10	2	x^6		x^2			
1	13		50	1	30	1	x							
3	15				20	1	40	2						
2	17	5	25	1	10	1	35	1						
1	19	30/65	x				5	1						
3	21				5	1	95	1						
3	22				5	1	95	1						
2	24		15	2	20	2			55^2	1	x^5		x^1	
2	26	80	x		x		20	1	x^2		x^5		x^1	
3	30		15	1	25	1	40	1	5^1	1	5^2	1		
2	32	15	10	1	20	1	30	1						
1	34		5	1			5	1	5^1	1	10^2	1		
4	36	50/45	x		x		x		5^2	1				
2	38	15/85	x		x/		/x							
2	40	30	x		5	1	15	1	25^2	1				
4	43	90	x		x		x		10^3	1				
4	45	90	x				5	1	5^3	1				
4	47	25/70			x/		x/5	/1	x^3					
4	51	95	x		x		5	1						
4	53	100	x		x		x							
4	54	90			x				10^3	1				

Beafield E (11)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	8	95	x		x		5	1						
1	10	95	x		x		5		x[7]					
1	12	90	x		x		5	1	5[3]	1				
1	14	95	x		x		5	1						
1	16	40/40					5	1						
1	18	55/45	x/		x/x		x		/x[5]		x[2]			
1	20	90	x		x		5	1						
1	22	10/85	x/x		x/x		/x		/x[5]		5[2]			
1	24	90	x		10	1	x							
1	26	95	x		5	1	x		x[3]					
1	28	100	x		x		x							
1	30	80/20	x/x		x/x		x/x		x[5]		x[6]			
1	32	85	x		10	2	5	2						
1	34	90	x		x		x							
1	38	100	x		x		x							
1	40	90	x		5	2	5	2						
1	42	90	x		x		10	2						
1	44	100	x		x		x							
1	46	95	x		5	1	x							
p	48	50	x		10	1	5	1						
p	49	45	x		x		x							
1	52	90	x		x		10	1						
1	54	90	x		x		10	1						
1	56	95	x		x		5	1						

Beafield Low

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	9	100	x		x		x		x[1]					
1	11	95	x		x		5	1						
1	13	95	x		x		5	1						
1	16	85	x		10	1	5	1	x[7]					
1	18	100	x		x		x							
1	22	90	x		5	1	5	1						
1	24	100	x		x		x							
1	26	100	x		x		x							
1	30	100	x		x		x							
1	32	100	x		x		x							
1	36	100	x		x		x							
1	38	100	x		x		x							
1	40	100	x		x		x							
1	44	90	x		5	1	5	1						
1	46	95	x		5	1	x							
1	50	100	x				x							
1	52	85	x		10	1	5	1						
1	54	75	x		15	1	10	1						

Westbrough 0-7.5cm (1)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	9	100	x		x		x							
1	11	100	x		x		x							
1	13	100	x		x		x							
1	17	100	x											
1	19	100												
1	23	100	x		x		x							
1	25	100	x											
1	27	100	x		x		x							
1	31	100	x		x									
1	33	100	x		x		x							
1	37	100	x		x									
1	39	100	x		x				5[2]	1				
1	41	100	x		x									
1	45	100	x		x		5	1						
1	47	100	x											
1	49	100	x		x									
1	51	55/45	x/x		x/									
1	53	100	x		x		x							
1	55	100	x				x							

Westbrough 6.5-14cm (2)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	9	100	x				x							
1	11	100	x		x									
1	13	100	x		x		x		x[3]					
1	17	100	x		x									
1	19	100	x				x		x[6]					
1	21	75/25	x/x		x		x							
1	23	100	x		x/		x/x							
1	25	100	x		x		x							
1	27	100	x		x		x							
1	31	100	x		x		x							
1	33	100	x		x		x							
1	35	100	x		5	1	x							
1	37	100	x		x		x							
1	39	100	x		x									
1	41	90	x		x		x							
1	45	100	x		x		x							
1	47	95	x		x		x							
1	49	40	x		20	1	10	1						
1	52	50	x		x		x							
1	54	100	x		x		x							
1	55	100	x		x		x							

Westbrough 13.5-20cm (3)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
2	3	30	x											
1	5	100	x		x		x							
2	9		x		5	1								
2	11	50/50	x		x/x									
1	13	100			x									
1	17	60	x/		x									
1	19	100	x		x		x							
1	21	95	x/x		x		x							
2	23	25/35	x		x/		/x							
1	25	80	x		x		x							
1	27	95	x		x									
1	31	85/5	x/x		5/	1/	5/x	3/						
1	33	85	x		10	1	5	1						
1	35	100	x		x		x							
2	37	10	x		x		x							
2	39	5	x											
2	41	30/50	x											
1	45	60	x		5	1	30	1						
2	47	45/15	x		x/		x/							
2	48	10/5	x		x/		x/		$/x^2$					
2	51	25/50	x		x/									
2	53	70	x				10	3						
1	55	100	x											

Westbrough 21.5-29cm (4)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
2	2	25	x				x							
1	4	55/10	x/x		x/		/x							
2	6	75	10/x	1			/x							
2	10	60			x		x							
1	12	100	x		x		5	1						
1	16	70	x/x		x									
1	18	80	x		5	1	5							
2	20	5/5	x/				20/x	1/						
1	23	60/5	x/x		x/									
1	25	80/5	x/x		x/									
2	27		5/	1/	x/		5/10	1/1						
2	31	/20	10/	1/	5/	2/	/x							
2	33	80/20	x/x		x/		x/x							
1	37	95	x		x		x							
1	39	95	x		5	1								
2	41	10/90	/x											
1	45	100	x		x									
2	47	85	x				x							

Westbrough 28.5-36.5 (5)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	9	85/5	x/x											
2	12	30/5	x/		x/		/5	/2						
1	16	100	x		x		x							
1	18	100	x		x		x							
1	20	100	x		x									
1	24	100	x		x		x							
1	26	100	x				x							
1	30	100	x		x		x							
1	32	100	x		x									
1	34	100	x		x									
1	38	100	x		x		x							
1	40	100	x		x									
1	42	100	x		x									
1	44	100	x											
1	46	100	x		x									
1	48	100	x		x									
1	51	100	x		x									
1	53	100	x		x		x							
1	55	100	x											

Westbrough 35.5-42.5 (6)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	3	100	x		x									
1	5	100	x		x									
1	11	95	x		5	2								
1	13	100	x		x									
1	17	70			5	1	x							
1	19	10	x											
1	21	100	x		x									
2	25	10	x											
1	27	95	x		5	1	x							
1	30	100	x		x									
2	32	15/75	x/x		x/									
2	34	85/15	x/x		x/x		x/							
2	38	60/40	x/x		x/x		x/							
2	40	90/10	x/x		x/				x[1]					
2	44	100	x		x		x							
2	46	90	x		10	2	x							
2	48	60	x		x		10	2						
2	52	100	x		x		x							
2	54	100	x		x									

Westbrough A (7)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
2	2	30/70	x/x											
2	4	100	x		x									
2	6	100	x											
2	10	100	x											
2	12	75	x											
2	16	25/75	x/x											
2	18	20/45	x/x		x/									
2	20	5/35	/x											
2	24	35	x											
2	26	20/80	x/x		x/		x^7							
1	30	100	x		x									
2	32	30/50	x/x		x/x									
2	34	20/30	x/x		x/x									
1	38	90	x		5	1								
2	40	35	x		x									
1	44	100	x											
1	46	100	x											
1	48	80/20	x/x		x/									
1	52	100	x											
1	54	100	x											

Westbrough B (8)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	2	100	x						x^2					
1	4	100	x						x^2					
1	6	100	x											
1	11	95	x		5	1								
1	13	95	x		5	1								
1	15	95	x		5	1			x^2					
2	18	65/35	x/				x/		/x^2					
1	20	90	x		5	2	5	2						
1	22	90/10	x/x		x/		x/x							
1	24	100	x											
2	25	50/50	x/x		x/x		x/							
2	27	50/50	x/x		x/x		x/							
1	29	100	x				x							
1	31	95	x				5	2	x^2					
2	34	35	x		x									
2	36						x							
2	38	85			x									
1	40	100	x		x		x							
1	41	30/40	x/x		x/		x/							
2	43	40	x				10	1						
2	45	60	x		x									
1	47	100	x											

Tofts 0-7.5cm (1)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	1		x		100	1								
1	3	80	x				20	1						
1	5	75	x		10	1	15	1						
1	8	90	x		5	1	5	1						
1	10	70	x		25	1	5	1						
1	13	90	x		5	1	5	1						
1	15	90	x		x		10	3						
1	17	100	x		x		x							
1	20	80	x		10	1	10	1						
1	22	100	x		x		x							
1	25	100	x		5	1	x							
1	27	90	x		5	1	5	1						
1	29	90	x		x		10	2						
1	32	85	x		10	1	5	1						
1	34	85	x		10	1	5	1						
1	36	65	x		15	1	20	1						
1	37	90	x		x		10	1						
1	39	90	x		5	1	5	1						
1	41	95	x		x		5	1						

