Examination of the relationship between the form and function of medieval or later field systems in Scotland using soil micromorphology

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VOLUME CONTAINS CLEAR OVERLAYS

OVERLAYS HAVE
BEEN SCANNED
SEPERATELY
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THE RELEVANT PAGE

Abstract

A possible relationship between the form and function of medieval or later field systems in Scotland is tested using soil micromorphology and quantitative analysis techniques. Existing survey data is used to develop a classification system of six medieval or later field systems in Scotland.

The topsoils of two abandoned field systems are sampled from field units representing the range of field classes identified during the field system classification of each site. Soil micromorphology is used to identify existing micromorphological evidence of past anthropogenic influences in these soils. Two methods of soil thin section description are employed using a specially devised coding method to increase the speed of soil thin section description; Level 1 description records a single entry per slide for 32 micromorphological parameters, Level 2 uses a 1cm^2 grid system over each slide to record an entry for alternate gridsquares for 15 micromorphological parameters. The soil micromorphological results are quantitatively analysed using HCA and non-parametric statistical tests to test for a possible relationship between the form and function of the field units within each field system.

The results indicate that automated image analysis and quantitative analysis techniques can be successfully applied to existing data to produce classification maps for medieval or later field systems which reflect the morphology of the different units but current methods of recording field systems needs to be more detailed and comprehensive before a functional classification can be produced. The Level 1 method of soil micromorphological description provides an efficient and accurate method of describing a large number of slides. No relationship between the form and function of the field units within each system was found using the available survey data and soil micromorphological evidence. The identified micromorphological evidence for past anthropogenic activity is associated with manuring practises rather than cultivation techniques.

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1. Field systems and soil micromorphology: Research design of the project

1.1 Introduction

Much work has been done on the study of field systems in Britain and Europe over the last century although the progress of studies on Scottish fields and their patterns is not comparable to that elsewhere in Britain and Europe (Whittington, 1973). Very few medieval or later field systems have been studied in Scotland and even fewer have been excavated (Foster & Hingley, 1994). The vast majority of the work carried out on these historic cultural landscapes has involved non-intrusive field survey and interpretation from aerial photographs and research of the historical literature (Bangor-Jones, 1993; Corser, 1993; Dixon, 1993). An increasing number of sites are under threat from developments such as the building of holiday homes and afforestation (Swanson, 1993). The threat of afforestation has led to a number of sites being recorded by the Afforestable Land Survey Unit of the Royal Commission on the Ancient and Historical Monuments of Scotland (RCAHMS) and the production of several useful publications in the 1990s (RCAHMS, 1997, 1994, 1993, 1990).

These increasing threats to medieval or later rural settlements (MOLRS) require rapid responses and decisions on the immediate future and management of these sites. The lack of knowledge and understanding of these sites to aid such decision and policy-making began to be appreciated and addressed by bodies such as Historic Scotland and English Heritage in the early nineties and led to the formation of the MOLRS Advisory Group in 1992 in Scotland (Foster & Hingley, 1994). One of the main aims of this group was to determine the MOLRS sites of national, regional and local importance throughout Scotland in order to establish policies for the management of these sites in the future. Regional variation in the historic field systems still evident across Scotland today has been recognised but not quantified in the past (Dixon, 1994). These regional variations in field patterns throughout Scotland are the product of a multiplicity of factors (Whittington, 1973). They have been attributed to the varying predominance of arable or pastoral farming in certain areas, to the tenurial law enforced by landowners (Dodgshon, 1979) and also to the nature of the cultivation tools used (Fenton, 1976; Parry, 1976).

Researchers from a number of disciplines have studied the form and function of field systems using an array of different techniques over the past century, although many have concentrated on the prehistoric period. Historians and geographers such as Seebohm (1883), Gray (1915), Dodgshon (1973, 1980, 1993) and Baker and Butlin (1973) have done much to further our understanding of historic field systems in Britain. Historical geographers make great use of historical documents such as estate plans, hearth taxes and charters to aid their interpretation. However, it is certainly the case that for Scotland, there is a lack of documentary evidence from the medieval period and most medieval field systems have been interpreted and described through the use of later estate plans and documentation from the 16th to the 18th centuries (Baker and Butlin, 1973; Corser, 1993; Dodgshon, 1975, 1980, 1981; Whittington, 1973). These are often only able to provide a "snapshot" of one particular period in the history of a field system (Dixon, 1993) and it is rare for the historical geographer or historian to have a full set of historical documents at his or her fingertips to provide a more "cinematic" study through time of the field system in question.

Archaeologists have added to the information gained from historical documentation through archaeological excavation and survey (Austin et al, 1981; Grant et al, 1983; Fairhurst, 1968; Ford et al, 1994). Archaeological survey and excavation can provide useful information on the chronological development of a field system by detailed study of the various field elements. These elements can be assigned to 3 main groups which can provide an increasing amount of archaeological recoverable information: the fields themselves, the field banks, and the associated settlement (Barber, unpublished). It is, therefore, not surprising to find most archaeological studies of field systems have concentrated on the actual field boundaries and the associated settlements rather than the field units themselves.

A large proportion of the archaeological literature concentrates on field systems of prehistoric origin (Bowen, 1978; Bradley, 1977; Fleming, 1987; Spratt, 1991). More detailed archaeological research of medieval or later field systems would add significantly to the current state of knowledge for this period which has mainly been derived from the analysis of historical documentation (Baker & Butlin, 1973; Brayshay & Williams, 1995; Dodgshon, 1992, 1981, 1975; Harrison, 1995). It is, however, acknowledged that one form of research does not preclude the other. Fairhurst's study of the deserted township of Rosal, Sutherland in 1962 is an excellent example of how archaeological excavation and examination of the available historical documentation can provide a detailed interpretation of the history of a settlement site and its associated field remains (Fairhurst, 1968). Fairhurst also examined all of the three groups of field elements detailed by Barber (unpublished) to further consolidate his work. The recent study of the landscape at Lairg, Sutherland by McCullagh et al (1998; 1992) and the study of Tofts Ness, Sanday in Orkney by Dockrill et al (1994) are further excellent examples of the multi-disciplinary approach to the study of archaeological landscapes.

Palaeoenvironmental studies have attempted to address questions regarding the function of these field systems using a variety of techniques such as pollen analysis (Hicks, 1988; Küster, 1988), bone identification (Schutkowski & Herrmann, 1996) and soil chemical analysis (Dodgshon & Olsson, 1988; Entwistle *et al*, 1998; Entwistle & Abrahams, 1997). Soil micromorphology has also been used along with archaeological excavation and survey and a range of palaeoenvironmental techniques in an attempt to identify evidence of past farming practises although this work has generally concentrated on the prehistoric period and soils buried by structures such as burnt mounds and barrows (Acott, unpublished PhD thesis; Dockrill et al, 1994; McCullagh & Tipping, 1998). Soil micromorphology has rarely been applied to the examination of the topsoils of historic field systems, although the soils of a recently abandoned field system on the island of Papa Stour, Shetland is currently being studied (Bryant & Davidson, 1996; Davidson & Carter, in press).

Soil micromorphology has the potential to identify features in the soil which can be related to past management practises such as manuring. Differences in the microstructure of soils cultivated using different cultivation implements under experimental conditions have also been identified (Gebhardt, 1992). This research project aims to test for a possible relationship between the form and function of the different field units that comprise medieval or later field systems in Scotland using soil micromorphology and quantitative analysis and classification techniques. A method for recording and classifying the various elements of Scottish field systems from the medieval period onwards has been devised. The different classes of field unit identified from this work have been sampled to produce soil thin sections and examined using soil micromorphology techniques to determine whether any micromorphological features which may be attributable to differences in management practises in the past exist in the soil today.

1.2 Field Systems

1.2.1 The Theory

Historic field systems in Britain and Europe have existed in many forms. This array of different forms has been categorised according to a small number of general field system models but it is the evolution and chronology of these different types of system which has caused the prolonged debate and interest in historic field systems. Open field, two- and three-field and infield-outfield systems of managing the land for agriculture have been shown to operate in different areas of Northern Europe at different times. The open-field system describes the practise of scattering the plots of individual cultivators throughout the lands of the farming township. These plots were not enclosed but were surrounded by grassy baulks and headlands to allow passage of the cultivators and their livestock across the landscape. Open field systems are common throughout Northern Europe. In Ireland they are known as "rundale" (Crampton, 1967) whilst the term "runrig" is commonly used in Scotland to describe similar open landscapes worked in a multitude of scattered, unenclosed strips. Strip arable cultivation is also common in NE England and NW Germany (Uhlig, 1956 cited in Butlin, 1964). This form of agricultural system is regarded by many as the primitive and inefficient precursor to the two- and three-field system where the land was divided into two or three main areas designated for crops and fallow on a rotational basis (Figure 1.1). However, open field systems have persisted in many areas into the medieval period and up to the 19th century (Clark, 1988) and several economists have argued that this method of farming open landscapes was actually an efficient method of risk aversion (Clark, 1988; Dahlman, 1980; McCloskey 1991, 1976).

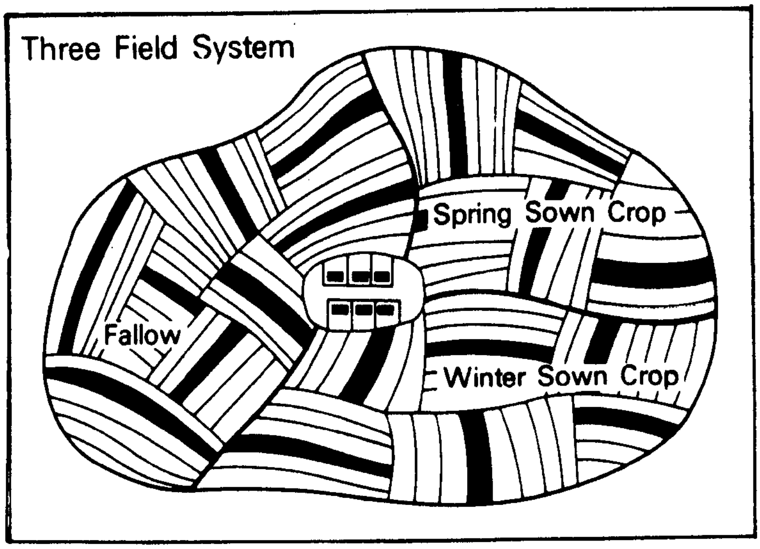


Figure 1.1 - Layout of a three-field cropping system (after Dodgshon, 1980)

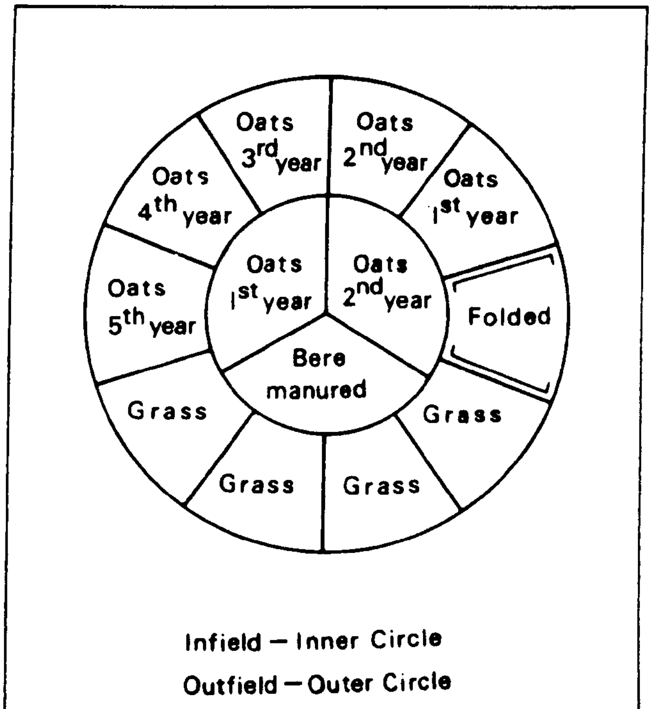


Figure 1.2 - Layout of an infield-outfield cropping system (after Dodgshon, 1980)

Scottish runrig field systems are generally regarded as remnants of early primitive open field systems of great antiquity which were superseded by the enclosed landscapes utilising infield-outfield methods of farming in the medieval period. However, Dodgshon (1993) argues that there is evidence that remnants of enclosed landscapes in the Highlands and Islands of Scotland are overlain by runrig cultivation, suggesting that the Scottish runrig landscape is not as ancient as is believed by many and that it actually replaced a former enclosed landscape. Similar debates also continue with regard to the infield-outfield and the two- and three-field system. Baker and Butlin (1973) and Thirsk (1967) regard the infield-outfield method of farming as the evolutionary ancestor of the two- and three-field system whilst Dodgshon (1978) suggests that there is more evidence for the occurrence of infield-outfield systems in 15th-17th century England than there is for the 13th and 14th centuries.

The infield-outfield system consisted of two main areas of agricultural activity. The area closest to the settlement (the infield) was under constant cultivation and was heavily manured to maintain the fertility of the soil. The outfield was located on the periphery of the main area of settlement and certain areas were brought into cultivation on a rotational basis by tathing stock on a selected area prior to cultivation. No other manure was added to the outfield crops after planting and the soil was cropped for a number of years until exhausted after which it was allowed to revert to fallow (Figure 1.2). Again, there is much debate as to the origins and development of this type of field system. Whyte & Whyte (1991), Uhlig (1961) and Whittington (1973) argue that the infield-outfield system was borne out of an intensification and settling of the early shifting cultivation practises of prehistoric times. Dodgshon (1973) argues that outfield was added to the existing intensive infield core of land as required during increases in population. Baker (1979) agrees that this interpretation is logical. Dodgshon (1980) also suggests that the distinction between infield and outfield is more closely related to the extent of the assessed and non-assessed land of medieval townships (or *fermtouns* in Scotland) than to the cropping regime.

It is largely accepted that an infield-outfield system operated to some degree throughout Scotland. However, Barber (unpublished) has described the "apparent formlessness of Scottish field systems [as] perhaps their outstanding characteristic" and that Scottish historic field systems are, in the main, "chaotic and fragmentary". Dodgshon (1981), on the other hand, is slightly more positive and clear-cut in his vision of the state of Scottish field systems within the medieval period whilst at the same time allowing for their apparent disparities. He suggests that the "basic social and economic unit of medieval Scotland was the farming township" yet concedes that there are considerable local and regional variants. He postulates that there are four key institutions which can be demonstrated to have been shared by all regions, the only difference being a variation in the development time for the various forms. These four proposed key institutions are:

1. A predominance of small, irregularly-shaped clustered settlements.
2. Multiple tenure, where more than one tenant in a toun shared a portion of the whole, but not a discrete area.
3. Where multiple tenure existed, land was allocated to tenants in the form of intermixed strips and parcels of land, commonly known as runrig or rundale
4. Infield-outfield, where the cropping of the toun's land was intensive on the infield and extensive and rotational on the outfield.

The different methods of cultivation employed from area to area in Scotland have been shown to have had considerable effect on the morphology of field patterns throughout Scotland, with use of the plough generally producing a more "regular" type of field pattern than that produced through the use of the spade or *cas-chrom*. The most extensive attempt at mapping cultivation remains throughout Scotland to a consistent survey standard has, perhaps, been undertaken by the Afforestable Land Survey (ALS) unit established within the RCAHMS in 1989. ALS reports such as those for Waternish and the Strath of Kildonan provide invaluable information on the nature of field systems throughout Scotland (RCAHMS, 1993). Reports such as these and the more detailed surveys of Perthshire (RCAHMS, 1992, 1994) and Dumfriesshire (RCAHMS, 1997), coupled with the excellent collection of vertical aerial photographs covering the vast majority of Scotland held at the RCAHMS headquarters in Edinburgh provide the best opportunity for studying the spatial variability of Scottish field systems at a local, regional and national scale. In addition, they provide a convenient means of detailing and measuring the physical cultivation remains themselves.

1.2.2 The morphology of cultivation remains

The rig and furrow

Piers Dixon (1994) presents a useful summary on much of the archaeological survey work carried out on Scottish medieval or later field systems to date providing us with clear definitions for the various types of cultivation remains to be found throughout the country. These definitions are based on Parry's (1976) work in the Lammermuirs and Bowen's (1961) identification of broad and narrow rig in England. He expands the classification of cultivation remains into 4 discrete groups and provides an indication of the distribution of each type of rig throughout Scotland.

Broad or reverse-S rig produced through the use of the fixed mould-board plough is stated as being "distributed from Sutherland in the north to the Border counties in the south with a pronounced eastern bias, although it is found in lowland Ayrshire and in Lanarkshire" (Dixon, 1994, p.38). The origins of this type of rig lie somewhere in the medieval period. Narrow curving rig, can only be dated in general terms to the pre-improvement period and has only been discovered in Galloway although it may be more widely distributed along the western seaboard. Narrow straight rig is associated with improved agriculture and is thus widely spread throughout Scotland. Lazy-bedding, generally produced through the use of the spade or *cas-chrom* is to be found mainly in the north west but examples are also to be found in Argyll, Galloway and in small patches in the upland areas of the south-east.

Jirlow and Whitaker (1957) present an excellent account of the history of the plough in Scotland and present much evidence for its use during the Improvements. There appears to be less in the way of information on the actual management of ploughing. Several writers describe touns held in multiple tenure where each tenant provided an animal for the plough which generally needed between four and eight animals to pull it as well as three or more men to guide both the animals and the plough (Dodgshon, 1992; Jirlow and Whitaker, 1957; Whyte and Whyte, 1991). This cumbersome arrangement needed considerable room at the end of each rig in which to turn which produced both the reverse-S shape previously mentioned and an area of land known as the headland. There were often grassy strips of land left between furlongs for access to the land and this may also have served as grazing for tethered animals (Beecham, 1956).

Environmental factors have been one strand of the argument for explaining why lazy-bedding occurred predominantly in the west and broad or reverse-S rig in the east. The Whytes' informative book on Scotland's changing landscape comment that over much of the Highlands the arable land was fragmented in tiny blocks and parcels among the boulder-strewn slopes (Whyte and Whyte, 1991). Dodgshon (1992) paints an even harsher picture of the difficult landscape which Highlanders and Islanders were faced with: "..where opportunities for settlement and cultivation did exist, they were seized upon and exploited to the full. Whatever the emptiness and silences between, the settlements he [Macculluch] passed through were burdened with numbers. Many had extended their bounds of cultivation to its absolute limits, with cultivation rigs pushed out over stony ground and between rock outcrops, floated across waterlogged ground and driven high up hillsides". Clearly, this was not a landscape conducive to the working of a cumbersome plough which often needed three men and 4-8 draught animals to operate it (Fenton, 1976; Jirlow & Whitaker, 1957). Often tenants' landholdings held in runrig were too small, due to the practice of partible inheritance and the pressures of increasing population during the 12th and 13th centuries (Barrow, 1962), to support the animal required to put towards the plough team used by the township to plough what little suitable land there was.

The use of the spade and *cas-chrom* (heavy footplough) (Jirlow and Whitaker, 1957) was highly labour intensive. Walker, during his survey in 1764, calculated that what took four men five days to cultivate with a plough would take the labour of 12 men to dig with spades in the same time (cited in Dodgshon, 1992). The use of a spade allowed the often thin, poor soils to be built up to form a steep ridge, often as much as 0.45m in amplitude (Dixon, 1994). This steep ridge, or deep furrow, allowed better drainage and gave a better depth of soil for the crops, particularly the potatoes grown latterly in this area (Whyte and Whyte, 1991). These ridges were also heavily manured with a wide variety of fertilisers such as seaweed, dung and turf which further added to the labour cost. However, Macculluch, writing in 1824 stressed the "sheer abundance of labour and the lack of alternative sources of employment" and spade and *cas-chrom* cultivation has been shown to produce a greater yield than that from ploughed land (cited in Dodgshon, 1992). There are, then, several reasons for the use of the spade rather than the plough in western Scotland and the Outer Isles and Dodgshon argues that, far from being a primitive and backward form of agriculture, it actually enabled the cultivation of much greater areas of land than would have been possible with only the plough. Indeed, Jirlow and Whitaker report that "in the parishes of Uig and Lochs in Lewis it was still the exclusive means of tillage in 1811, being used for potatoes and corn" (Macdonald, 1811 cited in Jirlow and Whitaker, 1957).