Tofts 6.5-14cm (2)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	1	90	x				5	1						
1	3	100	x				x							
1	5	100	x				x							
1	8	100	x						x^6					
1	10	100	x				10	1	x^2					
1	12	95	x				5	1						
1	13	95	x		x		5	1	x^2					
1	15	95	x		x		5	1						
1	17	90	x		5	1	5	1						
1	20	95	x		x		5	1						
1	22	100	x		x		x							
1	24	75	x		10	2	15	2	x^3					
1	25	100	x		x		x							
1	27	90	x		x		10	1						
1	29	100	x		x		x							
1	32	95	x		x		5	1						
1	34	85	x		x		10	1	5^3	2				
1	36	100	x		x				x^2					
1	37	95	x		x		5	1						
1	39	90	x		x		10	1						
1	41	85	x		5	1	10	1						

Tofts 15.5-21cm (3)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	1	90	x		5	1	5	1						
1	3	95	x				5	1						
1	5	95	x		x		5	1						
1	7	100	x		x		x							
1	9	95	x		x		5	1						
1	12	90	x		5	1	5	1						
1	14	100	x		x		x							
1	16	90	x		5	1	5	1						
1	18	90	x		5	1	5	1						
1	20	95	x		x		5	1						
1	22	85	x		5	1	10	1						
1	24	90	x		x		10	1						
1	26	95	x		x		5	1						
1	28	90	x		5		5	1						
1	30	85	x		5	1	10	1						
1	34	75	x		10	2	15	2						
1	36	100	x		x		x							

Tofts 20-27.5cm (4)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	2	100	x		x		x		x[3]					
1	4	85	x		5	1	10	1						
1	6	95	x		x		5	1	5[3]	2				
1	10	100	x		x		x							
1	12	95	x		5	1	x							
1	14	100	x				x							
1	16	70	x		30	1	x							
1	18	75	x		20	2	5	1						
1	20	95	x		5	1	x							
1	24	100	x		x		x							
1	26	90	x		x		10	3						
1	28	95	x		x		5	2						
1	30	90	x		x		10	1						
1	32	95	x		x		5	1	5[3]					
1	34	95	x		x		5	1						
1	38	85	x		x		15	1						
1	40	90	x		5	1	5	1						
1	42	100	x		x		x							
1	44	100	x											
1	46	85	x		x		15	2						
1	48	95			x		5	2						

Tofts 26.5-34cm (5)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	2	100	x		x		x		x[6]					
1	4	100	x		x		x							
1	6	90	x		x		10	1						
1	10	100	x											
1	12	100	x		x		x							
1	14	95	x		x		5							
1	17	100	x		x		x							
1	19	90	x		x		10							
1	21	90	x		x		10							
1	23	100	x											
1	25	100	x				x							
1	27	85	x		x		15	2						
2	31	40	x		x		60	1						
2	33	40	x		20	1	40	1						
1	35	80	x		x		20	2						
2	38	30/60	x/x		x/x		10	1						
2	40	75/20	x/x		x/x		x/x							
1	42	85	x		x		15	1						
2	45	90	10/x	1	x		x							
2	47	30/40	x/x		x		10	1						
1	49	85	x		x		15	1						

Tofts A (6)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	2	85	x		x		15	1						
1	4	65	x		x		35	1						
1	6	90	x		x		10	2						
2	10	80	x		5	1	15	1						
2	12	20/80	x/x		x/		x/							
1	16	80	x		x		20	1						
1	18	90	x		x		10	1	x[2]					
2	20	60/30	x/x		x/x		x/x							
1	24	100	x		x		x		x[2]					
1	26	90	x		x		10	1						
2	30	60/30	x/x		x/x		x/							
1	32	100	x		x		x							
2	34	20/80	x/x		/x		x/x							
1	38	70	x		x		30	1						
2	40	30/70	x/x		x/x		x/		/x[6]					
1	44	100	x				x							
1	46	100	x		x		x							
1	48	100	x		x		x							

Tofts B (7)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	2	100	x		x		x							
2	4	/25	x/x		x/x		10/x	1/						
2	6	75	x		5	1	20	1						
2	10	95	x		x		5	1						
2	12	60	x		10	1	20	1	5^{6}	1	5^{2}	1		
2	16	90	x		x		10	1	x^{6}					
2	18	60	x		5	1	15	1						
2	20	85	x		x		15	1						
2	24	100	x		x		x							
2	26	60	x		x		30	1						
2	30	80	x		5	1	15	1						
2	32	100	x		x		x							
2	34	25	x		50	1	25	1	x^{2}					
2	38	75	x		x		25	1						
2	40	80	x		x		20	1						
2	44	90	x		x		x							
2	46	90	x		5	1	5	1						
2	48	90	x		5	1	5	1						

Tofts C (8)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	2	100	x		x		x							
1	4	100	x		x									
1	6	100	x											
1	10	70	x		10	1	20	1						
1	12	100	x		x		x		x[6]					
1	16	100	x		x		x							
1	18	95	x				5	1						
1	20	100	x		x									
1	24	95	x		x		5	1						
1	26	100	x		x		x							
2	30	5	x				5	1						
2	32	25/75	x/x		/x		/x							
2	34	100	x		x		x							
2	38	95/5	x/x		x		x		x[2]					
2	40	85	x				5	1						
2	44	20	x		5	1	25	1						
2	46	100	x		x		x							
2	48	100	x		x		x		x[3]					
2	52	100	x		x		x							
2	54	100	x		x		x							

Tofts D (9)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	2	100	x		x		x							
1	4	100	x		x									
1	6	100	x											
1	10	70	x		10		20	1						
1	12	100	x		x		x		x[6]					
1	16	100	x		x		x							
1	18	95	x				5	1						
1	20	100	x		x									
1	24	95	x		x		5	1						
1	26	100	x		x		x							
2	30	5	x				5	1						
2	32	25/75	x/x		/x		/x							
2	34	100	x		x		x							
2	38	95/5	x/x		x		x		x[2]					
2	40	85	x				5	1						
2	44	20	x		5	1	25	1						
2	46	100	x		x		x							
2	48	100	x		x		x		x[3]					
2	52	100	x		x		x							
2	54	100	x		x		x							

Tofts E (10)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	2	95	x		x		5	1						
1	4	95	x		x		5	1						
1	6	100	x		x		x							
1	10	100	x		x		x							
1	12	95	x		x		5	1						
1	14	100	x		x		x							
1	16	100	x		x		x							
1	18	100	x		x		x							
2	20	95	x				5	1						
1	24	90	x		x		10	1						
2	26	95	x		x		x							
1	28	90	x		x		10	1						
1	30	100	x		x		x		5[3]	2				
1	32	95	x		x		5	1						
2	34	100	x		x		x							
1	38	95	x		x		5	1						
2	40	100	x		x		x							
1	42	95	x		x		5	1						
1	44	100	x		x		x							
1	46	95	x		x		x		5[3]	1				
1	48	100	x		x		x							

Tofts F (11)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	2	100	x		x		x							
1	4	60	x		x		40	2						
1	6	100	x		x		x							
1	10	85	x				5	1						
1	12	95	x		x		5	1						
1	16	100	x		x		x							
1	18	100	x		x		x							
1	2	90	x		x		10	1						
1	24	50/50	x/x				x/							
1	26	95	x		x		x							
1	30	100	x		x		x		x[2]					
2	32	50/40	x/x		x/x		x/x		x[2]					
1	34	90	x		x		5	1						
1	38	95	x		x		x							
1	40	100	x		x		x							
1	44	90	x		x		5	1						
1	46	90	x		x		5	1						
1	48	95	x		x		5	1						
1	51	80	x				x		x[6]					
1	53	100	x		x		x		x[6]					
1	55	100	x		x		x							

Tofts G (12)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	2	95	x				x		5[3]	2				
1	4	100	x						x[3]					
1	6	100	x				x		5[3]	1				
1	8	100	x		x		x		x[3]					
1	12	95	x		x		x		5[3]	1				
1	14	100			x		x		x[3]					
1	16	100	x		x				x[3]					
1	20	90	x		x		5	1	5[3]	1				
1	22	95	x				x		5[3]	2				
1	24	95	x		x				5[3]	2				
1	26	95	x		x		x		5[3]	2				
1	30	100			x		x							
1	32	100	x		x		x		x[3]					
1	34	100	x		x									
1	38	95	x		x		x		5[3]	2				
1	40	90	x		10	1	x		x[3]					
1	42	100	x		x		x		x[3]					
1	44	100			x		x		x[3]					
1	48	100	x		x		x							
1	50	100	x				x		x[3]					
1	52	100	x				x		10[3]	1				

Tofts H (13)

Zone	Grid Square	Total Biological Fabric	Fabric Pattern		Excrement, Mamillated		Excrement, Bacillo-Cylindrical		Other		Other		Other	
			%	Dist	%	Dist	%	Dist	%	Dist	%	Dist	%	Dist
1	2	95	x				x							
1	4	95	x				x							
1	6	100	x		x		x							
1	10	95	x		x		5	2						
1	12	85	x		x		15	1						
1	16	100	x		x		x							
1	18	100	x				x		x[2]					
1	20	90	x				10	2						
1	24	100	x		x		x							
1	26	100	x		x		x							
1	30	100	x		x		x							
1	32	95	x		x		5	1						
1	34	100	x		x		x							
1	38	95	x		x		x		5[3]	1				
1	40	100	x		x		x							
1	44	100	x		x		x							
1	46	100	x				x							
1	48	100	x		x		x							
1	52		x											

Key to Superscripts:

1: Cylindrical Excremental Pedofeature	2: Ellipsoidal Excremental Pedofeature	3: Textural Pedofeature	4: Impregnated Fabric
5: Tailed Conoidal Pedofeature	6: Spheroidal Excremental Pedofeature	/: Divisions between non-impregnated /impregnated fabric	

Appendix Four: Soil & Sediment Descriptions

On site descriptions are based on the systems outlined in the Soil Survey Field Handbook (ed. Hodgson 1976) and the Cambridge Archaeological Manual on Excavation (2001), those of the off-site profiles are based entirely on the Soil Survey Field Handbook.

Site Descriptions.

Beafield

Site description
The site is a mound of c2.5m height. Local relief is essentially level, with the mound forming the only higher ground in the immediate vicinity. The mound sides are straight to convex. There is no evidence of recent erosion or deposition on the area of the test pit. The land use regime of the current sampling area is permanent pasture. Vegetation cover is abundant on the sampling area. Slight poaching of surface due to animal (cattle) trampling is evident.

Unit 1
Section No: 1
18-20 cm thickness. Colour: 10 YR2/2. Organic matter intimately mixed with mineral component. Humose slightly sandy silt. Stones mostly concentrated at base of unit, as are shells (limpet). Stones c 1-2 cm long, sub-angular tabular. Material is moist. Structure consists of medium to coarse granular peds, weakly to moderately developed. The material is moderately weak to moderately firm, deformable and slightly to moderately plastic. Many to common (grading down unit) fine fibrous roots. Clear to gradual boundary.

Unit 1 is considered to be cognate with units 4, 9, 13, 17 and 19.

Unit 2
Section No: 1
Thickness: 38 cm. Colour: 10 YR3/2. Organic matter intimately mixed with mineral component. Humose sandy silt, with sand fraction coarser than unit 1. Slightly stony, predominantly small to mediumsub-angular tabular sandstone. Material is moist. Structure consists of medium to coarse granular peds, weakly to moderately developed. The material is moderately weak to moderately firm, deformable and slightly to moderately plastic. Common to few (grading down unit) fine fibrous roots.

Unit 2 is considered to be cognate with units 5, 10, 14,18 and 20.

Unit 3
Section No: 1
Thickness: 3cm. Colour: 2.5Y 3.5/1, Silt, with very little organic matter except charcoal/charred material (c. 3x5-7mm) which is abundant. Both organic fractions intimately mixed with the mineral fraction. Virtually stone free. Material is moist. Structure is apedal. Sediment strength is weak, is weakly deformable and non-plastic. No roots. The unit has an outer zone that interpenetrates with unit 2, with a diffuse bonundary with that unit. The outer zone has very many medium sized

mottles, with a colour of 2.5YR 4/8, a distinct contrast and a diffuse boundary with the matrix. The outer zone has a basic matrix colour of 10 YR 3/2, with a silt loam particle size distribution (very low on sand and clay).

Unit 3 is considered to be cognate with units 6 and 21.

Unit 4
Section No: 2
19-20 cm thickness. Colour: 10 YR2.5/2. Organic matter intimately mixed with mineral component. Humose, slightly sandy silt, with sand content reducing down profile. Stones mostly concentrated at base of unit, as are shells (limpet). Stones c 1-2 cm long, sub-angular tabular. Material is moist. Structure consists of medium to coarse granular peds, weakly to moderately developed. The material is moderately weak to moderately firm, deformable and slightly to moderately plastic. Many to common (grading down unit) fine fibrous roots. Gradual boundary.

Unit 4 is considered to be cognate with units 1, 9, 13, 17 and 19.

Unit 5
Section No: 2
Thickness: 38 cm. Colour: 10 YR3/2. Organic matter intimately mixed with mineral component. Humose sandy silt, with sand fraction coarser than unit 1. Slightly stony, predominantly small to mediumsub-angular tabular sandstone, occasional cockle, winkle and limpet shell fragments (c 4-8mm) and very occasional fragments of burnt bone (2-5 mm). Material is moist. Structure consists of medium to coarse granular peds, weakly to moderately developed. The material is moderately weak to moderately firm, deformable and slightly to moderately plastic. Common to few (grading down unit) fine fibrous roots. There are common, and locally very many (see section 2) fine to medium mottles, colour 7.5 YR 5/3 with a prominent contrast and sharp boundary with the matrix. Similar particle size distribution to the matrix, but with less sand. Boundaries clear to gradual, occasionally sharp.

Unit 5 is considered to be cognate with units 2, 10, 14, 18 and 20.

Unit 6
Section No: 2
Thickness: 3cm. Colour: 2.5Y 2.5/1, Silt, with very little organic matter except charcoal/charred material (c. 3x5-7mm) which is common. Both organic fractions intimately mixed with the mineral fraction. Virtually stone free. Material is moist. Structure is apedal. Sediment strength is weak, is weakly deformable and non-plastic. No roots

Unit 6 is considered to be cognate with units 3 and 21.

Unit 7
Section No: 2
Thickness: 40+ cm. Colour: 7.5 YR3/2.5. Organic matter intimately mixed with mineral component. Sandy silt, with very low sand content, but of coarse, almost

gritty nature. Very few clasts. Occasional fine mottles, colour; 7.5 YR 5/3, with prominent contrast and sharp boundary with the matrix. Material is moist. Structure consists of medium to coarse granular peds, weakly to moderately developed. The material is moderately weak to moderately firm, deformable and slightly to moderately plastic. No roots found. Boundaries clear to gradual, occasionally sharp.

Unit 7 has no cognate units.

Unit 8

Section No: 2

Colour: 7.5 YR 4/3. Organic matter intimately mixed with mineral component. Sandy silt/silt, with very low sand content, but of coarse, almost gritty nature. Very few clasts. Many fine mottles, colour; 7.5 YR 5/3, with prominent contrast and sharp boundary with the matrix. Material is moist. Structure consists of medium to coarse granular peds, weakly to moderately developed. The material is moderately weak to moderately firm, deformable and slightly to moderately plastic. No roots found. Boundaries clear to gradual.

Unit 8 has no cognate units.

Unit 9

Section No: 3

19-22 cm thickness. Colour: 10 YR3/2. Organic matter intimately mixed with mineral component. Humose, sandy silt. Stones mostly concentrated at base of unit, as are shells (limpet). Stones c 1-4 cm long, sub-angular tabular. Few very fine to fine mottles, colour; 7.5 YR 5/3, with prominent contrast and sharp boundary with the matrix. Material is moist. Structure consists of medium to coarse granular peds, weakly to moderately developed. The material is moderately weak to moderately firm, deformable and slightly to moderately plastic. Many to common (grading down unit) fine fibrous roots. Gradual boundary.

Unit 9 is considered to be cognate with units 1, 4, 13, 17 and 19.

Unit 10

Section No: 3

Thickness: 38 cm. Colour: 10 YR3/3. Organic matter intimately mixed with mineral component. Humose sandy silt. Slightly stony, predominantly small to mediumsub-angular tabular sandstone c.2cm. Material is moist. Structure consists of medium to coarse granular peds, weakly to moderately developed. The material is moderately weak to moderately firm, deformable and slightly to moderately plastic. Common to few (grading down unit) fine fibrous roots. There are common, and locally very many (see section 2) fine to medium mottles, colour 7.5 YR 5/3 with a prominent contrast and sharp boundary with the matrix. Similar particle size distribution to the matrix, but with less sand. Common to many fine fragments of charcoal/charred material. Boundaries clear to gradual.

Unit 10 is considered to be cognate with units 2, 5, 14, 18 and 20.

Unit 11
Section No: 3
Colour: 10 YR4/. Organic matter intimately mixed with mineral component. Humose sandy silt. Slightly stony, predominantly small to medium sub-angular tabular sandstone c.2cm. Material is moist. Structure consists of medium to coarse granular peds, weakly to moderately developed. The material is moderately weak, slightly deformable and slightly plastic. No roots. There are many fine mottles, colour 7.5 YR 5/3 with a prominent contrast and sharp boundary with the matrix. Similar particle size distribution to the matrix, but with less sand. Common to many fine fragments of charcoal/charred material. Boundaries clear to gradual.

Unit 11 is considered to be cognate with unit 15.

Unit 12
Section No: 3
Thickness: 3cm. Colour: 10YR4/1.5, Silt, with very little organic matter except charcoal/charred material (c. 3x5-7mm) which is common. Both organic fractions intimately mixed with the mineral fraction. Virtually stone free. Many very fine to fine mottles, colour; 7.5 YR 5/3, with prominent contrast and sharp boundary with the matrix. Material is moist. Structure is apedal. Sediment strength is weak, is weakly deformable and non-plastic. No roots

Unit 12 is considered to be cognate with unit 16.