For the medieval period up to the Improvements of the 18th century, therefore, it may be hypothesised that, generally, use of the old Scotch plough in the east created broad rig, typically with a reverse-S shape and the spade and *cas-chrom* cultivation of the west created lazy-beds. Why these different methods of cultivation and, if the picture is that simple, why the great debate and lack of consensus on the field systems of Scotland? Of course, rig morphology is not the only element in a field system.

Boundaries and enclosures

Boundaries, types and shape of enclosures as well as their spatial relationship with the settlement are all factors which make the classification of field systems much more complex. The debate on the chronology of open and enclosed landscapes in Scotland has already been discussed (Section 1.2). Enclosures exist in a variety of forms. Small enclosures close to the main settlement are generally interpreted as stock pens and garden plots, the function of the former being to keep stock in whilst the latter were built to exclude grazing animals. The development of sheep farming in the 18th century led to the enclosure of increasingly large areas (Dixon, 1994). The enclosing of larger tracts of land is hard to date precisely but the early development of such types of enclosure in the wet uplands of Ayrshire has been associated with the need to manage cattle to prevent depredation of the precious crops (Whittington, 1973).

Many medieval or later field systems in Scotland are enclosed by a head-dyke which separates the arable land from the pasture. Again, the date of origin of these structures is uncertain but a petition of 1758 from the tenants of Badentarbat in NW Ross details a feud between two tenants and a tacksman in which the tenants refuse to comply "till such time and he [Angus MacAulay, the "pretended" tacksman] compleate that part of the Dyke round the Town of Badintarbat which corresponds to his possession, the Petitioners having been at considerable expence in compleating their share.." (Bangor-Jones in McCullagh, 1996). This implies a fairly late date for the head-dyke construction but it is dangerous to extrapolate this evidence to interpret similar features elsewhere in Scotland.

The different attitudes of the lords and landowners towards this new type of progressive farming using enclosure has also been seen as a reason for the slow and "patchy" development of enclosure through the medieval period and later in Scotland. A grantee of a sixth part of Knokkorth in Angus was given the choice, in a charter of 1572, of having his share either as a consolidated holding or as one disposed in the form of runrig (Thomson, 1996 cited in Dodgshon, 1981). This does not implicitly imply enclosure but it was the reallocating of the land into consolidated "parcels" that was at the very heart of the method of enclosure.

1.2.3 Other factors influencing field systems

It is impossible to cover all the possible reasons for the differences in medieval or later field systems throughout Scotland and elsewhere in Britain and Europe. We may never be able to fully appreciate the main factors influencing the decision-making of the medieval tenant farmer which created the agricultural landscape of that time. Studies of historic field systems today are complicated by the persistence of remnants of a long and complex sequence of reorganisations of the landscape in response to changes such as climate and tenurial law as well as advances in agricultural husbandry.

The influence of the climate

Many of the remaining examples of historic field systems found in Scotland today occur in areas which are marginal for arable cultivation. The existence of field system remains in these areas suggests that they were not always considered so. Marginality is closely associated with climate and the marginal zones would have fluctuated along with changes in the climate (Halliday, 1993). Parry (1975, 1985) has studied the influences of climate change on agriculture in the Lammermuirs of south-east Scotland. Crop failures in this area rose from approximately one in twenty years in the 12th and 13th centuries to more than one in three by the mid-fifteenth century. During this period the climatic limit for arable cultivation in the Lammermuirs fell from 450m OD to approximately 320m OD. Evidence of similar climatic deterioration is found in Yorkshire, affecting the livestock as well as the arable crops (Muir, 1997) and in Greenland (Fredskild, 1988).

These increasingly marginal areas were not necessarily abandoned in a single phase and never reutilised. As populations increased, many farming townships were forced to encroach back into these relatively inhospitable areas in order to survive. Thus, even in these marginal areas, the evidence remaining today does not reflect a neat, single phase of occupation and management but an ebbing and flowing of use through the historic period, each phase modifying the remnants of the last.

Although the broad distinction between the wetter climate in the west and north and the drier and warmer climate of the east and south can be made to explain the apparent regional variations in Scottish farm systems, there is nevertheless a common thread in that all farming throughout Scotland was a mix of arable and pastoral; it was merely the predominance of each which varied from region to region (Smout, 1969). It must also be considered that marginality can be considered in geographic terms. The type of farming practised in a certain area is also influenced by the proximity or otherwise of markets. Marginality through climatic and market influences therefore combined to dictate the nature and use of field systems in these marginal zones. However, to accept these as the only influences on historic field systems in Scotland is to paint an over-simplistic picture.

Allocation of the land

The dispersed allocation of land allocated to tenants in the form of a number of parcels or strips of land dispersed throughout the toun allowed for equality in the sharing of both the quantity and quality of land. In 1468, the tack for the Grange of Balbrogy called for the division of the land into two lots but that "where the lot shall fall better, that part shall recompense the worse, until they shall be equal" (Rogers, 1880 cited in Dodgshon, 1981).

Another explanation for the dispersed nature of tenants' land throughout a township is the practice of sun-division, where a tenant was given the land towards the sun in the east or south of each furlong or to the shade in the west or north. A very clear reference to the use of this form of land division is cited in Dodgshon's 1980 book on *The Origins of the British Field Systems*. A widow's share of her husband's estate (terce) is described in Sir Thomas Craig's *Jus Feudale* (first printed in 1655) as representing the sunny or shadow third. His explanation of sunny or shadow determined whether they "should begin from the east, which is called the sun side, or from the west, in thus designating this third or terce; and as the lot turns out, they will begin from the sunny part, that is with the rising sun, or from the shady part and the setting sun, and will number off the rigs the first and second to the owner and the third to the widow".

The practice of partible inheritance can also be shown as playing a significant part in the continuing fragmentation of the landscape through time although Dodgshon cautions against over-emphasis on this point, arguing that by the time documentation becomes available to provide evidence for this practice, only the udal tenures of the Northern Isles can be shown to have permitted the division of property between co-heirs as of right (Dodgshon, 1980).

1.2.4 Field Systems - Summary

It has been demonstrated that there are a large number of factors and reasons for the variations in Scottish field systems. It must not be considered, however, that certain factors must produce only certain types of field pattern. The principles of equifinality and indeterminacy must always be borne in mind. Many of the fields studied and considered similar now may have had very different forms previously and have originated in different ways. Equally, similar processes acting in different areas at different times can result in very different field structures (Baker and Butlin, 1973).

Much work has been done on field systems and their various patterns yet there is still much to do. Dixon (1994) stresses the need for the excavation of sample rig from a variety of locations to allow a more complete knowledge of their spatial distribution to be achieved. Baker and Butlin (1973) state that "in different places at the same time and at different times in the same place, the key functional unit - the basis of the rotation - might be the parcel, the furlong, or the field, so that a crucial need in relation to particular field systems is to identify the structure and function of each of these units together with the nature of their connections". This is the main aim of this research project.

1.3 Soil Micromorphology

Soil micromorphology is a powerful diagnostic tool which has the potential for identifying soil features which may be overlooked or unidentifiable at the macroscopic scale of the field description of soil profiles. It was initially used by soil scientists to gain a better understanding of the physical effects of different pedological processes and to aid the classification of soils but it has increasingly been applied to a number of other disciplines.

1.3.1 Soil Micromorphology in Archaeology

Kubiena's work back in 1938 marks the first appearance of soil micromorphology as a soil science. It took twenty years from its inception for this technique to be applied to soils in an archaeological context (Cornwall, 1958; Dalrymple, 1958). However, it was not until the 1970's that soil micromorphology really began to be actively applied within the world of archaeology (Romans and Robertson, 1975) and its use has developed both in this and many other applications since.

The standardisation of the terms and methods of thin section description using a morphological approach was first attempted by Brewer in 1964. Fitzpatrick's useful book published in 1984 helped to further aid the struggling novice micromorphologist and the concerted efforts of some of the expert micromorphologists from around the world culminated in the production of the Handbook for Soil Thin Section Description in 1985 (Bullock et al, 1985). Soil micromorphologists were further aided in 1986 by the publication of Murphy's handbook on Thin Section Preparation of Soils and Sediments. The micromorphologists of the 1980's, then, were suitably armed to be able to turn their attentions fully to the application of soil micromorphology in other fields. Kooistra (1990) talks of soil micromorphology not as a science but as a "scientific activity using specific techniques". It, therefore, possesses the capability of being applied to a wide range of sciences.

As with any scientific technique, micromorphology has both its advantages and limitations (Gebhardt, 1991). It can provide detailed information on the nature and history of sediments through the detailed identification and description of their constituents at varying levels of magnification. The interpretation of these sediments can provide useful additional information for the archaeologist trying to piece together the history of a site using classic archaeological and sedimentological techniques such as phosphate, grain size and mineralogical analyses (Macphail et al, 1990).

The subjective nature of observation in soil micromorphology has long been a criticism (Gebhardt, 1991). This "subjective approach" has, to some degree, been broached by the publication of the handbook allowing a standardised approach to the description of slides (Bullock et al, 1985) and has been tested with a round-robin experiment (Murphy et al, 1985). However, little can be done to eliminate the differences of opinion regarding interpretation of thin sections from one micromorphologist to another. Attempts are being made to quantify observations and back this up with statistical analysis (Hall, 1990) but it must still be considered that no computer or machine will be able to apply the logic and make the transcendental leaps from one context to another often made by the expert micromorphologist in identifying features in their various, and often substantially dissimilar, forms.

The representativeness of a thin section of the whole sedimentological unit can be debated and examination of a three-dimensional phenomenon in only two dimensions presents certain problems with extrapolation back to "reality" (Gebhardt, 1991). Nevertheless, soil micromorphology has, over the years proved itself a useful technique over a wide range of applications and, particularly in the field of archaeology, provides a powerful diagnostic tool to aid the archaeologist to "fill in the gaps" left by the classic archaeological examination of archaeological landscapes. Further qualification of this opinion can be found in the paper of Macphail et al (1990), in which they state "soil micromorphology in archaeology can now be regarded not as a specialist technique of relevance to soil scientists alone, but one with tremendous potential for adding to our understanding of the cultural nature of an archaeological site".

1.3.2 Previous micromorphological studies of agricultural soils

Much of the work on the effects of cultivation on soils has, through necessity, been carried out on modern soils (Jongerius, 1970, 1983; Kooistra, 1987) by experimentation. Modern agricultural machinery has been shown to decrease ped size, produce slaking in the top layer of the tilled soil, often with the formation of a "plough pan" at the base of the cultivated layer. Jongerius (1970) used the term "agricutan" to describe the coatings and infills produced through downward translocation of silts and clays in the plough zone. However, Macphail *et al* (1990) caution that the structural and textural indicators of ancient agriculture vary according to soil type, grain size, organic matter content and base status and emphasise that "it is the *combination* of indicators that is important, so that, for example, 'agricutans' should not be regarded on their own as categorical evidence of cultivation".

Soil type is a major factor affecting the response to tillage. Most of the progress in this area has been from the study of modern agricultural soils. Macphail *et al* (1990), however, are of the opinion that this progress on modern soils, coupled with the experimental work carried out using ancient cultivation techniques at 'ancient' farms such as Butser Hill in Hampshire, England and Hambacher Forst in Esldorf, Germany, have allowed attempts to characterize the effects of ancient agriculture on a number of soil types. It is argued, however, that much more work needs to be done on this subject as well as further studies on the agricultural landscape of the historic period in Britain and elsewhere.

Although much work has been done using soil micromorphology in archaeology, the majority of this work has concentrated on the prehistoric period (Courty *et al*, 1991; Macphail, 1986; Macphail *et al*, 1990; Macphail *et al*, 1990; Macphail, Romans and Robertson, 1987, 1975; Simpson, 1994, 1993) with very little work carried out on landscapes or sites dating beyond the Iron Age (Bryant & Davidson, 1996; Carter & Davidson, in press; Gebhardt, 1993, 1991). This work does, however, provide valuable information on the development of soils through time and man's influence on them. Macphail *et al's* 1987 paper on *The Application of Micromorphology to the understanding of Holocene soil development* *in the British Isles* provides a useful summary of the work done throughout Britain to provide a rare picture of the spatial development and anthropogenic manipulation of soils throughout the country.

Gebhardt (1992) carried out the study which can be considered the most relevant to this project. She set out to compare the effects of cultivation with different cultivation implements; the ard, spade, hoe and motorized cultivator. The degree of soil compaction, porosity, ped form and shape, depth of organic matter burial and depth of tool impact were compared for each implement. From this, it was proposed that certain implements create recognisable structural features such as small clods (hoe), large clods with clean and straight edges (cultivator) and a plough pan (ard). It was, however, acknowledged that little is known about the behaviour of these structures as they age and what effect the weight of sediment layers or archaeological structures formed over this cultivated layer may have. Clearly, much more work needs to be done on the characteristics and development of cultivated soils through time. In ancient soils, microfabrics have to be studied on an hierarchical basis, so that agricultural features can be distinguished from those of the natural soil (Macphail *et al*, 1990).

A considerable amount of work has been carried out on plaggen soils in northern Europe (Conry, 1971, 1969; Davidson & Simpson, 1984; Groenman-van Waateringe & Robinson, 1988; Pape, 1970; Simpson, 1997, 1993). Although dating of these soils is difficult, Conry (1974) states that the majority of plaggen soils in Germany, Belgium and the Netherlands have their origins in the 6th to 8th centuries A.D. whilst there is some evidence for plaggen soils occurring in the 1st century A.D.. In Ireland, the majority of plaggen soils are regarded as no more than 300 years old. Examination of these soils using soil micromorphological techniques has aided the understanding of both the nature of the manures added to these soils and the general management of the landscape (Chrystall, unpublished; Dockrill *et al*, 1994; Mucher *et al*, 1990). The introduction of turves and heather sods into these soils may be identified from differences in the mineral composition of these soils using micromorphology. Similarly, differences in the composition and humification of the organic content of these soils can be identified using soil micromorphology, allowing interpretation of the possible source and decomposition process of the organic material (Mucher *et al*, 1990).

Despite basing their case study on the Neolithic caves of Arene Candide, Liguria in France and Italy, Courty *et al* (1991) provide useful information on the identification of coprolites from different animals and the subsequent reconstruction of their feeding habits and management. This is an excellent addition to the study of ancient agricultural practices which have largely concentrated on the examination of tilled and managed soils. In relation to this project, this is particularly useful when you consider the pastoral nature of the agricultural economy in much of Scotland during the medieval period.

Soil micromorphology, then, has much to offer the archaeological field of study. Kooistra (1990) believes that "the focus of attention needs to be on diagnostic criteria and interpretation rather than on descriptions, to attain high-level contributions for syntheses". He further advocates that in order to achieve this, "the micromorphologist must be familiar with the techniques of light microscopy and submicroscopy, and with the use of statistics and quantitative analyses". Submicroscopy has not been used for this research but statistics and quantitative analyses have been extensively applied in the collection of the data and its interpretation.

1.4 The link between field systems and soil micromorphology

As discussed in Section 1.2, historic field systems exist, and have existed, in a range of different forms. Each type of field system has been created in response to a number of factors which change through time. The physical layout of these field systems has been studied and debated for over a century. The nature and possible function of the various types of field unit which comprise historic field systems has been addressed by historians, historical geographers, archaeologists and historical economists. However, little attention has been paid to the soils which exist within these functional units of the field system. This is mainly because archaeologists consider the soil within the fields to contain little in the way of archaeological recoverable material (Barber, unpublished). Certainly, they rarely present sealed and undisturbed deposits to allow secure dating of the physical remains of rig and furrow cultivation. However, the nature of the soil is as much a consideration for the farmer of today as it was at the beginning of sedentary farming.

Good, fertile soil will always be exploited before poor, infertile areas. Soil is the very basic ingredient for any mode of farming. Even in areas where the climate is not particularly conducive to arable cropping, the more fertile, freely-draining and non-acidic soils will carry better grass and vegetation swards which will provide better fodder for livestock and, hence, better yields of milk and meat production. If the areas of good ground are sparse, then more effort is likely to be put into maintaining the fertility of these areas by using them efficiently to maximise yields. The history of farming has passed through the soils of the historic agricultural landscape. Evidence has begun to be found which indicates that some of this history remains stored in the soils today (Carter & Davidson, in press; McCullagh & Tipping, 1998; Mucher et al, 1990). Experiments on modern agricultural soils (Hall, 1990; Jongerius, 1983, Kooistra, 1987) and using ancient cultivation techniques (Gebhardt, 1992) provide useful information on the micromorphological features of the soils subjected to different agricultural practises. The next logical step is to test whether similar micromorphological features persist and can be identified in historic agricultural soils. Archaeology may be unable to glean much information from the examination of the soils contained within the various field units which comprise historic field systems but it is possible that soil micromorphology may hold the key to unlocking the history of human influence on these soils.

1.5 Research Design of Project

This research project aims to produce a method of analysing and classifying medieval or later field systems in Scotland using the available data. The different types of field unit (polygons) identified by the classification procedure can then be examined using soil micromorphology techniques in an attempt to establish whether each of these particular types of field unit had a particular function within these historic field systems.

1.5.1 Hypotheses

There are two main hypotheses to be tested by this research project:

1. Image analysis techniques and the use of statistical packages can be applied to existing data on medieval or later field systems in Scotland to generate maps indicating areas of distinctive land use and management in the past.

2. The soils in these functional areas will have distinctive signatures in terms of micromorphology which can be recorded using microscopic examination and analysed using quantitative statistical techniques.

1.5.2 Research Methodology

The methodology of the research can be broken down into three individual stages:

1. The desk-top study and analysis of data from the Royal Commission of Ancient and Historical Monuments in Scotland (RCAHMS) surveys across Scotland to produce spatial maps indicating areas of distinctive past land use.

2. Detailed field work, survey and sampling for the collection of undisturbed samples of topsoil for the preparation of thin sections and data on the chronology and dating of field elements within the field system.

3. The laboratory and office-based examination and analysis of the field evidence collected and the testing of the relationship between the micromorphological evidence (2) and the classification study (1).

1.5.3 The desk-top classification study

The Royal Commission of Ancient and Historical Monuments in Scotland (RCAHMS) has the largest collection of information on medieval or later field systems in Scotland. This information is held in the form of survey maps and aerial photographs. A selection of these survey maps and aerial photographs is used to classify six sites throughout Scotland. PC Image Analysis software and manual measurements and calculations are used to record a range of morphological and topographic parameters. These measurements are standardised using Gower's coefficient of similarity and input to a hierarchical cluster analysis (HCA) classification procedure. The results of the HCA procedure are used to create a map of the different classes of field unit within each of the six field systems examined.

1.5.4 Field Sampling and Survey

Two of the six sites used for the desk-top classification procedure are selected for further analysis via archaeological survey, excavation and soil micromorphology techniques (Boyken, Dumfries and Galloway and Badentarbat, NW Ross). Archaeological excavation and survey is carried out to answer questions raised during the desk-top classification study and to provide dates for certain elements of each field system. Soil pits are dug within field units representing the field classes identified during the desk-top classification of the field system and the soil profiles are described. Undisturbed soil samples are collected for micromorphological study in the laboratory.

1.5.5 Soil micromorphological description and analysis

The soil thin sections are described using two methods of description:

Level 1 - Each slide is described for 32 micromorphological parameters. Each description represents the estimate or predominant type of feature for each slide.

Level 2 - A selection of slides representing the range of field classes for each site are described using a 1cm^2 grid system for 15 micromorphological parameters. Every second gridsquare is described.

The two levels of micromorphological description aims to serve two purposes:

1. To determine which level of detailed description provides the most useful information for determining any possible differences between the soils from different field classes.

2. To check that the between-slide variation identified during the Level 1 work is greater than any within-slide variation which could not be quantified using the Level 1 method of description.