Unit 13
Section No: 4
17-20 cm thickness. Colour: 7.5 YR3/2.5. Organic matter intimately mixed with mineral component. Sandy silt. Stones mostly concentrated at base of unit, as are shells (limpet). Stones c 1-5 cm long, sub-angular tabular. Material is moist. Structure consists of medium to coarse granular peds, weakly to moderately developed. The material is moderately weak to moderately firm, deformable and slightly to moderately plastic. Many to common (grading down unit) fine fibrous roots. Gradual boundary.

Unit 13 is considered to be cognate with units 1, 4, 9, 17 and 19.

Unit 14
Section No: 4
Thickness: 38 cm. Colour: 7.5 YR3/1.5. Organic matter intimately mixed with mineral component. Sandy silt/sandy silt loam. Slightly stony, predominantly small to medium sub-angular tabular sandstone c.2cm. Occasional shell fragment, c. 2-3 cm length. Material is moist. Structure consists of medium to coarse granular peds, weakly to moderately developed. The material is moderately weak to moderately firm, deformable and slightly to moderately plastic. Common to few (grading down

unit) fine fibrous roots. There are many fine to medium mottles, colour 7.5 YR 5/3 with a prominent contrast and sharp boundary with the matrix. Similar particle size distribution to the matrix, but with less sand. Many fine fragments of charcoal/charred material. Boundaries clear to gradual.

Unit 14 is considered to be cognate with units 2, 5, 10, 18 and 20.

Unit 15
Section No: 4
Thickness: c. 20cm. Colour: 7.5 YR 4/3, Gritty silt, with very little organic matter except charcoal/charred material (c. 3x5-7mm) which is common. Both organic fractions intimately mixed with the mineral fraction. Slightly stony, predominantly small to medium sub-angular tabular sandstone c.2cm. Very many very fine to fine mottles, colour; 7.5 YR 5/3, with prominent contrast and sharp boundary with the matrix. Common grey mottles, colour; 2.5 YR 3.5/1, with distinct contrast and sharp boundary with the matrix. Material is moist. Structure consists of medium to coarse granular peds, weakly developed. Sediment strength is weak, is weakly deformable and non-plastic. No roots.

Unit 15 is considered to be cognate with unit 11.

Unit 16
Section No: 4
Thickness: c. 18cm. Colour: 7.5 YR 3/3, Gritty silt, with very little organic matter except charcoal/charred material (c. 3x5-7mm) which is common. Both organic fractions intimately mixed with the mineral fraction. Stoneless. Very many very fine to fine mottles, colour; 7.5 YR 5/3, with prominent contrast and sharp boundary with the matrix. Common grey mottles, colour; 2.5 YR 3.5/1, with distinct contrast and sharp boundary with the matrix. Material is moist. Structure consists of medium to coarse granular peds, weakly developed. Sediment strength is weak, is weakly deformable and non-plastic. No roots.

Unit 16 is considered to be cognate with unit 12.

Unit No: 17
Section No: 5
18-20 cm thickness. Colour: 10 YR2/2. Organic matter intimately mixed with mineral component. Humose slightly sandy silt. Stones mostly concentrated at base of unit, as are shells (limpet). Stones c 1-2 cm long, sub-angular tabular. Material is moist. Structure consists of medium to coarse granular peds, weakly to moderately developed. The material is moderately weak to moderately firm, deformable and slightly to moderately plastic. Many to common (grading down unit) fine fibrous roots. Clear to gradual boundary.

Unit 17 is considered to be cognate with units 1, 4, 9, 13 and 19.

Unit No: 18
Section No: 5
Thickness: 35-36 cm. Colour: 10 YR3/2. Organic matter intimately mixed with mineral component. Humose sandy silt. Slightly stony, predominantly small to

medium sub-angular tabular sandstone. Material is moist. Structure consists of medium to coarse granular peds, weakly to moderately developed. The material is moderately weak to moderately firm, deformable and slightly to moderately plastic. Common to few (grading down unit) fine fibrous roots. There are common, and locally very many (see section 5) fine to medium mottles, colour 7.5 YR 4.5/3 with a prominent contrast and sharp boundary with the matrix. Similar particle size distribution to the matrix, but with less sand. Boundaries gradual.

Unit 18 is considered to be cognate with units 2, 5, 10, 14 and 20.

Unit No: 19
Section No: 6
19-21 cm thickness. Colour: 10 YR2/2.5. Organic matter intimately mixed with mineral component. Humose slightly sandy silt. Stones mostly concentrated at base of unit, as are shells (limpet). Stones c 1-2 cm long, sub-angular tabular. Material is moist. Structure consists of medium to coarse granular peds, weakly to moderately developed. The material is moderately weak to moderately firm, deformable and slightly to moderately plastic. Many to common (grading down unit) fine fibrous roots. Gradual boundary.

Unit 19 is considered to be cognate with units 1, 4, 9, 13 and 17.

Unit No: 20
Section No: 6
Thickness: 35-36 cm. Colour: 10 YR2.5/2. Organic matter intimately mixed with mineral component. Humose sandy silt. Slightly stony, predominantly small to medium sub-angular tabular sandstone. Material is moist. Structure consists of medium to coarse granular peds, weakly to moderately developed. The material is moderately weak to moderately firm, deformable and slightly to moderately plastic. Common to few (grading down unit) fine fibrous roots. There are common fine to medium mottles, colour 7.5 YR 4.5/3 with a prominent contrast and sharp boundary with the matrix. Similar particle size distribution to the matrix, but with less sand. Boundaries gradual.

Unit 20 is considered to be cognate with units 2, 5, 10, 14 and 18.

Unit No: 21
Section No: 6
Thickness: 3-5cm. Colour: 2.5Y 3.5/1, Silt, with very little organic matter except charcoal/charred material (c. 3x5-7mm) which is abundant. Both organic fractions intimately mixed with the mineral fraction. Virtually stone free. Material is moist. Structure is apedal. Sediment strength is weak, is weakly deformable and non-plastic. No roots. The unit has an outer zone that interpenetrates with unit 2, with a diffuse bonundary with that unit. The outer zone has very many medium sized mottles, with a colour of 2.5YR 4/8, a distinct contrast and a diffuse boundary with the matrix. The outer zone has a basic matrix colour of 10 YR 3/2, with a silt loam particle size distribution (very low on sand and clay).

Unit 21 is considered to be cognate with units 3 and 6.

Tofts

Site description
The site is a mound of 2.75m height. Local relief is essentially level, with the mound forming the highest ground in the immediate vicinity, with some lower mounds at a distance of c 200m away, in a north to north-easterly direction. The mound sides are straight to convex. There is no evidence of recent erosion or deposition on the area of the test pit. The land use regime of the overall area is permanent pasture, with the immediate location of the sampling site being covered with vegetation more in line with rough grazing/set aside. Grass is rank, seemingly ungrazed, with c. 10% of the vegetation being formed by *Rumex spp.* Vegetation cover is abundant on the sampling area. Slight poaching of surface due to animal (cattle) trampling is evident.

Unit 1
Section No: 1
Depth: 37cm. Munsell colour is predominantly 10yr2/2 though locally value may reach 3 and chroma may vary between 1 and 3. Texture is predominantly a humose silty clay loam although locally the deposit may be a sandy clay loam. Sand content is generally coarse and increases slightly below c. 20 cm. Organic material is intimately intermixed with the mineral fraction. The deposit is heavily rooted to a depth of between 2 and 7 cm. Starting at a depth of 19-20 cm from the ground surface and continuing to a depth of 23-25 cm from the ground surface is a layer largely composed of limpet shells. Occasional clasts generally sub-angular and tabular in shape, size range 3-4 cm length by 1-2 cm thickness. Area above layer is generally free of inclusions, below this are occasional (locally frequent) shells, mainly limpet, occasional fish bone and occasional clasts, tabular, angular to sub-rounded varying from 2 -15 cm in length. Material is moist. Structure consists of medium to coarse granular peds, moderately developed. Soil strength is weak, is weakly deformable and slightly plastic. Lower boundary moderately distinct.

Unit one is cognate with units 3, 8, 11, 14 and 16.

Unit 2
Section No: 1
Thickness: 10+ cm. Munsell colour is predominantly 10yr3/1 Texture is predominantly humose silty clay loam. The material is more compact and may contain slightly less sand than the material in unit 1. Localised mottling, in section generally 3-4 cm across, colour predominantly 10yr5/6, with a prominent contrast and sharp boundary with the matrix. Also occasional orange flecking, 2-4mm, also 10yr5/6. Black flecks frequent throughout deposit, usually 2-4 mm with a prominent contrast and sharp boundary with the matrix. Possibly charcoal. Other inclusions include: occasional clasts, 3-4 cm in length, tabular, sub-rounded to sub-angular; occasional shells, mostly limpet. Upper boundary clear to gradual.

Unit 2 is cognate with units 7, 9, 12, 15, and 17.

Unit 3

Section No: 2
Depth: 37cm. Munsell colour is 10 YR 2.5/1. Texture is predominantly a humose silty clay loam. Sand content is generally coarse and increases slightly below c. 20 cm. Organic material is intimately intermixed with the mineral fraction. Many to common (grading down unit) fine fibrous roots. Starting at a depth of 21cm from the ground surface and continuing to a depth of 24 cm from the ground surface is a layer largely composed of limpet shells. Occasional clasts generally sub-angular and tabular in shape, size range 1x2cm. Area above layer is generally free of inclusions, below this are occasional (locally frequent) shells, mainly limpet, occasional fish bone and occasional clasts, tabular, angular to sub-rounded varying from 2 -15 cm in length.. Material is moist. Structure consists of medium to coarse granular peds, moderately developed. Soil strength is weak, is weakly deformable and slightly plastic. Lower boundary moderately distinct.

Unit 3 is cognate with units 1, 8, 11, 14, and 16.

Unit 4
Section No: 2
Thickness: 2-10cm. Munsell colour is 10YR 3/2 Texture is silty clay loam, with very little sand. Little organic matter except black flecks (see below). Very many mottles, in section generally 1-5 cm across, colour 7,5YR 4/4, with a prominent contrast and sharp boundary with the matrix. Black flecks frequent throughout deposit, usually 2-4 mm with a prominent contrast and sharp boundary with the matrix. Possibly charcoal. Other inclusions include: a very few shells, mostly limpet. Material is moist. Structure consists of fine to medium granular peds, very weakly developed. Soil strength is weak, is semi-deformable and non-plastic. Boundaries clear to gradual.

Unit 4 is cognate with units 10 and 13.

Unit 5
Section No: 2
Thickness: 15cm. Munsell colour is10YR 3.5/2. Texture: humose silty clay loam. Organic material is intimately mixed with the mineral fraction. Few mottles, in section generally 1cm across, colour predominantly 10 YR 5/6, with a prominent contrast and sharp boundary with the matrix. Other inclusions include: very few shells, mostly limpet. Few fine fibrous roots. Boundaries gradual.

Unit 5 has no cognate units.

Unit 6
Section No: 2
Thickness: 2-10cm. Munsell colour is 10YR 3/2 Texture is silty clay loam, with very little sand. Little organic matter except black flecks (see below). Very many mottles, in section generally 1-2 cm across, colour 10YR 4/2, with a distinct contrast and sharp boundary with the matrix. Black flecks frequent throughout deposit, usually 2-4 mm with a prominent contrast and sharp boundary with the matrix. Possibly charcoal. Material is moist. Structure consists of fine to medium granular peds, very weakly developed. Soil strength is weak, is semi-deformable and non-plastic. Boundaries clear to gradual.

Unit 6 has no cognate units.

Unit 7
Section No: 2
Thickness: 40+ cm. Munsell colour is predominantly 10 YR3/2. Texture is predominantly humose silty clay loam. Organic matter is intimately mixed with the mineral fraction. Black flecks frequent throughout deposit, usually 2-4 mm with a prominent contrast and sharp boundary with the matrix. Possibly charcoal. Other inclusions include: occasional clasts, 3-4 cm in length, tabular, sub-rounded to sub-angular; occasional shells, mostly limpet. Upper boundary clear to gradual.

Bone comb found in this context at a depth of 73 cm from the ground surface, 101cm depth from the site datum (see section two and plan).

Unit 7 is cognate with units 2, 9, 12, 15 and 17.

Unit 8
Section No: 3
Depth: 35cm. Munsell colour: 10 YR 3/1.5. Texture is predominantly a humose silty clay loam although locally the deposit may be a sandy clay loam. Sand content is generally coarse and increases slightly below c20 cm. Organic material is intimately intermixed with the mineral fraction. The deposit is heavily rooted to a depth of between 2 and 7 cm. Starting at a depth 20cm from the ground surface and continuing to a depth of 23cm is a layer largely composed of limpet shells. Below this layer there are occasional clasts, generally sub-angular and tabular in shape, size range 3-4 cm length by 1-2 cm thickness. Area above layer is generally free of clasts, below this are occasional (locally frequent) shells, mainly limpet, occasional fish bone and occasional clasts, tabular, angular to sub-rounded varying from 2 -15 cm in length. . Material is moist. Structure consists of medium to coarse granular peds, moderately developed. Soil strength is weak, is weakly deformable and slightly plastic. Lower boundary clear to gradual.

Unit 8 is cognate with units 1, 3, 11, 14 and 16.

Unit 9
Section No: 3
Thickness: 15+ cm. Munsell colour is predominantly 10 YR 3/1. Texture is predominantly humose silty clay loam. The material is more compact and may contain slightly less sand than the material in unit 8. Very few to few mottles, in section generally 2mm across, colour predominantly 10 YR 5/6, with a prominent contrast and sharp boundary with the matrix. Other inclusions include: a very few clasts, 2-3 cm in length, tabular, sub-rounded to sub-angular; very few shells, mostly limpet. Boundaries clear to gradual.

Unit 9 is cognate with units 2, 7, 12, 15 and 17.

Unit 10
Section No: 3

Thickness: 2-5cm. Munsell colour is 10YR 3.5/2.5 Texture is silty clay loam, with very little sand. Few to very few mottles, in section generally 1-4 cm across, colour 7.5 YR 5/6, with a prominent contrast and sharp boundary with the matrix. Other inclusions include: a very few shells, mostly limpet, and a very few clasts, tabular, sub-angular to angular. Material is moist. Structure consists of fine to medium granular peds, very weakly developed. Soil strength is weak, is semi-deformable and non-plastic. Boundaries clear to gradual.

Unit 10 is cognate with units 4 and 13.

Unit 11
Section No: 4
Depth: 35cm. Munsell colour: 10 YR 2/2. Texture is predominantly a humose silty clay loam. Organic material is intimately intermixed with the mineral fraction. The deposit is heavily rooted to a depth of 7 cm, with fine fibrous roots. There is a layer largely composed of limpet shellsat a depth of 19-25cm, of c.2cm thickness. Below this layer there are occasional clasts, generally sub-angular and tabular in shape, size range 3-4 cm length by 1-2 cm thickness. Area above layer is generally free of clasts, below this are occasional (locally frequent) shells, mainly limpet and occasional clasts, tabular, angular to sub-rounded varying from 2 -15 cm in length.. Material is moist. Structure consists of medium to coarse granular peds, moderately developed. Soil strength is weak, is weakly deformable and slightly plastic. Lower boundary clear to gradual.

Unit 11 is cognate with units 1, 3, 8, 11, 14 and 16.

Unit 12
Section No: 4
Thickness: 20+ cm. Munsell colour is predominantly 10 YR 3/1. Texture is predominantly humose silty clay loam. The material is more compact and may contain slightly less sand than the material in unit 11. Very few to few fibrous roots present. Very few to few mottles, in section generally 2-4mm across, colour predominantly 10 YR 5/6, with a prominent contrast and sharp boundary with the matrix. Other inclusions include: a very few clasts, 2-3 cm in length, tabular, sub-rounded to sub-angular; very few shells, mostly limpet. Boundaries clear to gradual.

Unit 12 is cognate with units 2,7, 9, 15 and 17.

Unit 13
Section No: 4
Thickness: 2-5cm. Munsell colour is 10YR 3/3 Texture is sandy clay loam. Many mottles, in section generally 1-4 cm across, colour 7.5 YR 5/6, with a prominent contrast and sharp boundary with the matrix. Few black flecks, generally c.2mm, with a prominent contrast and sharp boundary with the matrix. Other inclusions include: a very few shells, mostly limpet, and a very few clasts, tabular, sub-angular to angular. Material is moist. Structure consists of fine to medium granular peds, very weakly developed. Soil strength is weak, is semi-deformable and non-plastic. Boundaries clear to gradual.

Unit 13 is cognate with units 4 and 10.

Unit 14

Section No: 5

Depth: 38cm. Munsell colour is 10 YR 3/1.5. Texture is predominantly a humose silty clay loam. Sand content is generally coarse and increases slightly below c. 20 cm. Organic material is intimately intermixed with the mineral fraction. Many to common (grading down unit) fine fibrous roots. Starting at a depth of c. 24cm from the ground surface and continuing to a depth of c. 29cm from the ground surface is a layer largely composed of limpet shells. Occasional clasts generally sub-angular and tabular in shape, size range 1x2cm. Area above layer is generally free of inclusions, below this are occasional (locally frequent) shells, mainly limpet, occasional fish bone and occasional clasts, tabular, angular to sub-rounded varying from 2 -15 cm in length. . Material is moist. Structure consists of medium to coarse granular peds, moderately developed. Soil strength is weak, is weakly deformable and slightly plastic. Lower boundary moderately distinct.

Unit 14 is cognate with units 1, 3, 8, 11 and 16.