The data recorded for both levels of description are entered into an SPSS spreadsheet and analysed using the same classification procedure used for the desk-top field classification work. The results are analysed to determine the parameters which influence the classification procedure and to establish if there is any correlation with the field classes from which the soils have been sampled. The Level 1 and Level 2 data are also grouped according to field class membership and analysed for any micromorphological differences between the soils from the different field classes using the Kruskal-Wallis one-way analysis of variance by ranks test and cross-tabulation using the Chi-square bivariate statistical test. The Level 1 and Level 2 results and interpretation for each site are compared. The Level 1 and Level 2 results are also compared to assess which method is the most useful for determining the micromorphological characteristics of field system soils. Figure 1.3 details the research design of this project and the process of investigation.

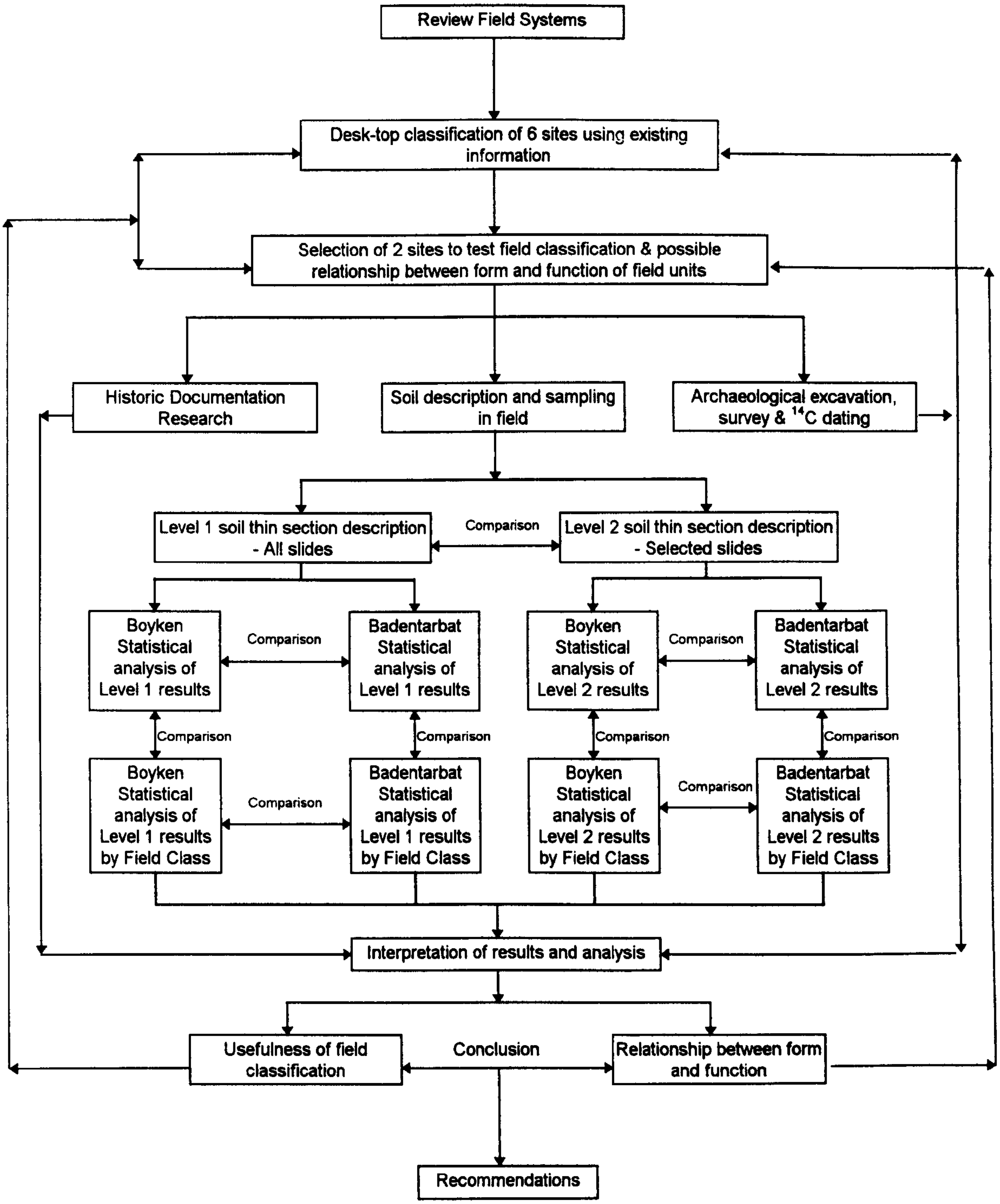


Figure 1.3 - Research design of project and procedures

2. Field System Classification

2.1 Introduction

A method of classifying medieval or later field systems in Scotland had to be devised using available data. It was not the aim of this research project to re-survey sites which had already been recorded. The objective was to use the existing data on Scottish field systems in a scientific manner to produce maps identifying the different types of field unit comprising each site. These could then be compared and contrasted in order to establish whether the regional variation acknowledged by the various researchers of field systems (Dixon, 1994; Thirsk, 1967) could be identified through quantitative analysis.

2.2 Choice of Data

Several sites had to be found which had similar available data to allow valid comparisons and the development of a classification system. A set of survey data produced by a standardised method of recording and mapping appeared the best option and the Royal Commission on the Ancient and Historic Monuments of Scotland (RCAHMS) was approached for suitable data from a range of sites throughout Scotland.

Despite the RCAHMS being the main body which is involved in surveying and recording historic field systems in Scotland, the information available was found to be of varying quality. Many site surveys had concentrated on the built elements within the landscape and the resulting maps produced from these surveys either did not include the entire field system associated with these built structures or the cultivation remains were merely depicted as representations of what was actually on the ground as only approximately one in every three furrows were recorded during the field survey. Other sites were known to exist but had not yet been surveyed and, hence, only aerial photographs were available. In order to get a reasonable geographical spread and range of field systems throughout Scotland, a mixture of survey maps and aerial photographs had to be used.

Six field systems were chosen from the available data. Survey maps and aerial photographs were available for the Boyken (Dumfries & Galloway), Badentarbat (NW Ross), Cleish (Fife) and Laughengie (Kirkcudbrightshire) sites. A good quality aerial photograph was the only available data for the Dùnan site (Isle of Lewis) whilst a survey map proved to be the only material available for the site at Learable (Ross & Cromarty).

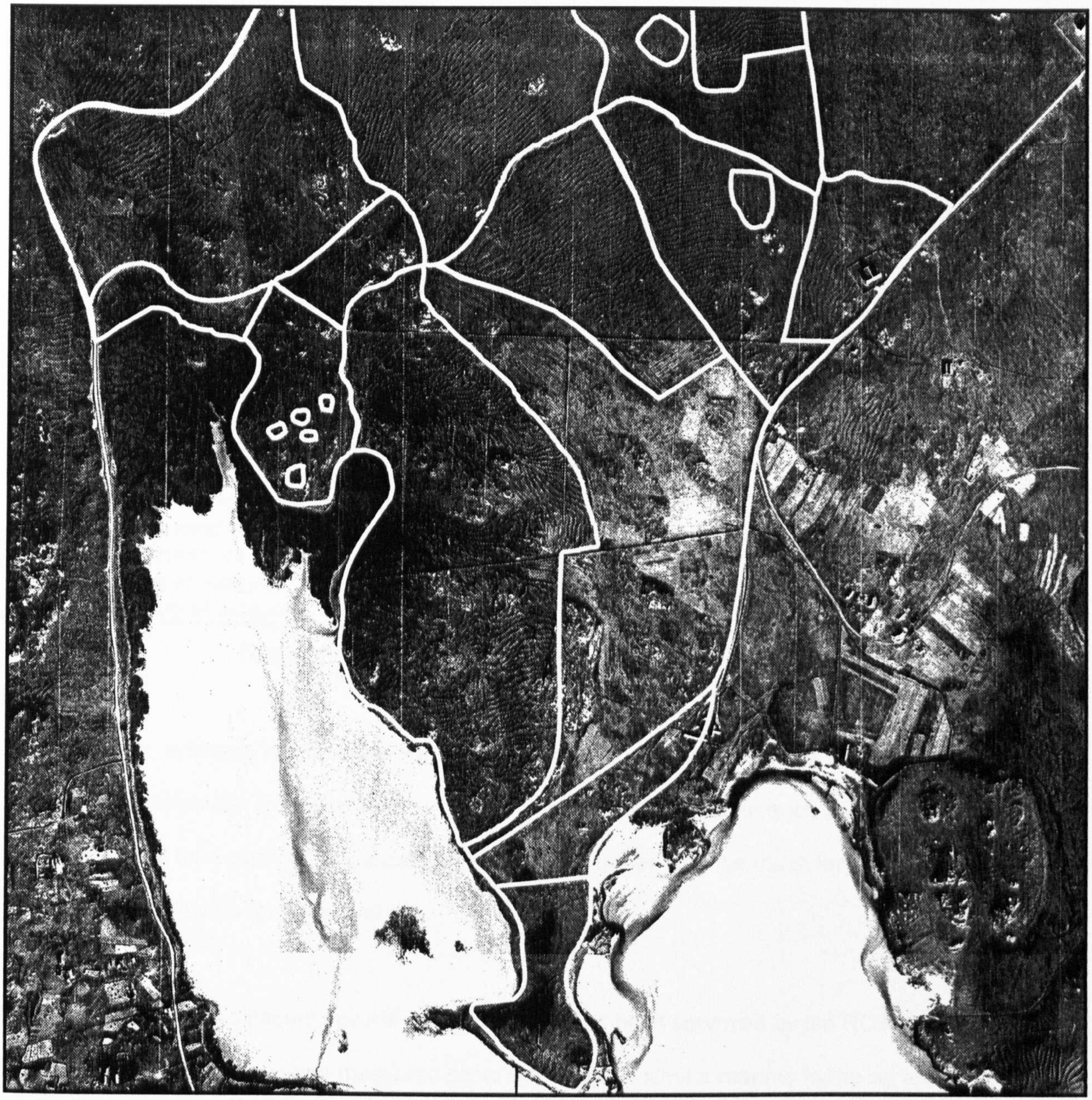
2.3 Method

2.3.1 Defining Polygons

Remnants of field boundaries were used as much as possible to define polygons within a site. This was a relatively easy task for enclosed landscapes such as Laughengie and Boyken. However, open landscapes such as Dùnan and Badentarbat proved more difficult. Where open landscapes with large areas of unenclosed cultivation remains were encountered, natural boundaries such as streams were used as much as possible to define the extent of each polygon. Aerial photographs were used since site survey maps, where they existed, only detailed a representation of the cultivation remains in the landscape and not their true extent. The number of these boundaries was kept to a minimum in an attempt to reflect the open nature of the landscape and resulted in large areas being defined as polygons, often containing a very diverse range of cultivation remains (Figure 2.1). All polygons were then allocated a number for recording purposes and ease of identification.

2.3.2 Choice of Variables

The characteristics of the field systems can be split into two broad categories; morphological features and topographical features (Table 2.1). Bowen (1961), Parry (1976) and Dixon (1994) have all distinguished distinct types of cultivation remains which can be associated with different methods of cultivation or the use of different models of plough. For example, broad rig with a sinuous reverse-S shape (Parry's Type 1 rig) is regarded as classic evidence for agricultural activity during the High



Modified and reproduced with the permission of the RCAHMS. Copyright of original survey map/AP belongs to RCAHMS

Figure 2.1 - Example of boundary definition applied to an open landscape of rig and furrow, Dùnan, Isle of Lewis.

Medieval Period when the heavy mouldboard or Old Scotch Plough, pulled by a large team of oxen and/or horses, was used. Narrow, curving rig, on the other hand, is considered to be a relic of activity from the Improvement period when the lighter swing plough came into use, although Dixon warns that this may be an oversimplistic interpretation as these narrow rigs can, in some cases, be dated prior to the invention of the swing plough by Small in 1767.

Morphological Features	Topographical Features
Total rig length Mean rig length Standard deviation of rig length Mean rig width Standard deviation of rig width Rig shape Total lynchet length Mean lynchet length Standard deviation of lynchet length Lynchet shape > 50% built boundary enclosing polygon Truncated polygon Perimeter of polygon Area of polygon Shape of polygon	Lower altitude Upper altitude Average angle of slope Aspect

Table 2.1 - Measures used in field system classification

Total rig length, mean rig length and width and the standard deviation of both rig length and width were calculated from the individual measurements recorded for each rig in each polygon. These parameters were then used in the classification procedure rather than the much larger raw data set detailing measurements for individual rigs.

The Boyken site also contained several polygons which had been surveyed by the RCAHMS as containing lynchets. These were measured separately but in a similar manner to the rig and furrow, although measurement of the width between these features was not calculated due to their irregular spatial pattern.

Rig shape and lynchet shape were seen as necessary qualitative measurements as differences in the shape of cultivation remains is considered by previous researchers as being diagnostic of different methods of cultivation. Parry (1976) and Dixon (1994) both use the distance between adjacent rigs as a useful measurement for differentiating types of rig cultivation. Based on the definitions contained in

Dixon (1994), narrow rig was defined as <5m between adjacent rigs whilst broad rig was categorised as >5m.

The presence or absence of a built boundary structure, such as a turf dyke, around greater than 50% of the polygon was also recorded along with information on whether each polygon was truncated by later landscape reorganisation. These variables were included in an attempt to overcome some of the difficulties encountered during the examination and analysis of the available data and will be discussed more fully in Section 2.3.9.

Although the perimeter, area and shape of each polygon is grouped under morphological features, they may also be regarded as having some association with topographical features. For example, the shape of a polygon might be affected by topographical features such as a sudden, steep break of slope which makes the building of a boundary dyke directly upslope a dangerous and energy-sapping task. In such circumstances, the farmer may well decide that the better strategy is to continue the boundary along the break of slope even if this leads to an irregularly shaped enclosure or field. The effect of such topographic features of the landscape will be discussed in more detail in Section 2.3.9.

Topographic features may dictate certain responses from a farmer. Steeper slopes may be considered unsuitable for cultivation by plough and may, alternatively, be either cultivated by spade or used as animal grazing. They are, therefore, important features of the agricultural landscape which require recording and assessing for their possible role in influencing the classification procedure. These topographic features must, however, be easily measured from the available data as individual field survey of every site is clearly impractical and defeats the purpose of this exercise to attempt to find a method of classifying field systems in Scotland using data which already exists. All the survey maps used for this study contained contour lines and, where no survey maps were available, 1:10000 Ordnance Survey maps were enlarged to 1:2500 scale and used. From these sources, the upper and lower altitude and average angle of slope of each polygon could be measured.

The aspect of the rig contained in the polygons was also considered important as documented methods of distributing farm land have used not only the quantity of the land as a guide but also the quality (Dodgshon, 1981). The practice of sun-division was often used where a tenant was given the land towards the sun in the east or south of each furlong or to the shade in the west or north (Dodgshon, 1980). The aspect of the rig and furrow or the field also often determined which crops were grown in that area, with cereals being grown on the sunnier east or south-facing slopes and root crops on the shadier fields to the north and west. This feature of the agricultural landscape was also measured in order to assess its importance in the classification process.

2.3.3 Method of measurement using PC Image Analysis

The PC Image Analysis software package produced by Foster and Findlay Associates was used on a DELL 486/33L computer linked to a Hitachi video camera with a JVC lens. The aerial photograph of each site was used for measuring the morphological features of the field system due to the incomplete nature of the site survey maps. However, these photographs often had to be captured at even larger scales to allow easy identification and measurement of individual rigs and this, coupled with the large size of the original APs, necessitated that each site was captured as a series of images which covered the entire area of the field system. A calibration file was created for each image to ensure accurate measurement (Figure 2.2).

The binary editor was used to create a manually digitised overlay of the boundary and rig of each polygon. The software was then used to measure the length of each rig and the shape, perimeter and area of the polygon. This information was saved as a text file and used to calculate the total rig length, mean rig length and standard deviation of the rig length for each polygon using the scientific calculator package in Microsoft Windows for Workgroups. Similar measurements were taken for lynchets. The distance between rigs was then manually digitised and measured to gain a record of the width between adjacent rigs. This information was added to the text file for the appropriate polygon and used to calculate the mean rig width and the standard deviation per polygon. Width was not measured for lynchets due to their irregular spatial pattern.

The shape of each polygon was calculated by the PC Image Analysis package as 4πarea/perimeter^2. This gives a value of 1.00 for a true circle and 0.78 for a true square. Rectangular shapes produce values between 0.00 and 0.77, depending on the shape of the rectangle. A rectangle of 10m length and 5m width, for example, produces a shape measurement of 0.70, whilst a rectangle 100m long and 1m wide, gives a value of 0.03. Polygon area was calculated in square metres and perimeter in metres.

2.3.4 Method of Manual Measurement

The topographical features were measured manually from either the RCAHMS survey maps or the enlargements of the 1:10000 Ordnance Survey maps. The highest and lowest point of each polygon was calculated using the contour lines, a ruler and the appropriate conversion scale to gain a measurement in metres.

The average angle of slope was calculated using basic trigonometry and a minimum of six readings per polygon. A greater number of readings was taken from larger polygons and, where a range of slope angles existed within a polygon, readings were taken from the shallowest to the steepest. The inverse tangent of the vertical distance (m) between contours over the horizontal distance (m) between contours was calculated to give the angle of slope for each reading.

$$x = \tan^{-1}\frac{O}{A}$$

where x = angle of slope (°)
O = Vertical distance between contour lines (m)
A = Horizontal distance between contour lines (m)

The Learable site posed an additional problem for the calculation of angle of slope. Much of the site was surveyed as a terraced landscape and the depiction on the survey map gave no indication of the scale of the individual terraces. It was thus impossible to calculate the average angle of slope across polygons containing these features and it was decided to give such polygons an arbitrary figure of 1000° to highlight this difference during the classification procedure.