Unit 15

Section No: 5

Thickness: 37+ cm. Munsell colour is predominantly 10 YR2.5/2. Texture is predominantly humose silty clay loam. Organic matter is intimately mixed with the mineral fraction. Black flecks frequent throughout deposit, usually 2-4 mm with a prominent contrast and sharp boundary with the matrix. Possibly charcoal. Other inclusions include: occasional clasts, 3-4 cm in length, tabular, sub-rounded to sub-angular; occasional shells, mostly limpet. Upper boundary gradual.

Unit 15 is cognate with units 2,7, 9, 12 and 17.

Unit 16

Section No: 6

Depth: 37 - 43cm. Munsell colour is predominantly 10yr2/2. Texture is predominantly a humose silty clay loam although locally the deposit may be a sandy clay loam. Sand content is generally coarse and increases slightly below c20 cm. Organic material is intimately intermixed with the mineral fraction. The deposit is heavily rooted to a depth of between 2 and 7 cm. Starting at a depth of 20-27 cm from the ground surface and continuing to a depth of 23-30cm from the ground surface is a layer largely composed of limpet shells. Occasional clasts generally sub-angular and tabular in shape, size range 3-4 cm length by 1-2 cm thickness. Area above layer is generally free of inclusions, below this are occasional (locally frequent) shells, mainly limpet, occasional fish bone and occasional clasts, tabular, angular to sub-rounded varying from 3 -15 cm in length. Material is moist. Structure consists of medium to coarse granular peds, moderately developed. Soil strength is weak, is weakly deformable and slightly plastic. Lower boundary moderately distinct.

Unit 16 is cognate with units 1, 3, 8, 11 and 14.

Unit 17

Section No: 6

Thickness: 34+ cm. Munsell colour is predominantly 10 YR3/1.5. Texture is predominantly humose silty clay loam. Organic matter is intimately mixed with the mineral fraction. Black flecks frequent throughout deposit, usually 2-4 mm with a prominent contrast and sharp boundary with the matrix. Possibly charcoal. Other inclusions include: occasional clasts, 2-5 cm in length, tabular, sub-rounded to sub-angular; occasional shells, mostly limpet. Upper boundary gradual.

Unit 17 is cognate with units 2,7, 9, 12 and 15.

Westbrough

The site is a mound of approximately 1.5m height. Local relief is essentially level, with the mound forming the only higher ground in the immediate vicinity. The mound sides are straight to convex. There is no evidence of recent erosion or deposition on the area of the test pit. The land use regime of the current sampling area is permanent pasture. Vegetation cover is very abundant on the sampling area. Slight poaching of surface due to animal (cattle) trampling is evident.

The units recorded at Westbrough were carefully followed through the course of sampling and excavation, as such there are no cognate units as all sections are effectively correlated.

Unit 1

Section No: 1

Depth: 12-16cm. Munsell colour is predominantly 2.5 Y 2.5/1. Texture is predominantly a humose silty loam. Organic material is intimately intermixed with the mineral fraction. The deposit has many fine fibrous roots to a depth of 7 cm. There is a layer largely composed of angular, tabular clasts with a thickness of 1-2cm, and a very few heavily dergraded shell fragments, at a depth of 12-16cm from the suface. Material is moist. Structure consists of medium to coarse granular peds, moderately developed. Soil strength is weak, is weakly deformable and slightly plastic. Lower boundary is clear, interdigitating considerably with unit below.

Unit 2

Section No: 1

Thickness: 10-15cm. Munsell colour is predominantly 10 YR 4/2.5 Texture: sandy silt loam. Many orange mottles, in section generally 2-4mm across, colour predominantly 7.5 YR 5/8, with a prominent contrast and sharp boundary with the matrix. Very few lenses of charcoal, tabular sub-rounded section, 4-7cm long, with prominent contrast and sharp boundary with the matrix. Other inclusions: few clasts, 1-2 cm in length, cuboidal/tabular, sub-rounded to sub-angular. Soil strength is weak, is weakly deformable and slightly plastic. Boundaries clear.

Unit 3

Section No: 2

Depth: 1-4cm. Munsell colour is predominantly 5 YR 4/6. Texture: sandy silt. Organic material is intimately intermixed with the mineral fraction. Many orange mottles, in section generally 2-4mm across, colour predominantly 7.5 YR 5/8, with a prominent contrast and sharp boundary with the matrix. Material is moist. Structure consists of medium to coarse granular peds, moderately developed. Soil strength is weak, is weakly deformable and slightly plastic. Lower boundary is clear to gradual.

Unit 4
Section No: 2
Depth: 12+cm. Munsell colour is predominantly 10YR 2/2. Texture is predominantly a slightly sandy silty loam. Little organic content, what organic material is present is intimately intermixed with the mineral fraction. The deposit has no roots. There are usually few clasts, those presently mostly as part of a layer composed of angular, prismoidal clasts with a thickness of 7-10mm, towards the base of the unit. Very few mottles, colour 10 YR 5/8 with a prominent contrast and sharp boundary with the matrix. Material is moist. Structure consists of medium to coarse granular peds, moderately developed. Soil strength is weak, is weakly deformable and slightly plastic. Upper boundary is clear, lower boundary is clear to gradual.

Unit 5
Section No:
Depth: 2-10+cm. Very many mottles, effectively forming fabric of deposit, colours 10 YR 5/3 and 10 YR 3/2 with a prominent contrast and sharp boundary with respect to one another. Texture: clay silt. Little organic content, what organic material is present is intimately intermixed with the mineral fraction. The deposit has no roots. Very few clasts, sub-angular, prismoidal clasts with a thickness of 5-7mm, towards the base of the unit. Material is moist. Structure consists of fine to medium granular peds, weakly developed. Sediment strength is moderately strong, is deformable and moderately plastic. Upper boundary is gradual, lower boundary is clear to gradual.

Unit 6
Section No:
Depth: 2-10+cm. Colour: 10 YR 3/1. Texture: clay silt. Little organic content, what organic material is present is intimately intermixed with the mineral fraction. The deposit has no roots. Many limpet shell fragments, heavily degraded. Material is moist. Structure consists of fine to medium granular peds, weakly developed. Sediment strength is moderately strong, is deformable and moderately plastic. Upper boundary is clear to gradual.

Unit 7
Section No:
Thickness: 10+cm. Munsell colour is predominantly 10 YR 3/1 Texture: clay silt. Very many mottles, in section generally 1-2cm across, colour predominantly 10 YR 5/3, with a prominent contrast and sharp boundary with the matrix. Within these are many flecks, colour 7.5 Y 5/8 with a distinct contrast and sharp boundary with the

matrix (i.e. enclosing mottle). Material is moist. Soil strength is weak, is deformable and moderately plastic. Boundaries clear to gradual.

Unit 8
Section No:
Thickness: 2-8cm. Munsell colour is predominantly 10 YR 3/3 Texture: slightly sandy silt. Very few to few mottles, in section generally 1cm across, colour predominantly 7.5 YR 5/6, with a faint to distinct contrast and sharp boundary with the matrix. Very few flecks of charcoal, c. 1-2 cm length. Material is moist. Soil strength is weak, is weakly deformable and slightly plastic. Boundaries clear to gradual.

Unit 9
Section No:
Thickness: 3-7cm. Munsell colour is predominantly 10 YR 3/2 Texture: slightly sandy silt loam. Many flecks of charcoal, c. 1-2 cm length. Many framents of highly degraded shell (?limpet) very many clasts, 20-50mm long sub-angular cuboidal/tabular. Material is moist. Sediment strength is weak, is weakly deformable and slightly plastic. Boundaries clear to gradual.

Unit 10
Section No:
Thickness: 8+cm. Munsell colour is predominantly 10 YR 5/3. Texture: sandy silt. Many framents of highly degraded shell (?limpet). Mottles common, c. 30mm in section, pure silt, 10 YR 2/1, with a faint to distinct contrast and sharp boundary with the matrix and orange flecks, 7.5 YR 7/8, c. 2mm. Material is moist. Sediment strength is weak, is weakly deformable and slightly plastic. Boundaries clear.

Off-site Descriptions

Beafield

Ah horizon
Thickness 12cm. Colour: 10 YR 2/2. Clay silt, with visible sand content. Clast free. Material is slightly moist. Structure consists of fine to medium granular peds, moderately developed. The material is moderately weak to moderately firm, deformable and slightly plastic. Many to common (grading down unit) fine fibrous roots. Clear to gradual boundary.

Bw horizon
Thickness 12cm. Colour: 10 YR 4/3. Silt loam with visible sand content. Very few clasts, c 6cm length, tabular sub-angular. Material is moist. Structure consists of medium to coarse granular/sub-angular blocky peds, moderately developed. The material is moderately weak to moderately firm, deformable and slightly plastic. Few to very few (grading down unit) fine fibrous roots. Clear to gradual upper boundary, clear lower boundary.

C horizon
Thickness: 8cm. Colour: 10 YR 7/3. Well sorted fine to medium sand. No clasts. Apedal structure. Material is loose, brittle and non-plastic. Clear upper boundary.