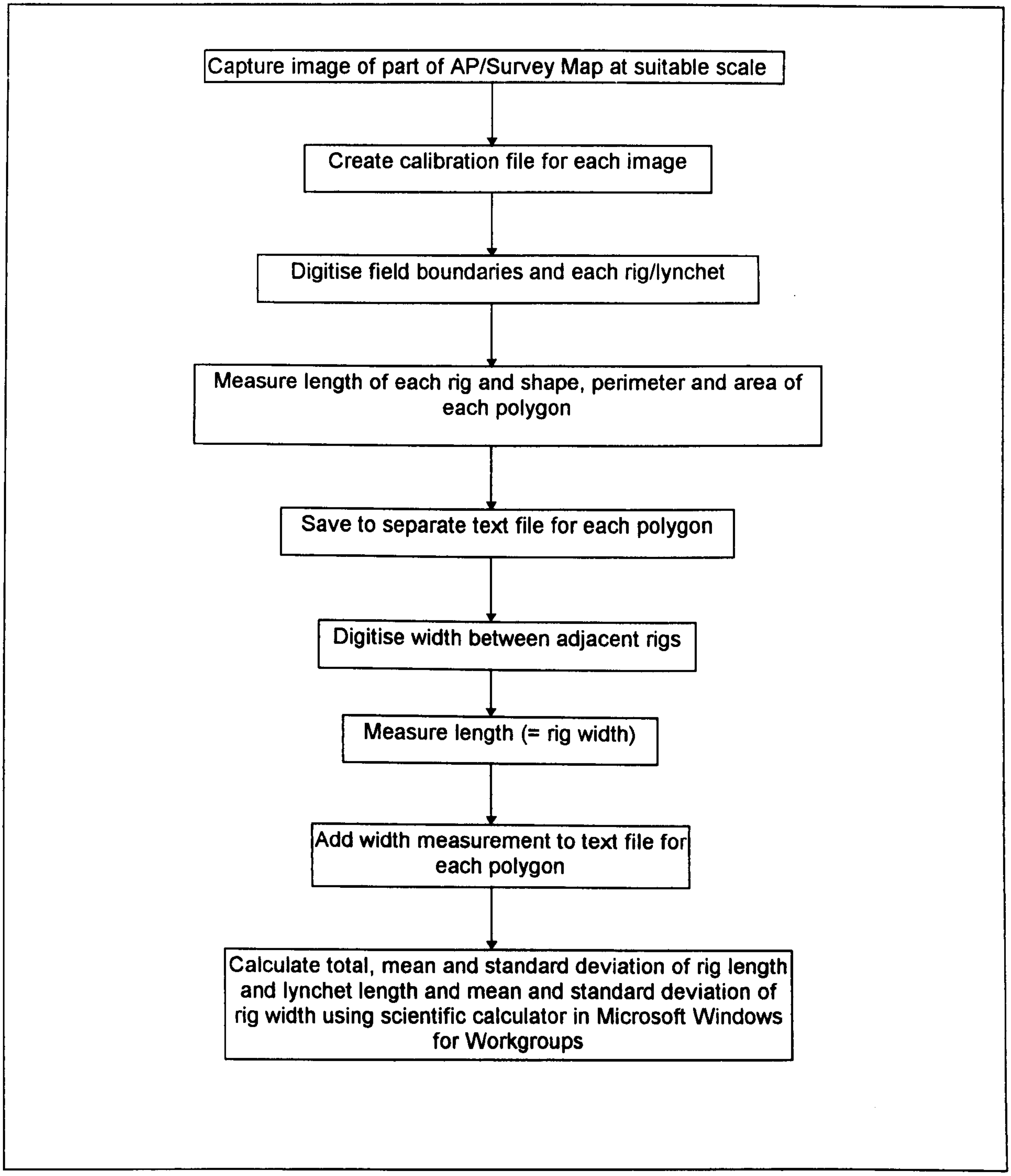


Figure 2.2 - Method of measuring field and rig morphology using PC Image Analysis

2.3.5 Coding of Variables

Several variables had to be allocated codes for entry into the SPSS spreadsheet to be used for the classification process using Hierarchical Cluster Analysis (HCA). Rig shape was coded according to the proportion of each type of rig contained in each polygon. For example, for the Badentarbat site: 1 = 100% broad straight rig, 2 = 100% broad curving rig up to 13 = 60%:20%:20% broad straight rig/narrow curving rig/broad lazybed. The coding had to be slightly modified for each site as new combinations of rig were found. Ideally, all combinations of rig types per polygon found for all six sites should have been entered into one single set of codes. However, computing and other problems caused several long delays to this part of the project and it became vital to gain classification results for the two field study sites before all 6 field systems could be completely analysed. Initial attempts at statistical analysis of the classification results using multiple analysis of variance also required consecutive coding numbers per variable per site which would not have been possible with only one set of codes for all sites. Lynchet shape was similarly coded but this proved to be less of a problem as only the Boyken site contained these features.

Aspect was also allocated codes according to the proportion of rig with each aspect contained in each polygon. Each point of the compass was associated with a range of values either side of its position on the dial as follows:

North	339° - 23°
North-east	24° - 68°
East	69° - 113°
South-east	114° - 158°
South	159° - 203°
South-west	204° - 248°
West	249° - 293°
North-west	294° - 338°

The aspect of every rig in each polygon was recorded and the results converted into a percentage ratio of each type per polygon. The resultant ratios were then allocated code numbers, e.g. 0 = No rigs, 1 = 100% N-S, up to 10 = 60%:40% E-W/SW-NE.

The boundary and truncate variables were allocated binary type coding: 0 = Yes, 1 = No. If a polygon possessed >50% built boundary then code 0 was used. Similarly, if a polygon was truncated by post-Improvement reorganisation of the land, it was coded 0.

Lower and upper altitude were coded in 5m ranges, e.g. 1 = 0-5m, 2 = 6-10m, 3 = 11-15m.

2.3.6 Gower's Coefficient of Similarity

The raw data set for each field system contains a mixture of ordinal, interval and nominal data which poses problems for the Hierarchical Cluster Analysis (HCA) process. Statistically, different types of analysis must be applied to the different types of data in order for results to be valid. For example, only non-parametric tests can be successfully carried out on nominal data. Similarity coefficients have long been used in taxonomy to overcome this problem during the classification of organisms and soils (Achab *et al*, 1992; Rayner, 1996; Sheals, 1964, Smith, 1963) and many different coefficients have been developed and used over the years. Johnson (1976, cited in Lim and Khoo, 1985) investigated 25 of these similarity coefficients and found Gower's (1971) general coefficient of similarity to be the best of those analysed. He equated "similarity" with "distance" in a vector space and found that the Gower's Coefficient of Similarity did not distort this space when negative matches were included in the data set and it maintained an "equal-interval property over all pairs in the samples" (Lim and Khoo, 1985, p. 1682). This is because similarities are normalised by the species range. This similarity coefficient was applied to the field system data.

Gower's equation for calculating the coefficient of similarity is:

$$S_{ij} = \sum_{k=1}^{v} s_{ijk}\delta_{ijk} \Big/ \sum_{k=1}^{v} \delta_{ijk}$$

where S_{ij} = Similarity coefficient between individuals *i* and *j*
v = total number of variables
k = variable being compared
s_{ijk} = score for comparison between individuals *i* and *j* of variable *k*
δ_{ijk} = quantity assigned for possibility of comparing individuals *i* and *j* for variable *k*

The score, s_{ijk}, is zero when *i* and *j* are considered different and a positive fraction or unity when they have some degree of agreement or similarity. The quantity, δ_{ijk}, is equal to 1 when variable *k* can be compared for *i* and *j* and 0 when they cannot. For qualitative variables, we set s_{ijk} = 1 if there is an agreement of variable *k* for both individuals *i* and *j* and s_{ijk} = 0 if they differ. For quantitative variables with values, $x_1, x_2, \ldots\ldots, x_n$ of variable *k* for the total sample of n individuals we set $s_{ijk} = 1 - \left|x_i - x_j\right| / R_k$. R_k is the range of variable *k* and can be either the total range in the population or the range in the sample. When $x_i = x_j$, then s_{ijk} = 1 and when x_i and x_j are at opposite ends of the range of variable *k*, s_{ijk} = 0 when R_k is determined from the sample. Intermediate values give a positive fraction value for s_{ijk}.

The calculation of scores for both qualitative and quantitative variables was written as a macro for the DOS version of the Minitab statistical software package by Dr Karen Chang, formerly of the Mathematics Department of Stirling University. The raw field system data was transferred from the SPSS software package into a DOS Minitab spreadsheet. The 'Gower' macro was run on the raw data set to produce a series of files containing the scores for each variable. These files were then read into Minitab as matrices and summed and averaged to produce the final matrix of similarity coefficients which was then transferred back into an SPSS spreadsheet in order to carry out the hierarchical cluster analysis.

2.3.7 Hierarchical Cluster Analysis

Hierarchical Cluster Analysis (HCA) was used in preference to Discriminant Analysis. The number of clusters to be produced from the data sets has to be determined and input prior to running the Discriminant Analysis test. This clearly involves subjective decision-making early in the classification process. With HCA, such decisions are left until after the objective clustering of the cases by the computer has taken place. Subjective decisions cannot be avoided entirely during classificatory procedures but the later in the process these decisions can be made, the more objective information is available upon which to base such a decision. Discriminant analysis also assumes normally distributed data. The distribution for all variables was non-normal and no transformation could be found to normalise the raw data. Hierarchical Cluster Analysis (HCA) was, therefore, carried out on the similarity coefficients for each site using complete linkage and Squared Euclidean distance. All variables were given equal weighting and were entered into the HCA process simultaneously. An agglomeration schedule and icicle plot were generated for each site indicating the cluster memberships at each stage of the process.

Choosing the best cluster solution in the process is very subjective, relying heavily on personal judgement. The guidelines for using the HCA procedure indicate that the best way of identifying the most significant clusterings is to analyse the agglomeration schedule and establish at which stage there is the largest difference between two adjacent coefficients. This large difference signifies the point in the process where the distance between the cases or clusters being combined is the greatest. However, the largest difference is invariably between the penultimate and ultimate stages of the process where the clusters are merged from two groups into one. This is clearly not the most appropriate grouping for all data sets. The differences between coefficients from consecutive stages in the process were examined and ranked from 1 to 6, 1 being the largest difference and 6 being the 6th largest difference. The cluster memberships at each of these stages were then examined by creating spatial overlays of each site. A subjective decision was then taken as to the most appropriate clustering solution, using personal judgement and knowledge gained of the site from the process of measuring the variables for the data set. Such an approach can clearly be criticised. However, as discussed, Discriminant Analysis did not provide a better solution and no other statistical technique could be identified which could produce useful and valid results using these data sets.

2.3.8 Statistical Analysis

Statistical analysis of the field classification results was carried out using two main techniques; cross-tabulation for the nominal and ordinal data and multiple comparisons using the Kruskal-Wallis one-way analysis of variance by ranks for the interval and ordinal data.

Cross-tabulation was used with the Chi-square bivariate statistical test to see if the data in the rows and columns were independent (Clarke, 1980). The Chi-square test is only valid if no cell in the table has an expected value of <1 and if less than 20% of the cells have expected values of <5 (Kinnear & Gray, 1994). Observed and expected counts were also calculated to test the validity of the Chi-square statistics.

The Kruskal-Wallis one-way analysis of variance by ranks tests for significant differences between groups that cannot be accredited to random chance alone, looking at each variable individually. All observations (N) for a variable are ranked as a single series. The sum of the ranks for each class, k, and the average rank are then calculated. The number of possible comparisons between classes is defined as k(k-1)/2. The difference between the average rankings for each of these comparisons is calculated and compared to the multiple comparison test using:

$$\left|\overline{R}_u - \overline{R}_v\right| \geq z_{\alpha/k(k-1)} \sqrt{\frac{N(N+1)}{12}\left(\frac{1}{n_u} + \frac{1}{n_v}\right)}$$

where $\left|\overline{R}_u - \overline{R}_v\right|$ is the observed difference between the average ranks for classes *u* and *v*,
$z_{\alpha/k(k-1)}$ is the value of *z* at a critical value, α, for the number of possible comparisons,
N is the total number of observations for the class, and
n_u and n_v are the number of observations for classes *u* and *v*.

If the observed difference between two classes is greater than or equal to the required difference calculated for that comparison, then the null hypothesis, $H_0 : \theta_u = \theta_v$ can be rejected in favour of the alternative hypothesis, $H_1 : \theta_u \neq \theta_v$ (Siegel and Castellan Jr., 1988).

The pairings showing significant differences for each variable were then summarised in a single table in order to establish which combination of variables characterised the differences between each possible comparison of the field classes.

2.3.9 Problems with the data

Several problems were encountered whilst trying to use the available data to create a method for the classification of field systems in Scotland. The main problem of actually obtaining the best, standardised information for different sites has already been discussed and has led to a number of subsequent issues in the process of developing this classification method.

The dividing of the landscape into discrete areas, commonly known as fields, is a fundamental part of agricultural activity, both now and in the past. However, enclosure of the landscape was not practised to the same degree in all areas of Scotland. Field systems of the north and west of Scotland are generally more open landscapes than those found in the south and east and this is demonstrated by the mainly unenclosed nature of the Dùnan and Badentarbat sites on the Isle of Lewis and on the coast of North West Ross, respectively. For the purposes of this classification it was necessary to divide the systems into polygons, each with its own set of associated characteristics, in order to be able to compare and establish if there were any similarities between one or more of these distinct areas. It was hoped that these similar areas, or polygons, could then be associated with similar types of agricultural activity, such as animal husbandry or arable cropping.

This was a relatively easy operation for enclosed landscapes such as that found at Laughengie, Kirkcudbrightshire. No additional interpretation of the landscape had to be made and all enclosures had complete, constructed boundaries. The Badentarbat site, however, contained a mixture of enclosures and open areas of rig and furrow. Several different types of cultivation remains are to be found in these open areas and artificial polygon boundaries had to be added to the landscape to allow the classification process to distinguish these differences and compare them. This was a subjective process but was carried out using two basic rules. Firstly, documentation often cites natural features such as streams, woods and breaks of slope as the boundary to a piece of land (Rackham, 1986). These features were used, where possible, to define the boundaries of polygons where little or no constructed boundary existed. Secondly, these artificial boundaries were kept to a minimum in order to minimise the effects of additional interpretation of the landscape and to create large polygons which reflected the open nature of the landscape.

The term "polygon" was used in the context of this classification rather than the term "field" as many of the defined areas created by this classification procedure could not be seen to fulfil the definition of " field" as a "tract of unwooded land usually enclosed and cultivated or used for pasture" (Garmonsway, 1991). A variable was added to the data for classification in order to provide the classification procedure with some means of distinguishing these artificial polygons from the true, enclosed areas of the landscape. If a polygon had >50% of its perimeter bounded by a constructed boundary, a "0" was entered under the "Boundary" variable column to denote "Yes". In the case of an unbounded polygon, "1" was entered for "No".

During the examination of the Boyken survey map, it became apparent that several of the boundaries were not contemporary but were superimposed on earlier structures in the landscape (see upper field complex to east of site in Figure 2.5). Although, in this case the subsequent field survey work clarified and confirmed this observation, this practise was clearly not possible in all cases. This field system classification was a desk-top exercise which aimed to develop a method of classification that could be effectively carried out using existing information rather than requiring further field work.

This palimpsest of the field system structures creates truncation of certain features. However, the complexity and chronology of these features cannot be identified or appreciated from the survey map and aerial photographic evidence alone. Truncation of the medieval landscape by the reorganisation of the land during the post-Improvement period, however, is much more easy to identify and was evident in several of the sites studied for this project. This truncation of some polygons clearly had a significant effect on characteristics such as shape, perimeter, average angle of slope, upper and lower altitude and total and mean rig length and some means of identifying these truncated polygons had to be found. It proved impossible to identify truncation by pre-Improvement activity from the information available but post-Improvement truncation was relatively easy to identify and a "Truncate" variable was created where a polygon truncated by such activities as forestry plantation or reorganisation of the land into regular, geometric fields was given the value "0" for yes and an untruncated polygon "1" for no.

Certain topographic features were not identifiable from maps at the 1:2500 scale used here and several changes in angle of slope within a polygon, for example, may have gone unrecorded. It is hoped that a general impression of each polygon has been achieved by using the average angle of slope and the two sites from this study used for further field and micromorphological work did not display any major features which had remained unidentified from the desk-top study.

The data available proved to be inadequate for this level of detailed study and the researcher was forced to make several interpretations of the landscape rather than merely recording and measuring the required elements. The accuracy of the interpretation is clearly open to debate but it is considered likely that two individuals with a similar knowledge base of field systems and given the same information would come up with similar, although not identical, interpretations if they both used the basic rules set out during this study. This, however, remains an untested hypothesis.

One problem that was encountered during this study was loss of the field evidence. The 1947 aerial photograph of the Cleish site in Fife was used by the RCAHMS to produce the current survey map. Despite not having been physically surveyed by the RCAHMS, the data was considered to be of sufficiently good quality for use in this study, particularly in the absence of any better information for other sites in this area of Scotland. However, on detailed examination of the AP, it became difficult to establish if the broad, straight rigs running perpendicular to the contour were actually the remains of agricultural cultivation or evidence of artificial drains created prior to afforestation. Several of the "rigs" appeared not to respect polygon boundaries (Figure 2.3) and it was decided that a visit to the site was the only way to settle the debate. This was only considered possible due to the close proximity of the site to the university and, again, illustrates the problems with attempting to classify field systems from desk-top study alone. The field system was found to be under an approximately 30 years old coniferous plantation and it proved impossible to find, let alone interpret, the features in question.

Subsequent enquiries to the Forestry Commission confirmed that the land had been bought in 1959 and drained and planted in 1961. The features on the AP were therefore interpreted as rig and furrow. However, some doubt still remains about the dating of the cultivation remains in relation to the enclosures. It seems that, in some cases, these features may not be contemporary. However, it is impossible to tell from the AP which feature is the earlier. The classification for the Cleish site was run twice; once using all the variables and a second time using all variables except those pertaining to the

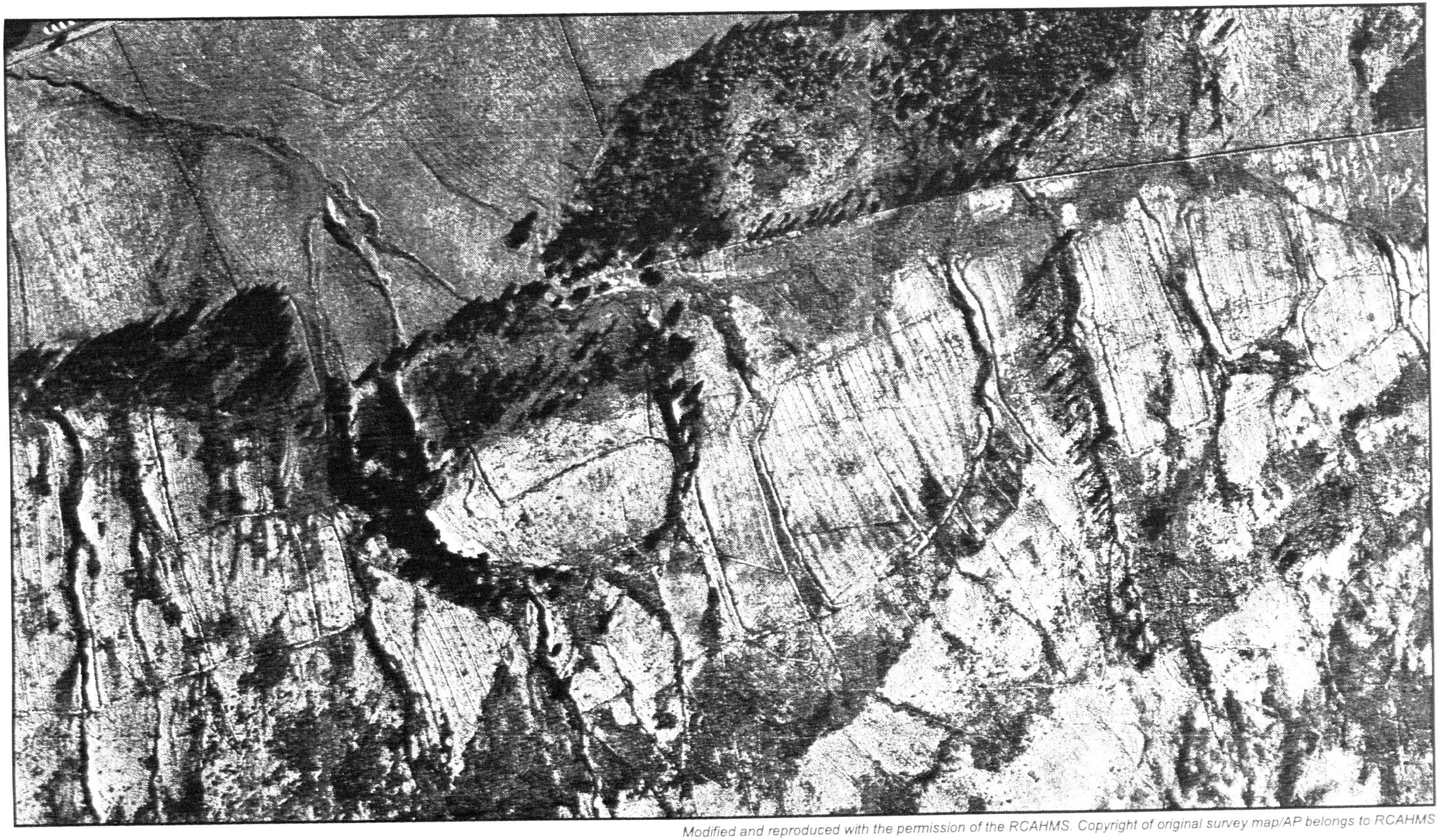


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Figure 2.3 - Aerial photograph of field system at Cleish, Fife. Note how some of the rig and furrow do not respect the field boundaries

rig morphology. The classification using all variables appeared to give the better results (Appendix 1).