Tofts

Ap(h) horizon
Thickness 32cm. Colour: 10 YR 3/2. Silt loam texture. Many clasts of 2-5cm, sub-rounded to sub-angular tabular/prismoidal, concentrated at 5-10cm depth, with few clasts below this. Material is slightly moist. Structure consists of medium to coarse granular peds, moderately developed. Soil strength is weak, is weakly deformable and non-plastic. Many to common (grading down unit) fine fibrous roots. Clear to gradual boundary. Local informants tell that the field has been ploughed, once, around 10-12 years ago.

AB horizon
Thickness 30+cm. Colour: 10 YR 3/2. Silt loam. Very few clasts, c 6cm length, tabular sub-angular. Material is moist. Material is slightly moist. Structure consists of medium to coarse granular peds, moderately developed. Soil strength is weak, is weakly deformable and non-plastic. Few fine fibrous roots. Clear to gradual upper boundary. Combined depth of horizons suggests that this may be a deepened topsoil.

Westbrough

Ah horizon
Thickness 7cm. Colour: 10 YR 3/2. Clay silt. Clast free. Material is moist to wet. Structure consists of fine to medium granular peds, moderately developed. The material is moderately firm, deformable and moderately plastic. Many to common (grading down unit) fine fibrous roots. Clear boundary.

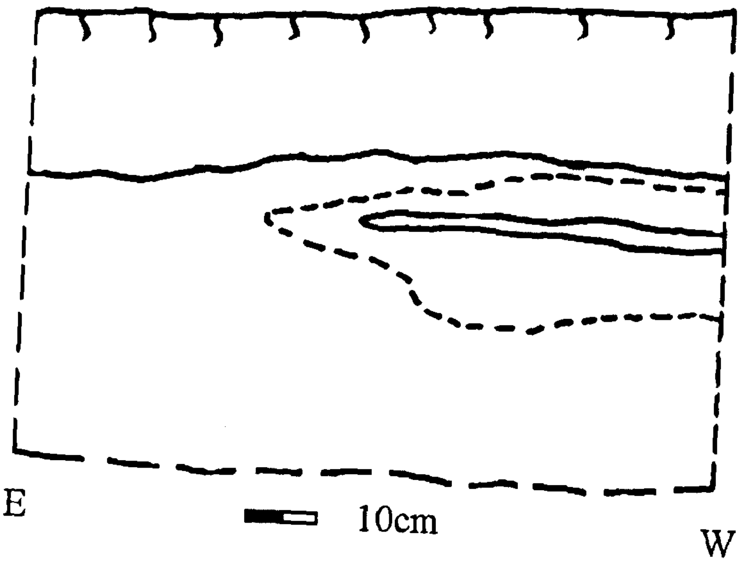
Bgf horizon
Thickness 15cm. Colour: 10 YR 4/3. Clay silt texture. Very few clasts, c 6cm length, tabular sub-angular. Many mottles, 7.5 YR 5/6,c. 2cm in section, with a faint to prominent contrast and sharp boundary with the matrix. Material is moist to wet. Structure consists of medium to coarse granular/sub-angular blocky peds, weakly to moderately developed. The material is moderately weak to moderately firm, deformable and moderately plastic. Few to very few (grading down unit) fine fibrous roots, with ferruginous deposition in rootlet channels. Clear to gradual upper boundary, gradual lower boundary.

Cgf horizon
Depth 22+cm. Colour: 10 YR 4/3. Clay silt texture. Very few clasts, c 6cm length, tabular sub-angular. Few mottles, 7.5 YR 5/6,c. 2cm in section, with a faint to prominent contrast and sharp boundary with the matrix. Material is moist to wet. Structure consists of medium to coarse granular/sub-angular blocky peds, weakly

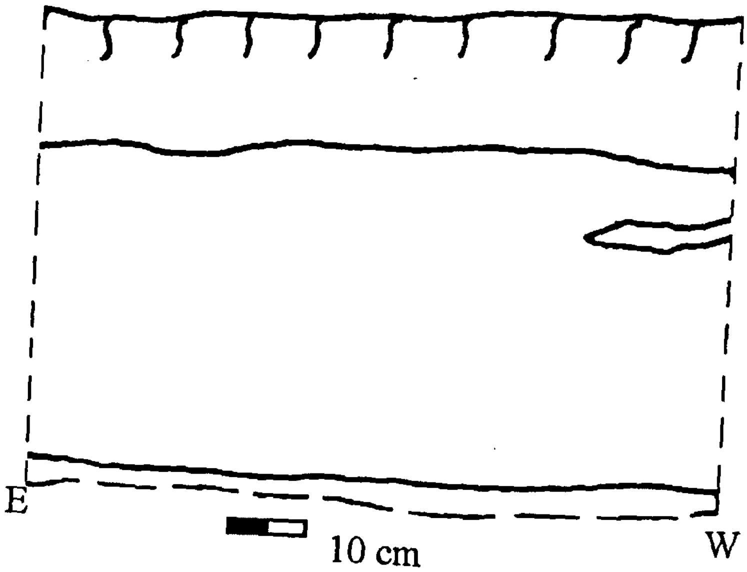
developed. The material is moderately firm, deformable and moderately plastic. Gradual upper boundary.

Appendix Four, Part Two: Field Sections

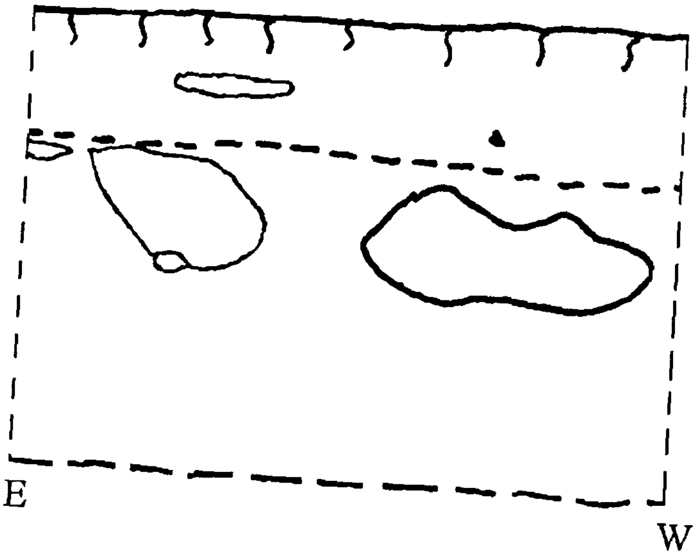
Beafield Section One



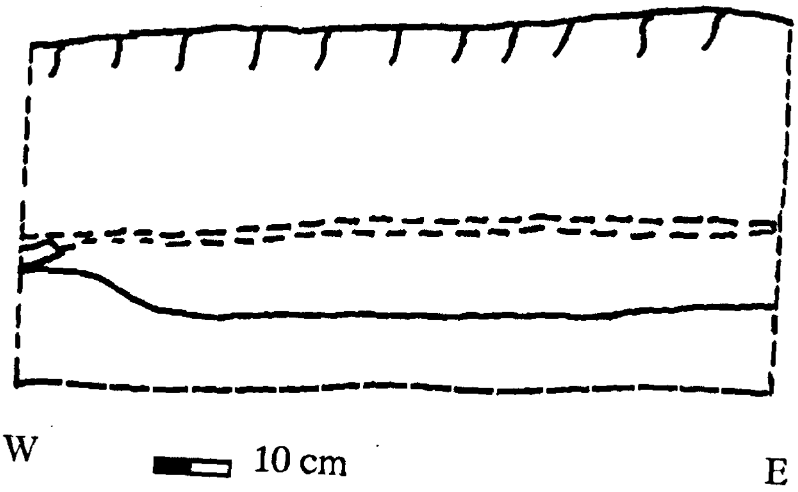
Beafield Section Three



Beafield Section Four



Tofts Section One



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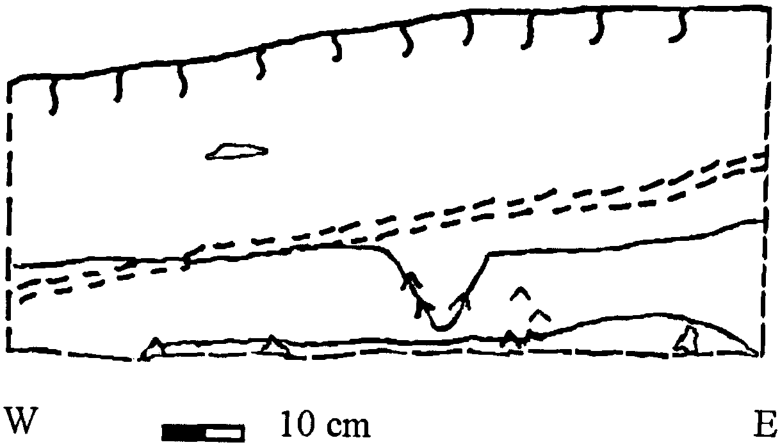