The subjectivity of the hierarchical cluster analysis procedure is an inherent problem. Identification of the largest differences between coefficients for adjacent stages in the process is suggested as the best method of identifying significant clustering stages in the HCA procedure as these large differences indicate the largest distances between the cases or clusters being combined. However, post-hoc statistical analysis of the results obtained for the Learable site found that the 4 cluster solution was the most significant, despite the difference between the two adjacent coefficients at this stage in the HCA process being negligible (Appendix 1).

2.4 Results and Analysis

2.4.1 Badentarbat, NW Ross

The five cluster solution was chosen as the best classification of the Badentarbat field system (Appendix 1 and Figure 2.4). Only comparisons between field classes 1 & 2, 2 & 5 and 3 & 5 showed any significant difference between classes for the interval data (Table 2.2).

Field Class comparisons showing statistically significant (95% C.I.) differences for certain variables (interval data only)			
1 & 2	**2 & 3**	**2 & 5**	**3 & 5**
Total rig length Mean rig length SD rig length Mean rig width SD rig width	Total rig length Mean rig length SD rig length	Total rig length Mean rig length SD rig length Mean rig width SD rig width Field perimeter Average slope	Average slope

Table 2.2 - Interval data showing statistically significant differences between certain field class comparisons, Badentarbat.

None of the ordinal or nominal data was found to be statistically significant due to the minimum expected cell frequency being <1 and more than 20% of cells having an expected frequency <5. However, inspection of the distribution of each variable per field class did show that 75% of the polygons in Field Class 1 contained rigs with 100% E-W aspect. Twenty-nine percent of the polygons in this class contained 100% broad lazybed whilst a further 33% contained 100% narrow lazybed and 88% of the polygons were not truncated.

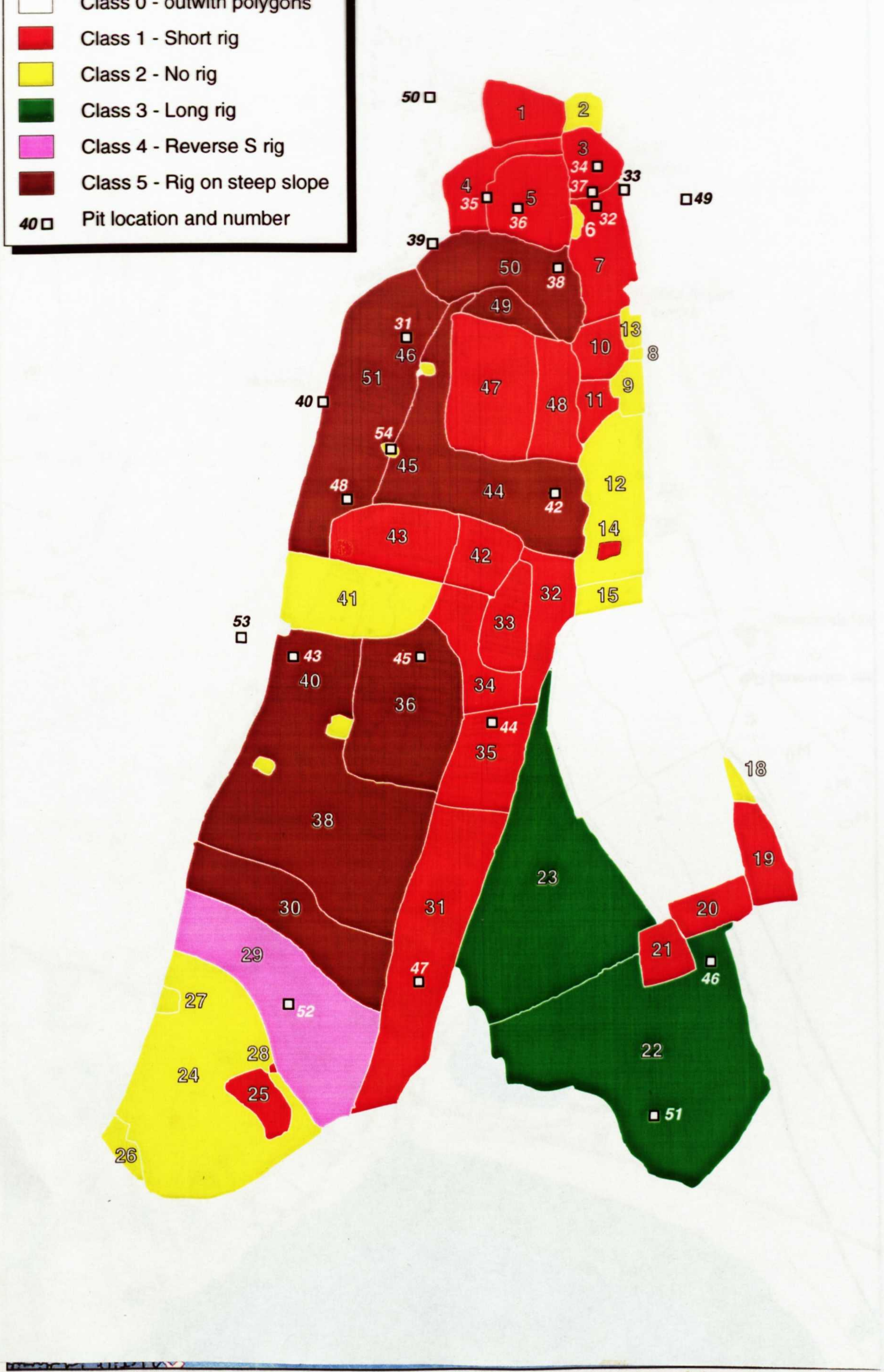

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Figure 2.4 - Classification of Badentarbat field system, NW Ross.

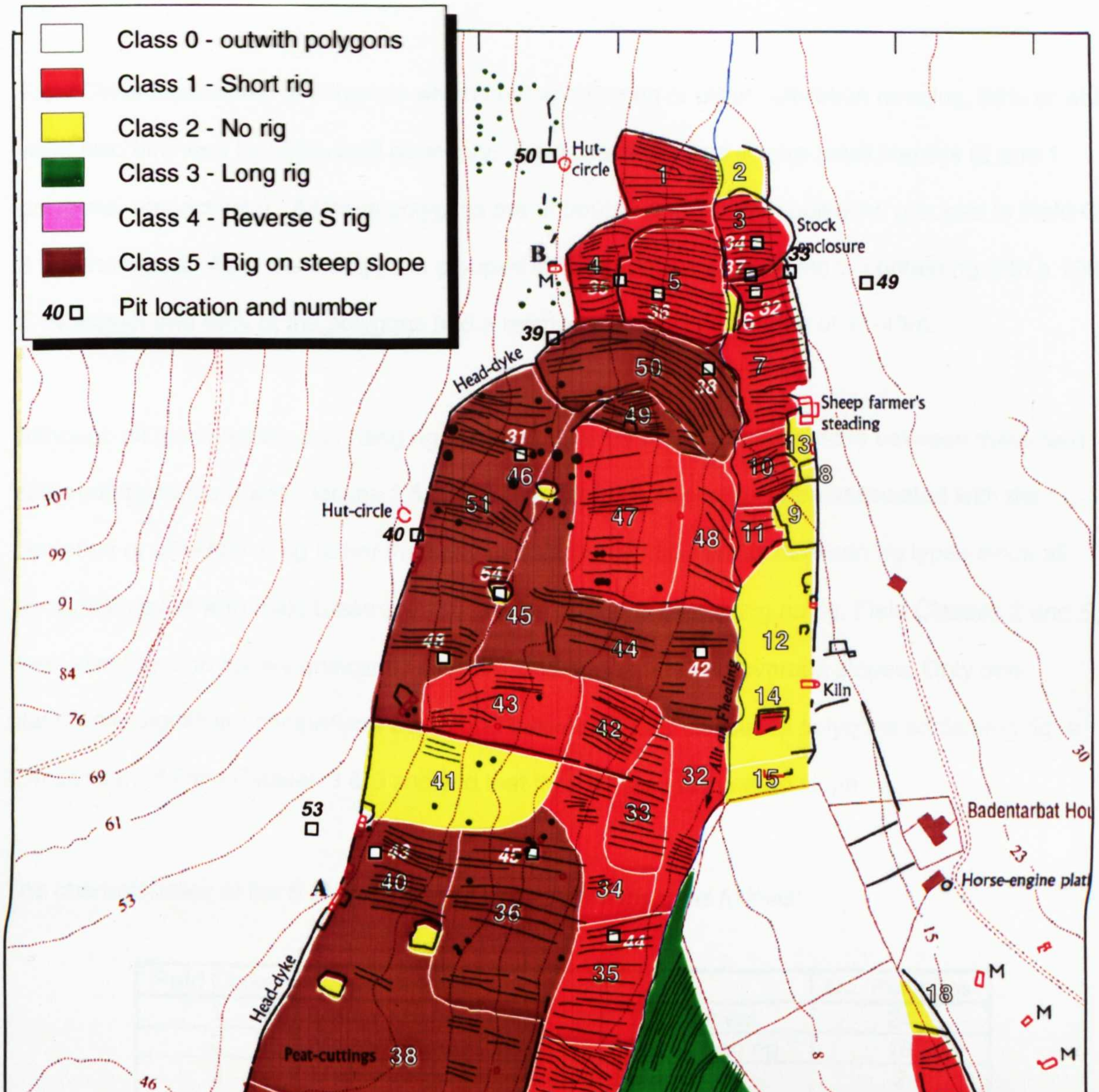

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Figure 2.4 - Classification of Badentarbat field system, NW Ross.

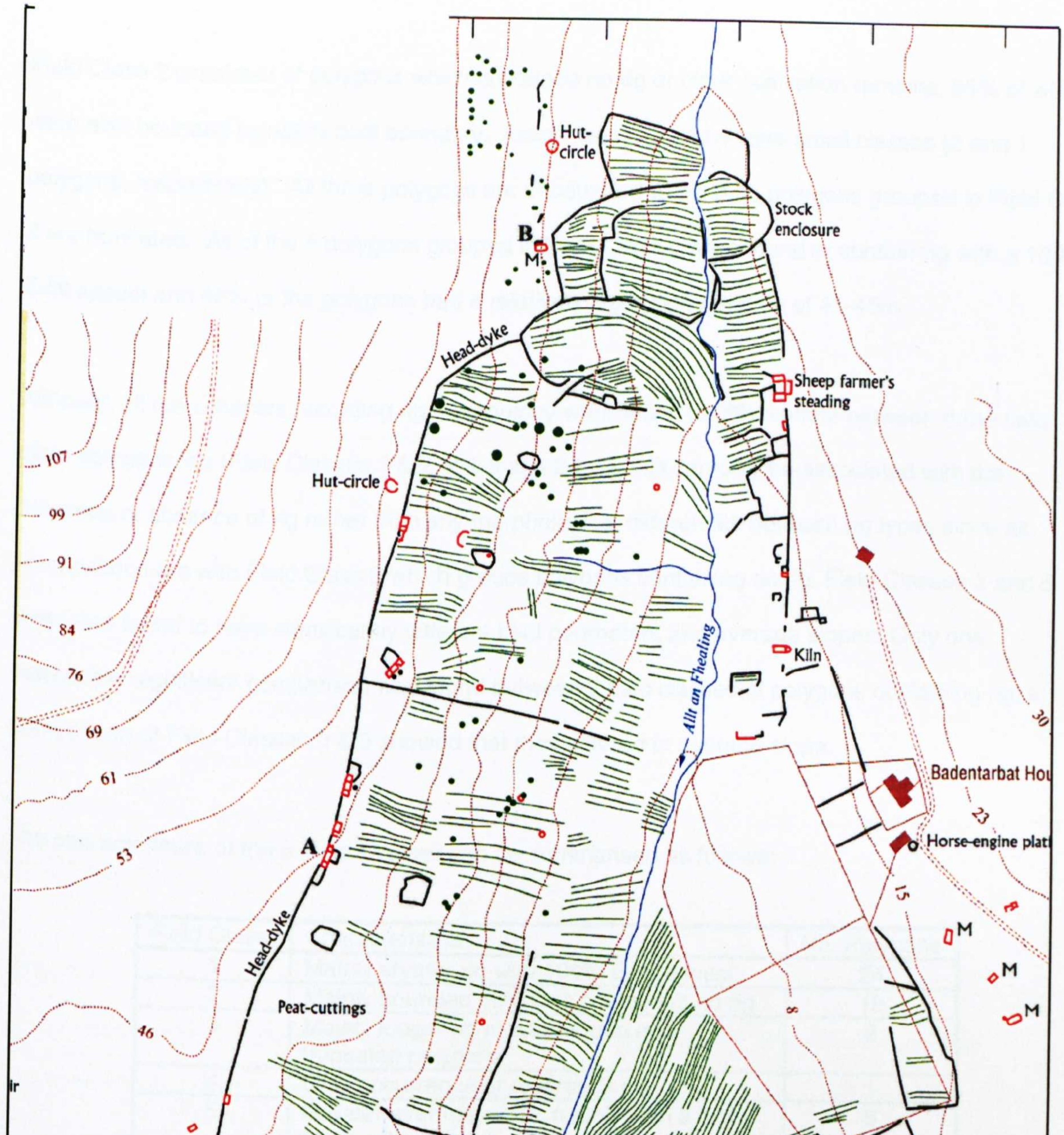

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Figure 2.4 - Classification of Badentarbat field system, NW Ross.

Field Class 2 consisted of polygons which contained no rig or other cultivation remains, 95% of which were also bounded by >50% built boundary. Field Classes 3 and 4 were small classes (2 and 1 polygons, respectively). All three polygons are unbounded whilst both polygons grouped in Field Class 3 are truncated. All of the 6 polygons grouped in Field Class 5 were found to contain rig with a 100% E-W aspect and 68% of the polygons had a relatively high upper altitude of 41-45m.

Although all the variables recording rig morphology were found to differentiate between three field class comparisons (Field Classes 1 & 2, 2 & 3 and 2 & 5), this can only be associated with the presence or absence of rig rather than any morphological differences between rig types since all comparisons are with Field Class 2 which groups polygons containing no rig. Field Classes 2 and 5 were also found to have significantly different field perimeters and average slopes. Only one statistically significant comparison was found between 2 field classes of polygons containing rig: a comparison of Field Classes 3 & 5 showed that they differed in average slope.

The characteristics of the 5 Field Classes can be summarised as follows:

Field Class	Characteristics	No. Polygons
1	Mainly shorter rig with 100% E-W aspect	24
2	Mainly bounded polygons containing no rig	18
3	Mainly longer rig in unbounded and truncated polygons	2
4	Only occurrence of reverse-S rig	1
5	Greater average slope, mainly with a high upper altitude and containing rigs with 100% E-W aspect	6

Table 2.3 - Field Class characteristics for Badentarbat, NW Ross.

2.4.2 Boyken, Dumfries and Galloway

The six cluster solution was chosen for this site (see Appendix 1 and Figure 2.5).

The statistical analysis of the interval data showed only significant differences (95% C.I.) between Field Classes 1 & 3 and 2 & 3. This is probably due to Field Classes 4, 5 and 6 containing only 1, 2 and 1 members, respectively and therefore insufficient data could not allow a valid comparison of these Field Classes with the larger Classes 1, 2 and 3.

Field Class comparisons showing statistically significant (95% C.I.) differences for certain variables (interval data only)	
1 & 3	**2 & 3**
Total rig length	Total rig length
Mean rig length	Mean rig length
SD rig length	SD rig length
Mean rig width	Mean rig width
Field area	SD rig width
	Field perimeter
	Field shape

Table 2.4 - Interval data showing statistically significant differences between certain field class comparisons, Boyken.

The variables giving various measures of rig morphology were found to be significantly different between both Field Classes 1 & 3 and 2 & 3. As for Badentarbat, this may be attributed only to the presence or absence of rig given that both comparisons involve Field Class 3 which consists of polygons containing no rig. Field Classes 1 and 3 were also found to differ in field area, whilst the comparison of Field Classes 2 and 3 recorded a difference in field perimeter and field shape between the classes.

Again, the cross-tabulation of the ordinal/nominal data did not give any statistically significant results due to a small minimum expected frequency and a high percentage of cells with an expected frequency of less than 5. However, certain field classes appeared to display certain characteristics worthy of note. All polygons grouped in Field Class 1 are truncated, for example. Similarly, all polygons in Field Class 3 contain no rig and all but one of the polygons in this group are bounded by a >50% built boundary. Field Class 2 appears to be less homogeneous with 52% of the polygons in this class containing rig with 100% E-W aspect and 67% being bounded. Although the distribution of upper and lower altitude ranges is fairly even for all field classes, the polygons grouped in Field Class 3 appear to be generally higher in both upper and lower altitude than those of Field Class 2. No topographical interval data was used to differentiate between classes but all field morphology variables were found to be useful differentiators (see Table 2.14).

From the analysis of the results, the following summary details the general characteristics of each field class.

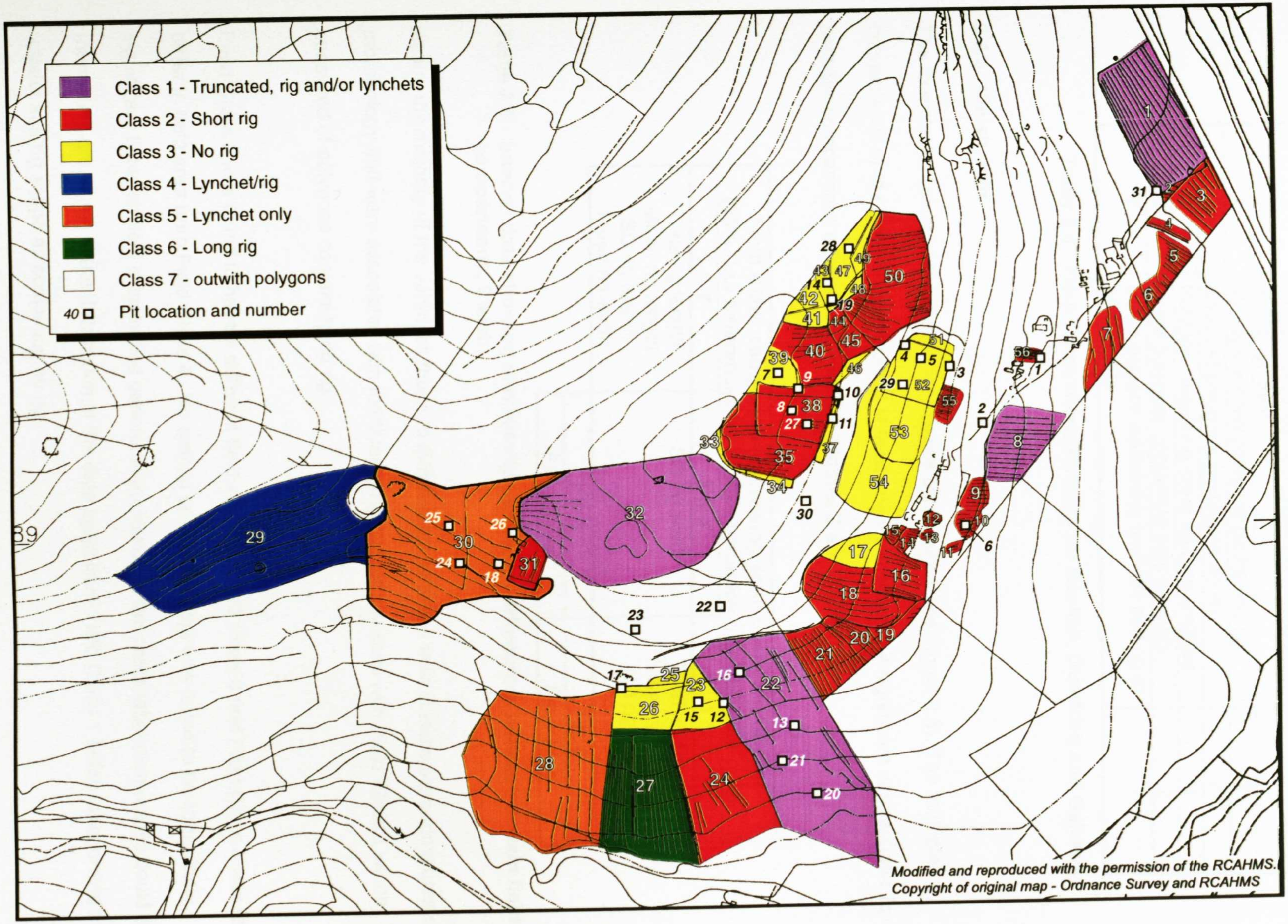

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Figure 2.5 - Classification of Boyken field system, Dumfries & Galloway.