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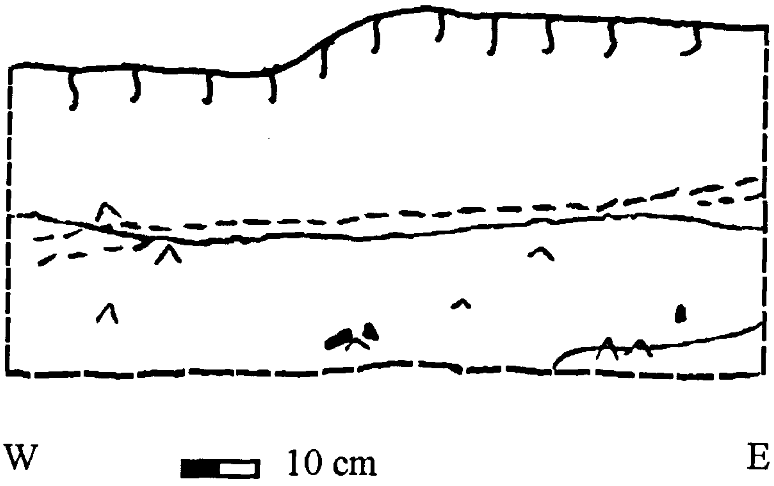
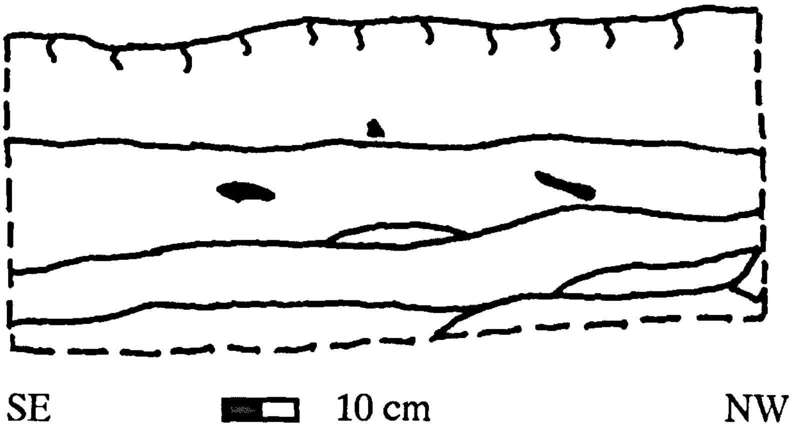
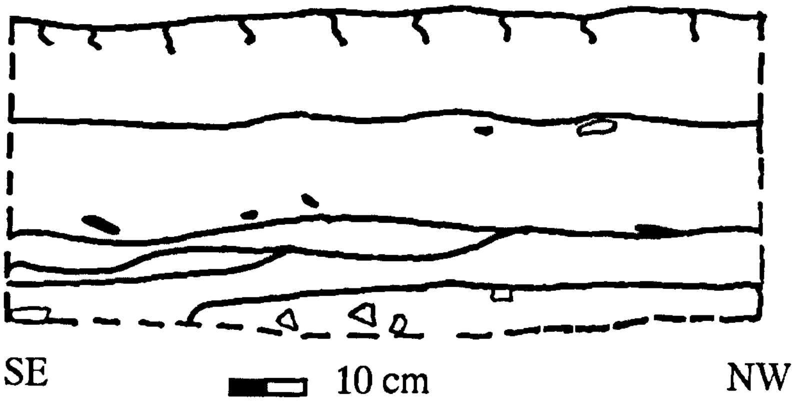


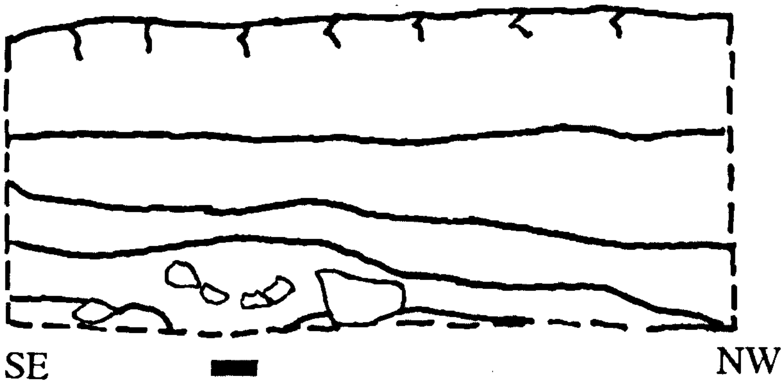
Westbrough Section One



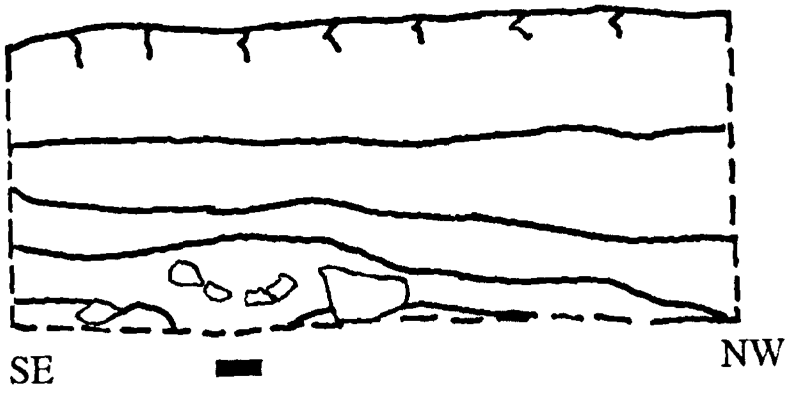
Westbrough Section Three



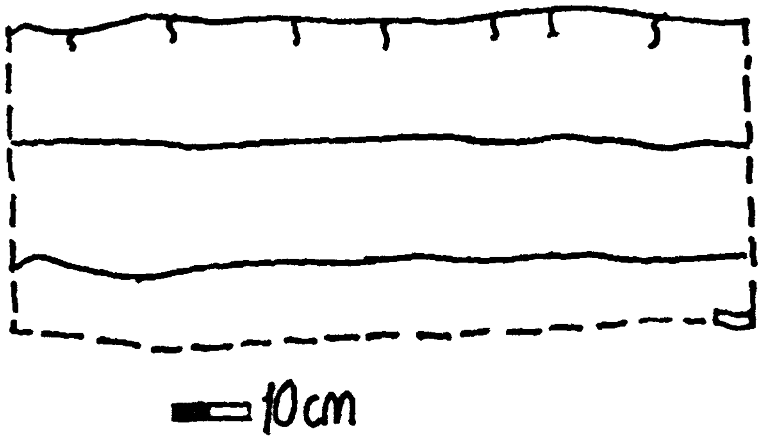
Westbrough Section Four



Westbrough Section Five



Westbrough Section six



Appendix Five
Caesium Data

Beafield

Depth (cm)	Activity (Bq kg^{-1})	Error (1σ) (Bq kg^{-1})
1	43.99	1.86
2	51.8	2.42
3	51.48	2.25
4	54.69	2.01
5	38.73	1.64
6	60.74	2.44
7	55.07	2.27
8	57.62	2.1
9	50.65	2.43
10	44.7	1.88
11	39.24	0.86
12	31.74	0.86
13	2.92	0.37
14	15.51	0.59
15	10.95	0.43
16	5.09	0.44
17	5.22	0.41
18	3.07	0.33
19	2.61	0.39
20	1.41	0.33
21	1.25	0.2
22	0.83	0.19
23	0.85	0.19
24	2.39	0.53
25	0.71	0.17
26	0.39	0.19
27	0.62	0.14
28	0	0
29	0	0
30	0	0

Westbrough

Depth (cm)	Activity ($Bq\ kg^{-1}$)	Error (1σ) ($Bq\ kg^{-1}$)
1	29.35	0.65
2	26.74	1.55
3	33	1.42
4	33.31	0.61
5	35.4	1.22
6	32.66	0.42
7	31.21	1.21
8	26.28	0.53
9	29.97	1.15
10	23.42	1.14
11	18.32	0.88
12	18.12	1.03
13	12.67	0.81
14	9.12	0.49
15	7.7	0.56
16	5.6	0.56
17	4.95	0.47
18	4.28	0.51
19	3.06	0.32
20	3.19	0.52
21	2.21	0.3
22	1.97	0.32
23	1.8	0.26
24	1.82	0.25
25	1.44	0.25
26	1.91	0.43
27	1.5	0.31
28	1.53	0.29
29	1.11	0.37
30	1.04	0.3

Tofts

Depth (cm)	Activity (Bq kg^{-1})	Error (1σ) (Bq kg^{-1})
1	36.23	1.42
2	47.96	1.16
3	53.54	1.27
4	51.91	1.24
5	64.51	1.63
6	50.53	1.2
7	43.66	1.82
8	35.47	1.71
9	38.38	1.11
10	26.79	0.8
11	21.98	0.72
12	17.94	0.63
13	13.7	0.54
14	13.01	0.55
15	10.28	0.53
16	10.63	0.64
17	7.57	0.48
18	6.55	0.45
19	5.27	0.49
20	5.4	0.47
21	2.96	0.41
22	3.28	0.46
23	2.06	0.35
24	2.39	0.41
25	1.71	0.42
26	1.35	0.4
27	0.96	0.24
28	0.87	0.25
29	1.14	0.23
30	0.95	0.35