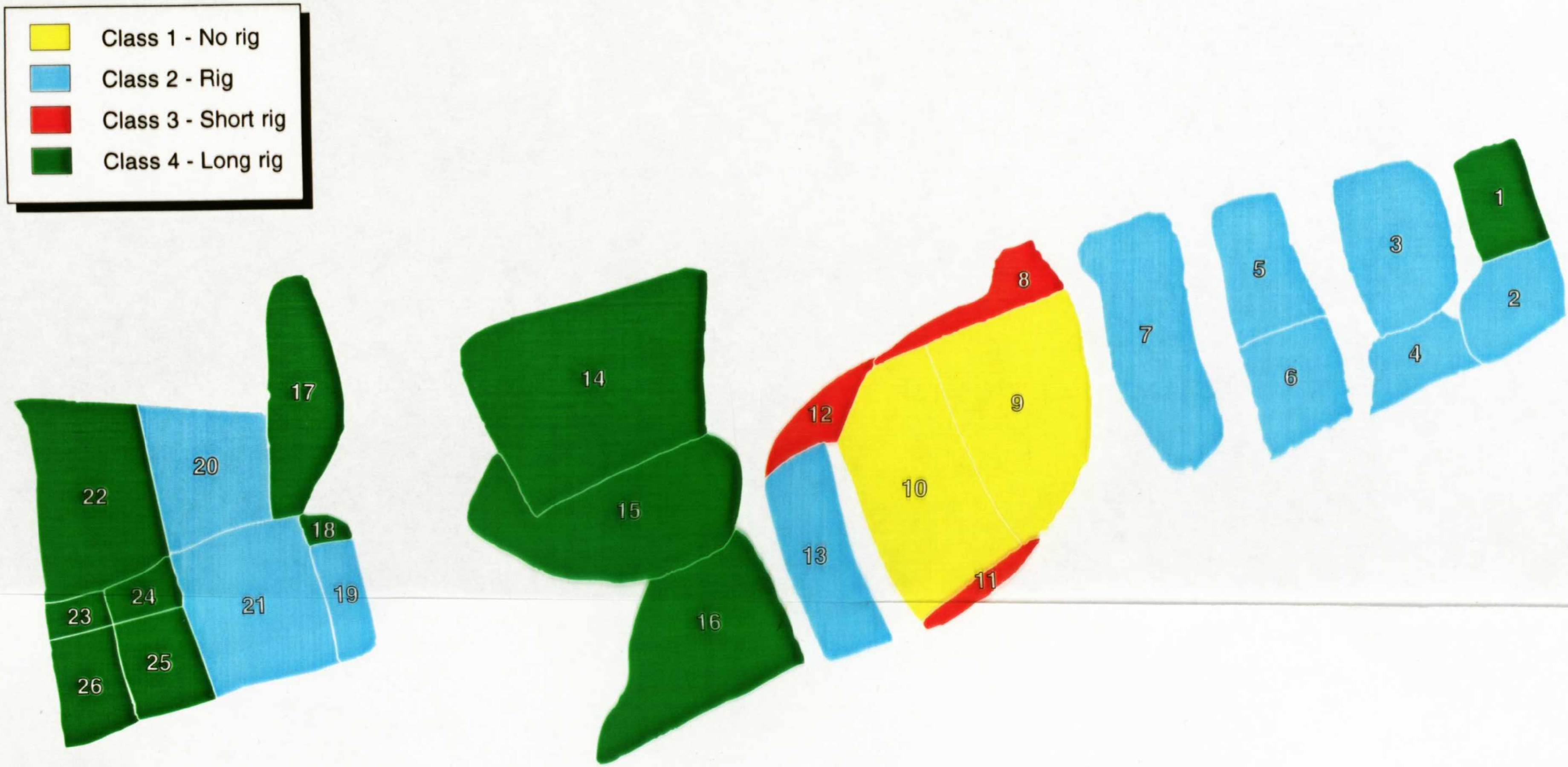

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Figure 2.6 - Classification of Cleish field systems, Fife.

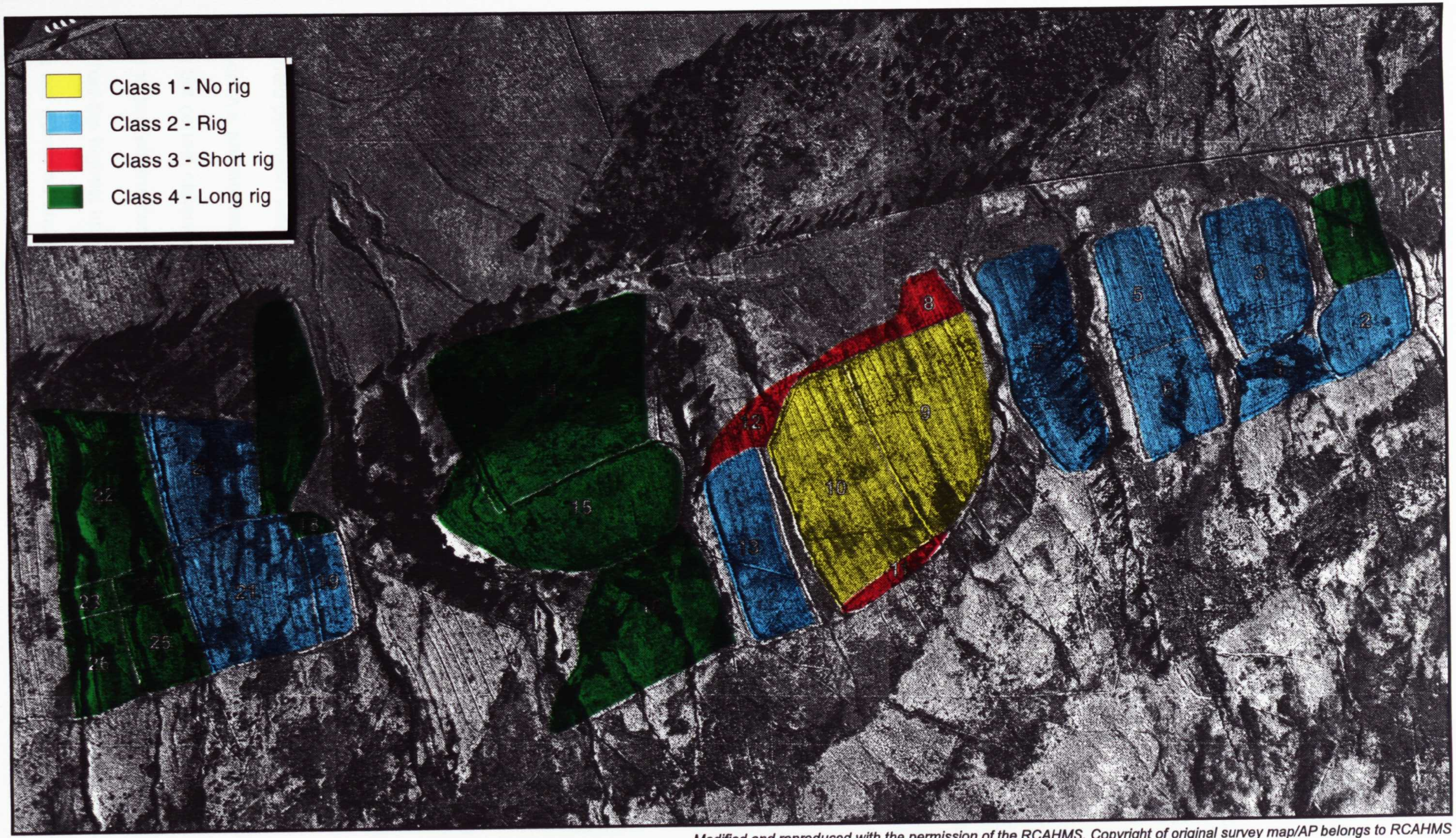

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Figure 2.6 - Classification of Cleish field systems, Fife.

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Figure 2.6 - Classification of Cleish field systems, Fife.

The following summary of field class characteristics can be produced for the Cleish site.

Field Class	Characteristics	No. polygons
1	Polygons containing no rig	11
2	Polygons containing rig	10
3	Polygons containing rig with unusual field shape	3
4	Polygons containing no rig with a large field area	2

Table 2.7 - Field Class characteristics for Cleish, Fife

2.4.4 Dùnan, Isle of Lewis

A five cluster solution was accepted as the best solution for this site (Appendix 1 and Figure 2.7). As for Boyken, two of these five classes were small containing one member each (Field Classes 4 and 5). As a consequence, comparisons between these field classes and others did not produce any statistically significant results. The multiple comparison tests showed there only to be differences between Field Classes 1 & 3 and 2 & 3 (Table 2.8).

Field Class comparisons showing statistically significant differences (95% C.I.) for certain variables (interval data only)	
1 & 3	**2 & 3**
Total rig length Mean rig length SD rig length Mean rig width SD rig width Field area Field perimeter	Mean rig width

Table 2.8 - Interval data showing statistically significant differences between certain field class comparisons, Dùnan.

Again, the majority of the variables showing a significant difference were measures of rig morphology and can be attributed to the fact that all polygons grouped in Field Class 3 contain no rig. Field area and field perimeter were also found to be differentiators between Field Classes 1 and 3.

The ordinal and nominal data was not statistically significant for the same reasons stated for other sites but certain observations of the distribution of this data were made. All polygons in Field Class 1 were truncated and contained 100% broad lazybed whilst 57% contained rig with 100% E-W aspect and had the highest upper altitude at 51-55m. Four out of the five polygons grouped in Field Class 2 were not truncated and also contained 100% broad lazybed. Sixty percent had a low lower altitude of

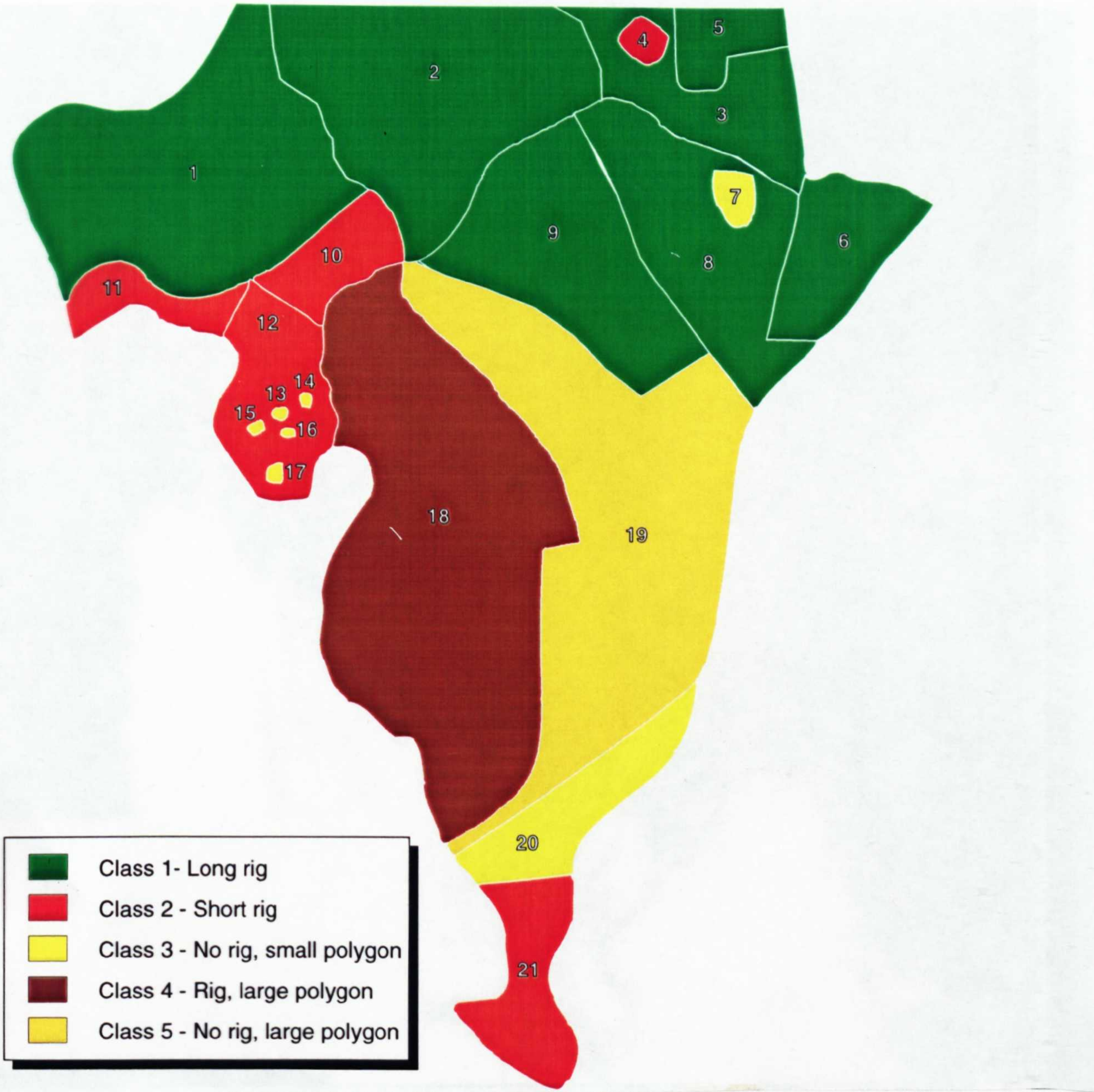

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Figure 2.7 - Classification of Dùnan field system, Isle of Lewis.

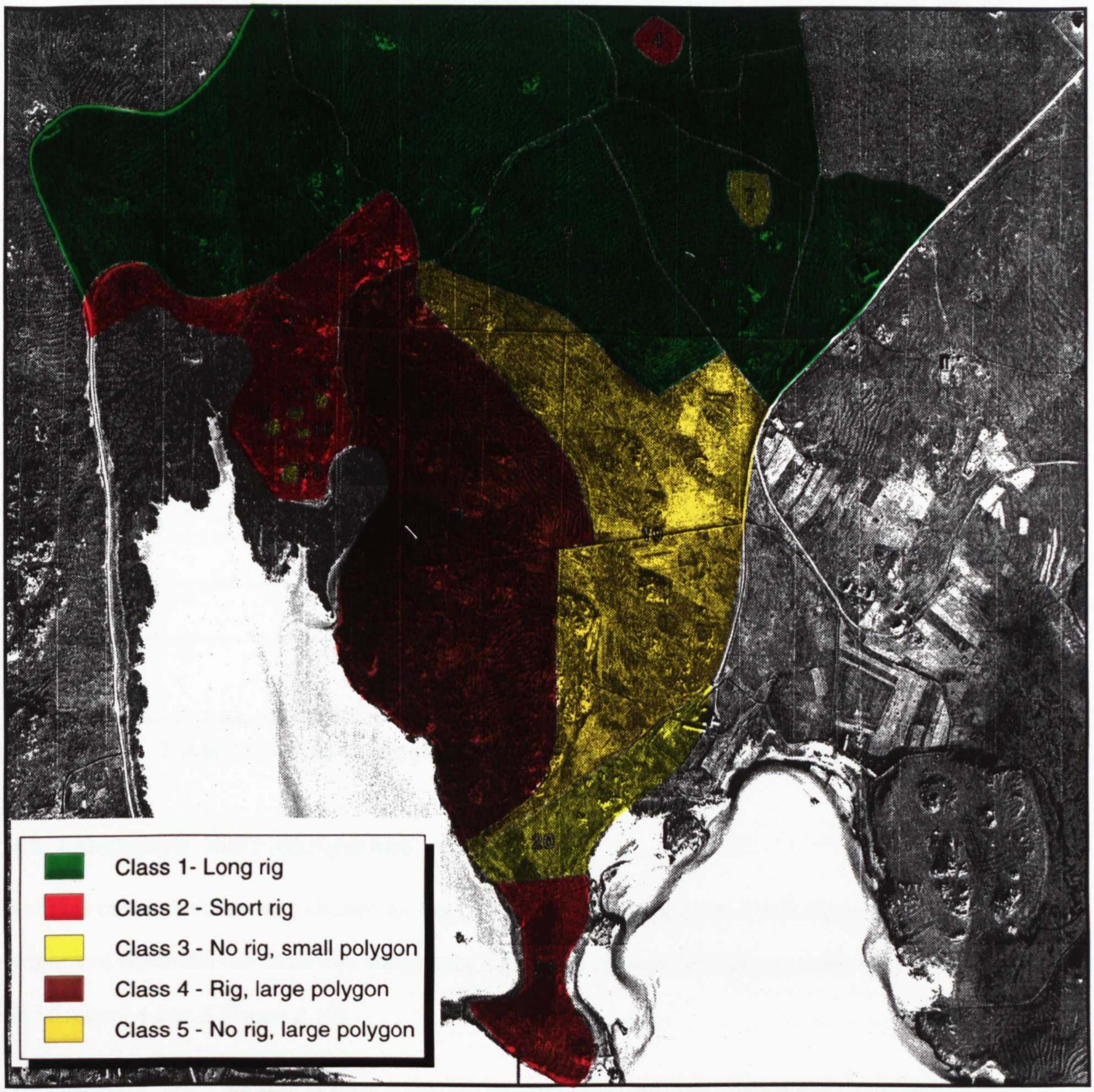

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Figure 2.7 - Classification of Dùnan field system, Isle of Lewis.

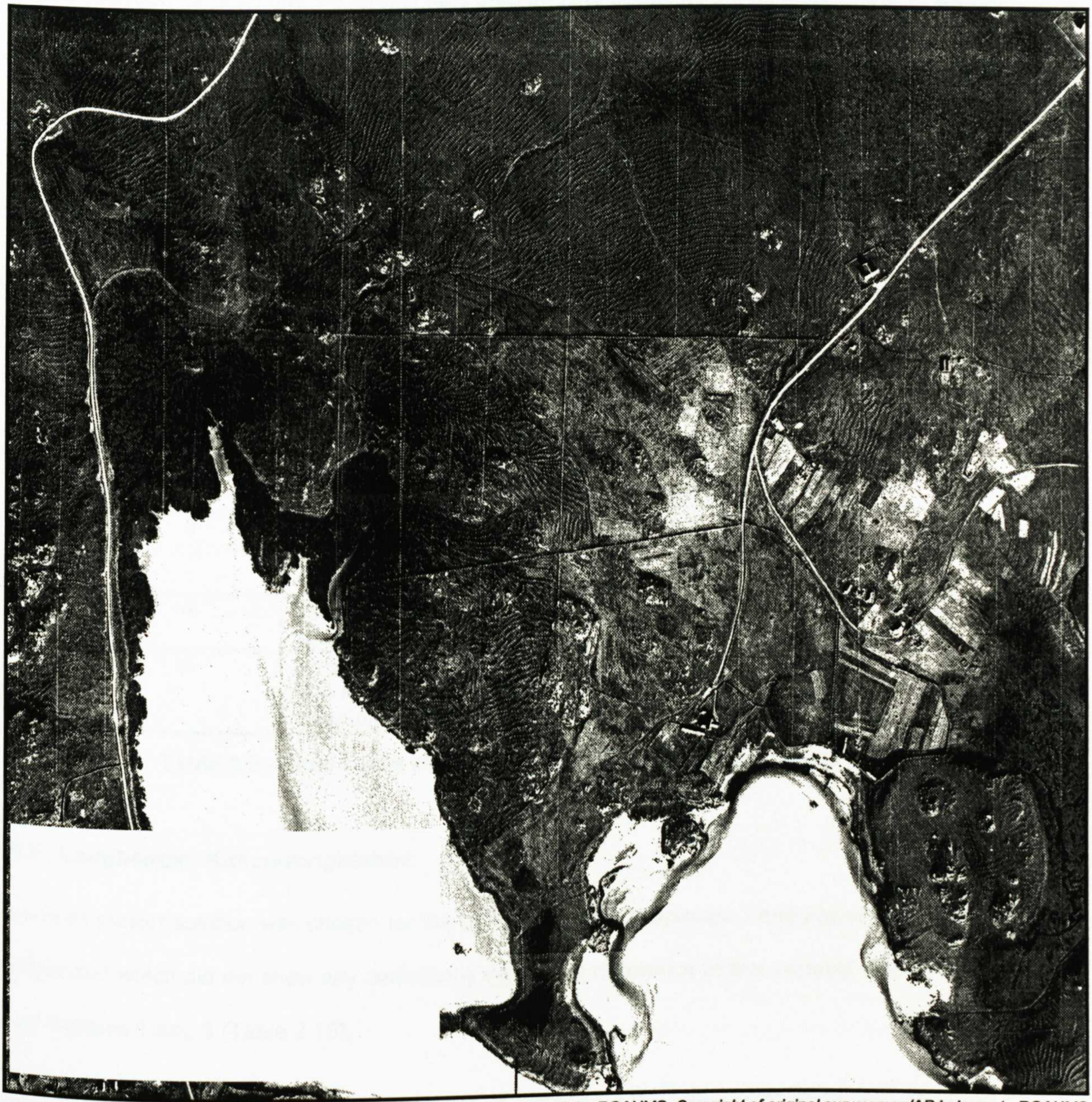

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Figure 2.7 - Classification of Dùnan field system, Isle of Lewis.

0-5m whilst 80% were also found to have a lower upper altitude than Field Class 1 at 26-30m. Polygons in Field Class 3 were all bounded by >50% built boundary and were not truncated. Fifty-seven percent had a lower altitude of 0-5m whilst 86% also had a low upper altitude of 6-10m. Field Class 4 (polygon 18 only) has the largest field area and the greatest total rig length. It also has the greatest range of rig aspects at a 60:20:10:5 ratio of E-W/NW-SE/N-S/NE-SW. Field Class 5 also contains only one polygon - polygon 19 - which is characterised by having the largest field perimeter although it only has the second largest field area. It also has the second largest average angle of slope.

The field characteristics of the Dùnan site can be summarised thus:

Field Class	Characteristics	No. polygons
1	Polygons containing 100% broad lazybed mainly with 100% E-W aspect, not truncated	7
2	Polygons containing rig, mainly not truncated and with a low upper altitude	5
3	Bounded polygons, not truncated with a small field area and field perimeter containing no rig.	7
4	Largest polygon containing greatest amount of rig	1
5	Large polygon with largest field perimeter, with a high average angle of slope and containing no rig	1

Table 2.9 - Field Class characteristics for Dùnan, Isle of Lewis

2.4.5 Laughengie, Kirkcudbrightshire

The three cluster solution was chosen for the Laughengie site (Appendix 1 and Figure 2.8). The only comparison which did not show any statistically significant difference in any variable was between Field Classes 1 and 3 (Table 2.10).

Field Classes 1 and 2 differed in total rig length, the Standard Deviation (SD) of the individual rig length as well as field area and field perimeter. The polygons in Field Class 2 have a large field area and perimeter and also contain the greatest total rig length. The SD of the individual rig lengths in this class are also large but there is no significant difference in either the width of the rig or the SD of the individual rig widths between Field Classes 1 and 2.

Field Class comparisons showing statistically significant differences (95% C.I.) for certain variables (interval data only)	
1 & 2	**2 & 3**
Total rig length SD rig length Field area Field perimeter	Total rig length Mean rig length SD rig length SD rig width Field area Field perimeter

Table 2.10 - Interval data showing statistically significant differences between certain field class comparisons, Laughengie.

Field Classes 2 and 3 differ in all the measured variables of rig morphology apart from mean rig width. Field area and field perimeter also differ between these two classes, with the polygons in Field Class 3 being much smaller than those of Field Class 2. The topographical interval data (average slope) was not statistically significant for any comparison.

Six out of eight of the polygons grouped in Field Class 1 contained rig with 100% NW-SE aspect whilst seven contained 100% narrow straight rig. However, Field Class 2 also appears to have these same features in the majority of its polygons, with seven out of eight of the polygons with rig at 100% NW-SE aspect and 6 with 100% narrow straight rig.

The field class characteristics of the Laughengie site can be summarised as follows.

Field Class	Characteristics	No. polygons
1	Smaller polygons with a small SD in rig length	8
2	Largest polygons with a large total rig length and SD in rig length	8
3	Smallest polygons containing no rig	3

Table 2.11 - Field Class characteristics for Laughengie, Kirkcudbrightshire.

2.4.6 Learable, Ross & Cromarty

The six cluster solution was originally chosen as the best solution for this site using the criteria discussed in Section 2.2.6. However, post-hoc statistical analysis of the results from this stage in the process did not show any significant differences between the classes and the 4 cluster solution was found to produce more significant results. The 4 cluster solution was thus accepted as the better solution (Appendix 1) and the distribution of the 4 field classes across the site is shown in Figure 2.9.

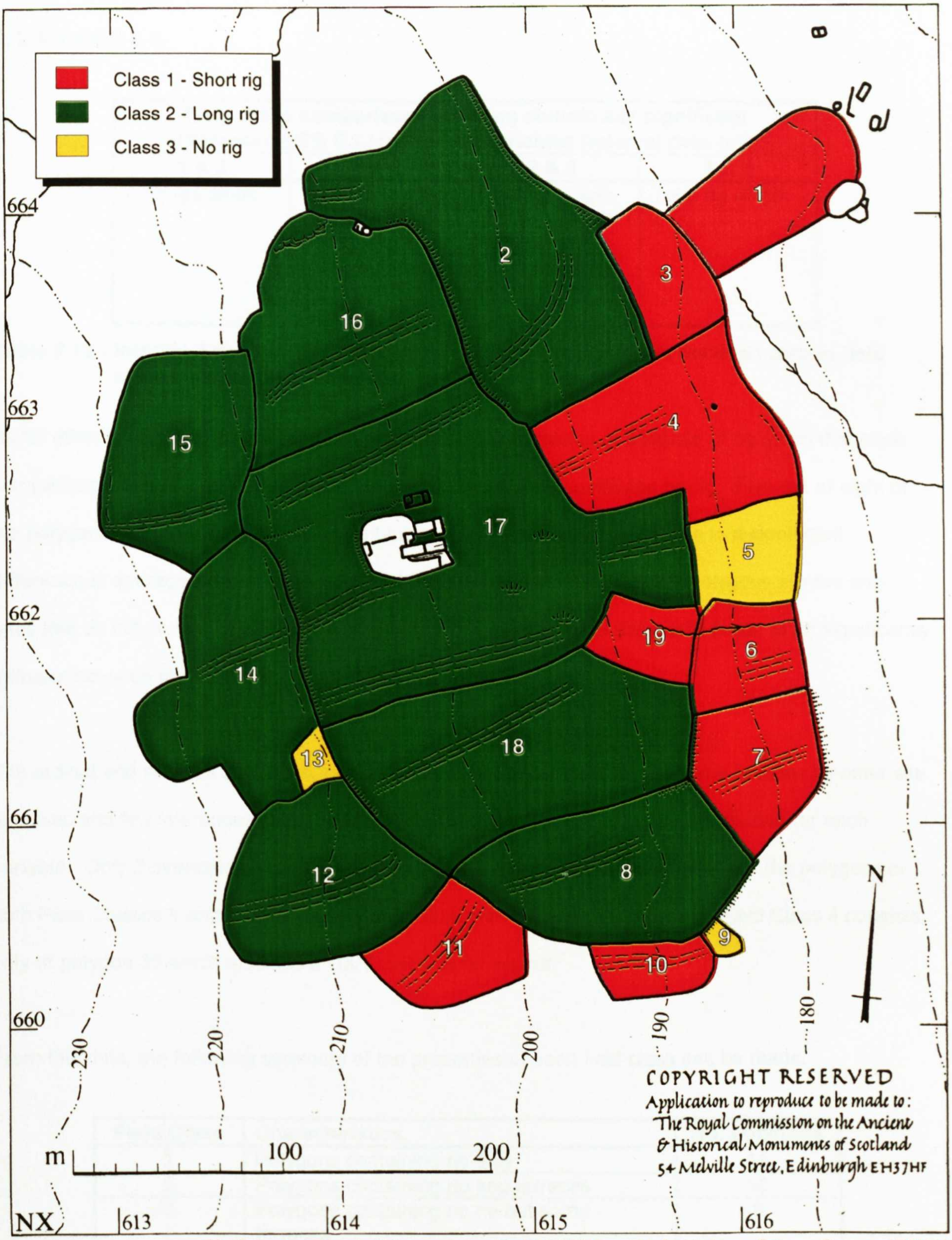

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Figure 2.8 - Classification of Laughengie field system, Kirkcudbrightshire.

The rig morphology variables are significant differentiators between comparisons of Field Classes 1 & 3, 2 & 3 and 3 & 4.

Field Class comparisons showing statistically significant differences (95% C.I.) for certain variables (interval data only)			
1 & 2	**1 & 3**	**2 & 3**	**3 & 4**
Average slope	Total rig length Mean rig length Sd rig length Mean rig width SD rig width Average slope	Total rig length Mean rig length Sd rig length Mean rig width SD rig width	Total rig length

Table 2.12 - Interval data showing statistically significant differences between certain field class comparisons, Learable.

As for other sites, the difference actually recorded is the presence or absence of rig given that each comparison involves Field Class 3 which consists of polygons containing no rig. Five out of eight of the polygons in this field class do contain terraces, however, which gives rise to a significant difference in average slope between Field Classes 1 and 3 as Field Class 1 polygons are the only ones that do not contain terraces. No other variables using interval data were found to be significantly different between classes.

The ordinal and nominal data were, again, found to be insignificant for the same reasons as other site analyses and few inferences could be made from studying the groupings in distribution for each variable. Only 2 interesting groupings with regard to aspect were observed; 64% of the polygons in both Field Classes 1 and 2 contained rig with 100% SW-NE aspect. However, Field Class 4 consists only of polygon 35 which also has a 100% SW-NE rig aspect.

From this data, the following summary of the properties of each field class can be made.

Field Class	Characteristics	No. polygons
1	Polygons containing rig only	14
2	Polygons containing rig and terraces	16
3	Polygons containing no rig but some terraces	8
4	Large polygon containing rig	1

Table 2.13 - Field Class characteristics for Learable, Ross and Cromarty

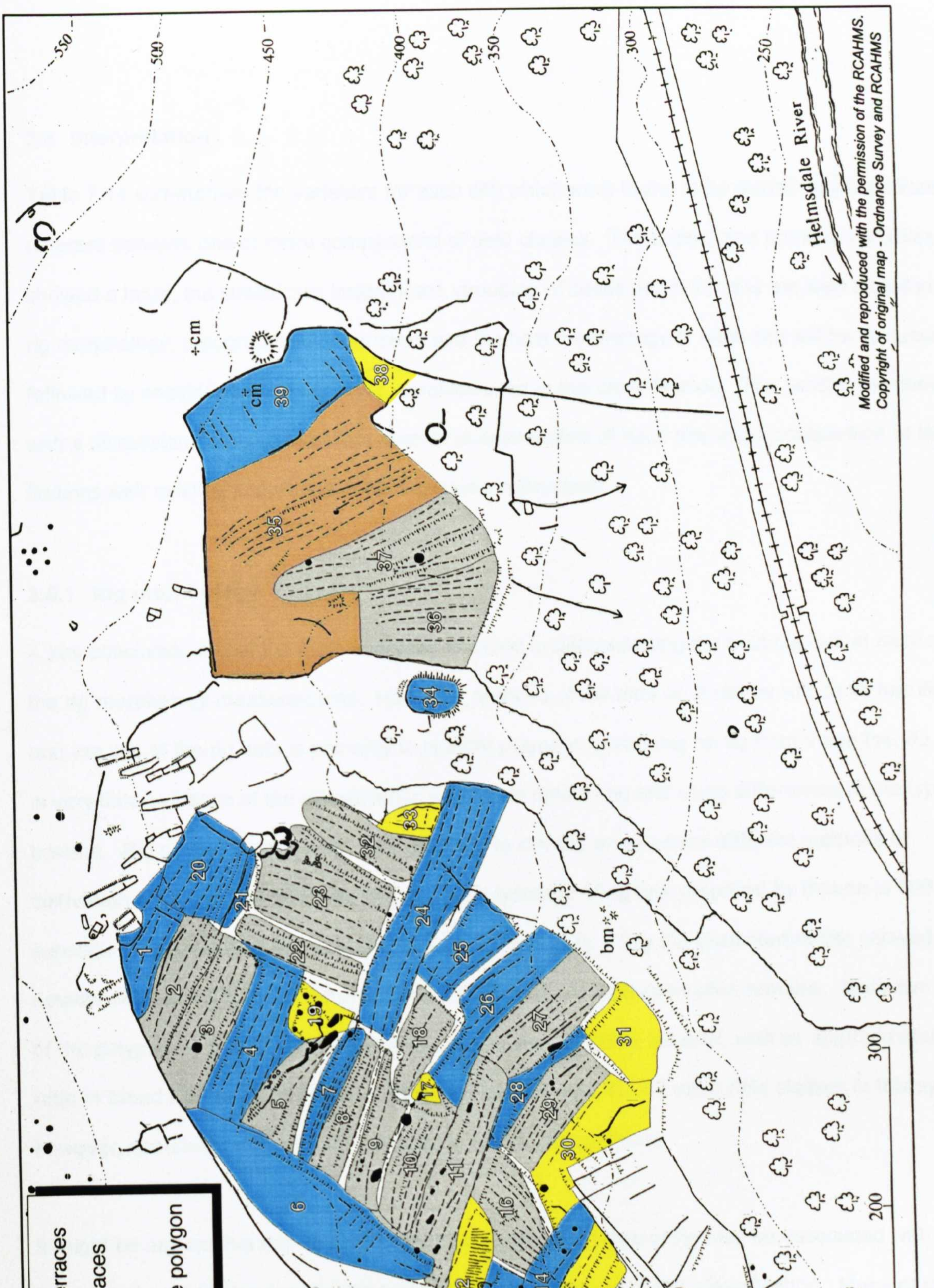

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Figure 2.9 - Classification of Learable field system, Ross & Cromarty.

2.5 Interpretation

Table 2.14 summarises the variables for each site which were found to be statistically significantly different between one or more comparisons of field classes. The ordinal and nominal variables which showed a large, but statistically insignificant, grouping of cases per field class are also included. The rig morphology, topographical parameters and the field morphology of each site will be discussed followed by consideration of the other variables used in this classification. The section will conclude with a discussion of the general field system characteristics of each site and a comparison of these findings with existing knowledge of field systems in Scotland.

2.5.1 Rig morphology

A key conclusion is that the main variables involved in differentiating the field classes at each site are the rig morphology measurements. However, analysis of the data on a site by site basis has illustrated that the use of the rig data is primarily to identify polygons containing no rig from those that do. There is very little evidence of the classification procedure identifying and using differences in the type of rig present. Rig shape, for example, was expected to identify areas where different methods of cultivation were used within a site, based on the typology of rig first proposed by Bowen in 1961 and subsequently developed by Parry (1976) and Dixon (1994). Only the Badentarbat site showed any notable differences in rig shape other than the absence of such cultivation remains. Sixty-two percent of the polygons in Field Class 1 at Badentarbat contained 100% lazybed, with an approximately 50:50 ratio of broad:narrow width between adjacent rigs (Figure 2.4). All other field classes in this system, however, contained a variety of rig shapes in various proportions.

It might be argued that this non-differentiation of different types of rig may be associated with the interpretation of the landscape into polygons for the purposes of this classification. Many of the polygons, as discussed earlier, had to be defined using evidence other than existing built boundaries. In order to minimise the effects of possible misinterpretation of the landscape, the number of "artificial" polygons was kept to a minimum. However, this very precaution often produced large polygons containing a variety of cultivation remains which then had to be accurately recorded as a single entry into the data set (Figure 2.1). This necessitated the use of ratios to ensure that recording was as

		Badentarbat	Boyken	Cleish	Dùnan	Laughengie	Learable
Interval data	**Rig morphology**	Total rig length Mean rig length SD rig length Mean rig width SD rig width	Total rig length Mean rig length SD rig length Mean rig width SD rig width	Total rig length Mean rig length SD rig length Mean rig width SD rig width	Total rig length Mean rig length SD rig length Mean rig width SD rig width	Total rig length Mean rig length SD rig length SD rig width	Total rig length Mean rig length SD rig length Mean rig width SD rig width
	Field Morphology	Field perimeter	Field area Field perimeter	Field area Field shape Field perimeter	Field area Field perimeter	Field area Field perimeter	-
	Topography	Average slope	-	-	-	-	Average slope
Nominal/ Ordinal data	**Rig morphology**	Rig shape	Rig shape	Rig shape	Rig shape	Rig shape	Rig shape
	Topography	Aspect Upper altitude	Aspect Lower altitude Upper altitude	Aspect	Aspect Lower altitude Upper altitude	Aspect	Aspect
	Other	Boundary Truncation	Boundary Truncation	-	Boundary Truncation	-	-

Table 2.14 - Variables used in the field system classification process which indicate differences between the field classes obtained for each site.

Note that all interval data shown here have statistically significant differences (95% C.I.) between certain classes for each site whilst the nominal/ordinal data are not statistically significant. Only those nominal and ordinal variables which show a difference with >50% of the members for each class are shown.

precise as possible and this produced a large number of different permutations of the various types of rig found both within and between sites. The suggestion that the large, artificial polygons are the only ones displaying this variety in rig is, however, incorrect.

Boyken, for example, can be classified as an enclosed field system with 77% of the total number of polygons on this site being bounded (Figure 2.5). Of all the polygons containing a variety of rig types on this site, 77% are bounded - exactly the same proportion as the overall ratio of bounded:unbounded polygons for the entire system. Cleish shows similar results (Figure 2.6). There is only one unbounded polygon in the entire system and although this polygon does contain a variety of rig, so do 5 other bounded polygons in this site. Analysis of the figures for the Learable site shows that a greater proportion of the bounded polygons (27%) contain a variety of rig whilst only 20% of the total polygons for the site are bounded. Badentarbat is the only site that appears to support the suggestion that unbounded polygons are the main source of polygons with more than one type of rig with 6 out of the 8 possible polygons falling in this category (Figure 2.4). It is interesting to note that the Badentarbat site actually contains 31 bounded polygons and only 20 unbounded. However, in terms of area, the unbounded polygons cover a greater proportion of the site. Both the Dùnan and Laughengie sites do not contain any polygons with more than one type of rig (Figures 3.7 and 3.8).

It would appear, therefore, that misinterpretation of the units of the field system and/or over-precise recording of rig types is not the only possible reason for the rig morphology variables not being used to differentiate between different types of cultivation remains. The fact that several bounded polygons contain a variety of rig types appears to indicate that these units of the field system have been subjected to a variety of uses which may not all be contemporary. For example, polygons which contain evidence of both plough rig and lazybed such as Polygon 4 at Badentarbat (Figure 2.4), may have had a variety of uses through time and it is only because not all of the polygon was utilised every time that evidence of previous activity also remains. Such palimpsest of field systems has been demonstrated by detailed excavation and survey of the boundaries at both Boyken and Badentarbat (McCullagh, 1996) and the irregular shape of Polygon 4 suggests that it may be a relict of an earlier layout of the landscape that was subsequently truncated by the creation of Polygon 5. Polygon 35 at

Boyken also demonstrates similar features with a variety of rig types and apparent truncation by Polygon 38 (Figure 2.5).

2.5.2 Topography

Aspect was not found to be a statistically significant factor in the classification process although some field classes have 57-100% of the polygons contained within a class demonstrating a single type of aspect. Interestingly, 100% E-W aspect was found to be a predominant aspect for field classes at Badentarbat, Boyken and Dùnan. All rig at Cleish had a 100% N-S aspect whilst Laughengie also showed extremely uniform rig aspect with most of the rig contained in Field Classes 1 and 2 being 100% NW-SE per polygon. Learable showed similar homogeneity with the majority of polygons in both field classes containing rig of 100% SW-NE aspect. It is also worth noting that rig cultivation at all sites was generally carried out perpendicular to the contour, even in steeper areas such as Boyken and the western part of the Badentarbat site. Certainly the heavy peat soils at Badentarbat, coupled with the wet climatic conditions of the west coast of Scotland, require a higher degree of drainage which could be achieved by high amplitude ridging orientated downslope. However, the more friable and better drained soils at Boyken would not require such an emphasis on drainage and indeed, may lead to substantial downslope movement of soil (see Section 6.1.4). The cultivation remains at this site are, for the most part, less substantial than those at Badentarbat and the steepest parts of the Boyken site have been left uncultivated.

It is difficult to interpret this predominance of E-W rig orientation as anything other than symptomatic of the slope aspect for the sites studied. Land division has been carried out in a number of ways over the centuries but the practice of sun-division, or *solskift* as it was known from Norse influence in the northern highlands and islands of Scotland, was common practice (Dodgshon, 1980). No evidence for such land division between tenants can be inferred from the spatial pattern of the field systems studied here and no explicit evidence was found in the historical documentation researched for the Boyken and Badentarbat sites. However, this regard for light and shade for crop-growing is still demonstrated by arable farmers today and it can be noted that the east-facing slopes at both Badentarbat and Boyken carry the greatest concentrations of rig. Laughengie is entirely situated on a generally east-facing slope whilst Dùnan and Learable have slopes with a southerly orientation. However, it should be noted that these latter three sites have considerably shallower and more uniform slopes than those found at Boyken and Badentarbat.

The exception to this trend is Cleish where the entire system is located on steep, north-facing slopes. It is difficult to understand why anyone would wish to cultivate this particular site in a fairly unwelcoming, exposed area. This site was visited in December 1996 in wintry showers and was particularly bitter and exposed. However, the reason for this visit was because of questions raised about the origins of the rig cultivation seen on the aerial photograph for this site. Although enquiries to the Forestry Commission established that the area had not been bought and planted with conifers until the late 1950's/early 1960's, they did comment that at least part of the site contained a stand of hardwood at the time of purchase (Robertson, personal communication). The exact location of this wood could not be determined from the information at hand but the 1947 aerial photograph for the site shows a hardwood stand immediately to the north. Although this information appeared to favour the interpretation of the cultivation remains as rig and furrow rather than forestry drains, some doubt still remains as to their association with the field system as several of these rigs do not appear to respect the field boundaries. It is, therefore, suggested that the cultivation remains designated as rig and furrow for the purposes of this classification may, in fact, be evidence of later activity not associated with the enclosures. The steep nature of the site, its aspect and the exposed nature of the site seem to make it an unlikely prospect for arable cultivation and it is considered more likely that the enclosures were used for animal husbandry in pastoral farming activities.

Average slope, the only interval data for topographical features, proved only to be significantly different between field classes at Badentarbat and Learable. However, the only differentation for the Learable site was between polygons containing terraces, which had been assigned an arbitrary value of 1000°, and those without which were measured using the standard recording method (Figure 2.9). Significant differences in average angle of slope other than for terraces was not expected for this site due to the uniform nature of the contours across it. Badentarbat, however, displays distinct differences in slope between the eastern half of the site and the west. The western half of the site is characterised by quite steep slopes, levelling off towards the *Allt an Fhealing* burn. Field Class 5 for this site was found to have a significantly steeper average angle of slope than any other field class and examination of the spatial distribution of these field classes (Figure 2.4) shows that all polygons in Field Class 5 are located in the western half of the site, most extending upslope to the head dyke. If average slope was a significant factor at this site, it is surprising that this was not also the case for the Boyken site where several polygons were located on steep slopes whilst others were located on the more shallow slopes towards the upper reaches of the site (Figure 2.5). It must be remembered that the HCA process used all variables simultaneously with no weighting to obtain the results shown here and it is, therefore, difficult to extricate the influence of one variable from all others. It may be that the polygons in Field Class 5 at Badentarbat were not significantly different in any other variable whilst the polygons on the steeper parts of the site at Boyken showed more similarities with other polygons in other parts of the site than differences in terms of angle of slope.

Upper and lower altitude was not a statistically significant variable for the classification of any site and, although some field classes for Badentarbat, Boyken and Dùnan do show some degree of grouping within each field class, this is by no means conclusive evidence that upper and lower altitude are useful variables for the classification process.

2.5.3 Field morphology

Field area and field perimeter are closely related for most sites although Badentarbat appears to have no significant differentiation in field area between field classes although Field Class 2 is shown to have significantly shorter field perimeters than other field classes. Boyken, Cleish, Dùnan and Laughengie all used field area to characterise fields containing no rig. These fields were consistently smaller than those containing rig. Learable, however, showed no difference in area between fields containing rigs and those not. Nevertheless, 3 of the 8 polygons categorised as containing no rig did have terraces which would suggest that some form of arable cultivation has occurred in these areas in the past to create these features.

Field shape was not a significant factor for any site other than Cleish where the 3 polygons grouped in Field Class 3 all have a median field shape of 0.36 compared with medians around 0.70. This equates to a long, narrow shape rather than the more rectangular shapes of the other polygons at this site. The shape of these fields may be due to truncation by polygons 9, 10 and 13 but without detailed field survey this cannot be ascertained from the survey map and aerial photograph alone. This information will probably never be known given that the site is now covered by a mature coniferous plantation.

2.5.4 Other parameters

It is difficult to determine how large a part the boundary and truncation variables played in determining the clusterings during the HCA procedure for each class. Certainly for predominantly enclosed sites such as Cleish and Laughengie and open sites such as Learable, they played virtually no part due to their homogeneous nature in this respect. The two smallest classes, 3 and 4, for Badentarbat both contain polygons that are unbounded and this may suggest that an error was made in defining these areas as discrete polygons. Apart from this, there would appear to be little to be gained from the use of the boundary variable.

The truncation variable may only have been used by the classification procedure for the Dùnan site as Field Classes 1 and 2 both contain rig but 100% of the polygons in Field Class 1 are truncated whilst 80% of those in Field Class 2 are not. However, this is not conclusive due to polygon 11 being grouped in Field Class 2 despite being truncated by a track. These two variables do, however, alert the researcher to possible reasons for problems with the results.

2.5.5 General Field System Characteristics

The proportion of polygons containing no rig:polygons that contain rig was calculated for each site and compared (Table 2.15).

Proportion of No Rig : Rig (No. Polygons)					
Badentarbat	**Boyken**	**Cleish**	**Dùnan**	**Laughengie**	**Learable**
0.35	0.38	0.39	0.38	0.16	0.20

Table 2.15: Proportion of polygons containing rig to polygons not containing rig for all sites.

Badentarbat, Boyken, Cleish and Dùnan have very similar proportions. Laughengie and Learable contain more polygons with rig but, again, in very similar proportions. They are in very different locations; Laughengie is situated in the south-west of Scotland at an altitude of approximately 200m whilst Learable is located in the north-east at a much higher altitude of around 400m. They appear to have little in common apart from this proportionality as Laughengie is a compact enclosed field system

(Figure 2.8) whilst Learable, although fairly compact, is characterised by its open nature and terraced landscape (Figure 2.9).

Again, the four sites all with proportions between 0.35-0.39 are very different, despite this similarity. Does this indicate that there is an underlining homogeneity in Scottish field systems that cannot be identified from the classification procedure? An alternative method of determining the extent of non-rigged land from rigged land using field area rather than number of polygons was explored and gave the following results (Table 2.16).

Proportion of No Rig : Rig (Field Area)					
Badentarbat	**Boyken**	**Cleish**	**Dùnan**	**Laughengie**	**Learable**
0.23	0.13	0.41	0.21	0.03	0.10

Table 2.16-Proportion of the field area of each field system which does not contain rig to the field area that does contain rig.

These results illustrate a much less uniform nature for the field systems studied and show that the use of polygons as a measure does not give a true indication of the extent of non-rigged and rigged land within a field system. The two sites located on or off the west coast of Scotland (Badentarbat and Dùnan) have very similar ratios and illustrate that a greater proportion of the land was not under cultivation in these areas. The wet climate of the west coast of Scotland and the Western Isles is well documented and both of these sites are exposed to the strong predominantly south-westerly winds which are common on the western seaboard. Badentarbat and Dùnan are also two of the three most northerly sites studied for the purposes of this field system classification exercise. These conditions are not conducive for any form of profitable arable cropping and what little the Medieval farmers could grow would barely provide a means of subsistence from one year to the next. Indeed, the Old Statistical Account of 1794 records, for the Lochbroom Parish of Coigach in which Badentarbat is situated, that *"For moſt years the produce of the ſoil does not afford them a ſufficient ſupply of meal"*.

However, Learable - the other northernmost site, is located on the drier east coast. It is located in an area of high altitude and, whilst Boyken is located at a somewhat lower altitude, both are situated in hilly areas. Both these sites lie in the eastern half of Scotland and this may suggest that there is some difference between the methods of farming practised in the east and those in the west. An east-west split of the country in terms of rig type has been proposed by Dixon (1994) with the distribution of broad rig created by the use of the heavy mould-board plough from Sutherland to the Borders with a distinct eastern bias. Lazybedding, created by use of the *cas-chrom* or footplough (Fenton, 1963), is seen as a predominant landscape feature mainly in the north-west of Scotland with some occurrences in Argyll and Galloway. Whilst this classification study has not found direct evidence to support this observation, it may be that inferences can be made indirectly through exploration of the importance of arable cultivation within each field system and their spatial distribution throughout Scotland.

However, the Laughengie site in the south-west of Scotland has only a very small proportion of non-rigged land which appears to dispute this supposed eastern distribution of the more progressive arable farming activity during the Medieval period. This site does, however, have a high proportion of narrow straight rig (Parry Type 2) which has been dated at other sites to the later eighteenth and nineteenth centuries and it may be that Laughengie originates from the post-Improvement period rather than the medieval period.

Cleish has the highest proportion of non-rigged land in terms of field area of all the sites and this would appear to concur with the interpretation that this site was originally used for pastoral farming rather than arable given the inclement conditions experienced at this location.

2.6 Conclusion

The procedure developed during this research for classifying medieval or later field systems in Scotland has successfully distinguished several different types of rig and field morphologies. A clear distinction has been made between fields or enclosures containing no extant rig and furrow and those that do. It has also distinguished between areas containing long rig and furrow from those containing relatively short cultivation remains. The shape of the rig and furrow plays little part in distinguishing between polygons. The size of the individual units has also played a part in the classification process of the Dùnan and Learable sites, although the classification of the Learable site merely identifies one polygon from the rest in terms of field area. It is interesting to note that the classification of the relatively open agricultural landscape of Badentarbat has not identified field area as a key distinguishing feature between field classes for this site. This is probably because the Badentarbat site contained a number of areas in the unenclosed landscape to the south of the site with distinctly different rig morphologies (reverse-S rig, lazybedding, broad straight rig, narrow straight rig) compared to the more uniform lazybedding of the Dùnan site. The unenclosed landscape at Badentarbat, therefore, required a greater number of "artificially defined" boundaries in order to distinguish between these areas of different rig morphologies than the Dùnan site.

Apart from demonstrating the predominance of lazybedding in the north-west, this study has produced little evidence to confirm the theory that certain types of rig are found in certain areas. It does, however, appear to have found some tentative evidence of a trend towards pastoral farming in the west and arable farming in the east. This can only be proved or disproved by further examination and classification of a greater number of sites.

Determining the variables which have been used in defining the clusters selected from each Hierarchical Cluster Analysis requires detailed and extensive statistical analysis. The use of computing facilities capable of running adequate multivariate tests would greatly improve the quality of the statistical analysis and the interpretation of this classification procedure as well as significantly reducing the length of time required for analysis of the HCA results. However, the methods employed have provided sufficient results to be able to assess the usefulness of the devised classification procedure.

The measurements of rig morphology used here appear to do little more than distinguish polygons containing rig from those that do not. Topography does appear to have some influence in the clustering procedure although measurements of altitude were not found to be particularly useful. Similarly, field shape played little part in the classification of polygons and the close correlation between the results for field area and field perimeter would indicate that only one of these parameters is required in order to define polygon size. The boundary and truncation variables also played little part in the classification process but proved to be of some use in identifying possible problems with the data.

The various problems encountered in using the available data highlight a need for an improved system for recording field systems in the future to provide a better database from which to work.

Establishment of a standardised method of recording which gives due importance to the field remains and not just the built elements associated with these cultural landscapes must be achieved to enable a greater understanding of the historic agricultural landscape. Recommendations of how best to improve the current recording system are very much dependent on budget and manpower constraints.

Interpretations from aerial photographs alone have been shown to be particularly difficult. The main recommendation must be that all field systems are subjected to field survey to some degree. Clearly, major features can be measured, mapped and interpreted from the aerial photographs and perhaps the best use of field survey would be to answer questions raised from such work. From this work, the main problem with interpreting these historic landscapes from aerial photographs and existing survey maps is that of palimpsest. The current recording system does not identify the chrono-sequence of the built elements in the landscape. Detailed field survey of specific areas of each site where this is a particular feature (see the upper complex of polygons 32-50 in Boyken, Figure 2.5) may help to unravel this palimpsest. A recording system should be devised where boundaries and other built elements in the landscape, which are regarded as contemporaneous, can be denoted by the same type of symbol, such as dashed or dotted lines. However, it is appreciated that it is often impossible to establish whether two discrete structures are contemporary. However, at the very least, the stratigraphy of these features can be mapped. For example, boundaries which run over earlier structures may be depicted by using a different style of line. It is appreciated that this may lead to rather "busy" survey maps but this research has shown that the existing data is over-simplistic for any meaningful and detailed study.

It is clearly impractical to suggest that every rig be measured and mapped. However, survey maps must provide a true reflection of the actual landscape. This is particularly important for sites which are predominantly unenclosed. A point in case is the survey map for Badentarbat which does not depict the extensive nature of the rig and furrow and peat cuttings on the western slopes of the site. Such details may be "filled in" using the aerial photographic evidence, when available. If aerial photographs do not exist for a site, then a comprehensive description of the nature of the cultivation remains should accompany the survey map to complete the unfinished picture presented by the representative rig and furrow measured and depicted on it.

A description of the topographic and environmental conditions of the site should also be noted. Any significant changes in slope which cannot be appreciated from the contours at the scale of the site survey map may provide important information which affects the interpretation of the past use of that area for agriculture. Whilst it is appreciated that this work must be non-intrusive and therefore cannot include direct soil sampling, it is possible that indications of the soil drainage, fertility and pH may be obtained from even quite general surveying of the vegetation present on the site today. This information cannot be obtained from aerial photographs but may be a useful parameter to include in the classification procedure in order to characterise areas according to soil type as well as to the morphological features of the rig and furrow and the field. The nature of the soil clearly has a bearing on its agricultural use and this may provide a more direct key to the functional classification of medieval or later field systems without physically disturbing the site.

3. Archaeological and Site Context

3.1 Introduction

The fieldwork was carried out for a number of purposes. The field sites were chosen from the six which had been classified during the desk-top study of existing survey maps and aerial photographs. The main hypothesis to be tested during this research project is that a possible relationship can be identified between the form and function of field units in historic field systems using soil micromorphology and quantitative analysis. The different forms of field unit identified from the desk-top field classification of each site can be used to develop a sampling strategy in which soils are sampled from each of these "field classes". These soils are examined using light microscopy to identify and record micromorphological features which may be indicative of differing landuse in the past.

The archaeological fieldwork carried out in conjunction with the soil profile description and sampling serves several purposes: to establish the relationship between the extant cultivation remains and the built elements of the landscape, to answer questions on the chronology of the boundaries in each field system raised during the desk-top field classification, and to gain material from certain elements within the field system for radiocarbon dating.

3.2 Choice of Sites

The selection of two contrasting sites was an appropriate and realistic strategy for testing the results of the field system classification and any possible link between existing soil signatures and the nature of past agricultural management. A number of different parameters were considered important in the choosing of these sites. Differences in environmental context which may influence manuring practises and the type of cultivation remains and field system type (e.g. enclosed or unenclosed) were considered the most important criteria. However, it was also thought important that each site should have a good historical documentary record to supplement the archaeological and soil fieldwork and to help in the interpretation of the results obtained from this work.

The choice of field sites had to be taken early in the project timetable to allow fieldwork to be undertaken during 1995. One of the conditions of the grant kindly provided by Historic Scotland for supplementary archaeological fieldwork on the chosen sites was that a report had to be produced by early 1996. All fieldwork therefore had to be completed during 1995. Several sites were considered; Badentarbat in NW Ross, Boyken in Dumfries and Galloway, Glenshee in NE Perthshire, Learable in Sutherland, Southdean in the Borders and Waternish in NW Skye (Table 3.1).

Glenshee looked promising in most respects but did not have a good historical record. Learable is a good example of a terraced field system. However, there was considerable evidence of prehistoric activity in this area. This was considered a potential problem for differentiating the medieval or later evidence from the earlier relict features of the landscape and the lack of a good quality aerial photograph resulted in this site being dismissed for fieldwork purposes. The Southdean site in the Borders was regarded as possibly atypical of field systems in Scotland given that it featured an assart dyke with an external ditch. There was also a lack of any detailed historical documentation relating to the settlement of the forest in the 13th to 15th centuries. Waternish was considered an ideal site in all respects, having an excellent documentary record and good aerial photographs and survey maps available as well as an extensive landscape of open areas of lazybedding and rigging with associated clusters of sub-circular enclosures. However, the extent of this area of cultivated land was considered a problem for defining the limits of one field system. The area was too large to be considered as one single field system to be surveyed and sampled for the purposes of this study and it was considered impossible to accurately sub-divide the landscape into units which could be categorised as individual field systems. Badentarbat and Boyken thus remained as the best choices for field sites.

3.3 Soil fieldwork

The soil fieldwork was mainly carried out in conjunction with the archaeological fieldwork in order to make optimum use of all relevant trenches. This was particularly important at Boyken where consent for excavation had to be sought due to the scheduling of the site. The soil fieldwork shall be discussed separately for clarity.

	Environmental Context	Historical Documentation	Types of Cultivation Remains	Types of Enclosure	Associated Settlements
Badentarbat, NW Ross	• Soils: Torridon Association • Parent Material: Drifts derived from Torridonian sandstones and grits.	• Earliest document - 1572 Charter • Good docs. from mid-17th C onwards	• Extensive curvi-linear, straight and reverse-S plough rig • Variety of amplitudes • Extensive lazybedding •	• Head-dyke • Few circular enclosures • Some sub-rounded enclosures to north of site	• Settlement structures mainly aligned along westen head-dyke • Possible prehistoric structures outside north-west portion of head-dyke
Boyken, Dumfries & Galloway	• Soils: Ettrick Association. • Parent Material: Drifts derived from Lower Palaeozoic greywackes and shales	• Good docs. From mid-17th C: Series of Rentals of Buccleuch estate • Good estate plans, 1718, 1810.	• Straight & curvi-linear plough rig • Most rig not well developed • Lynchets, aligned across and downslope	• Low earthen banks • Mainly sub-rectangular • Substantial bank runs along lower slopes of eastern part of site	• 30 buildings on artificial platforms • 3 main settlement clusters along bank running along lower slopes of eastern part of site • 3 prehistoric structures
Glenshee, NE Perthshire	• Heavily glaciated with extensively cultivated glacial and alluvial deposits	• Quite sparse (Corser, pers. comm.) • Late 18th & 19th C maps • Pendicle of Menach 1642	• Plough rigs • Broad strip fields • Cultivation terraces • Well-defined lynchet system	• Rigs grouped and defined by earth and stone banks	• Various fermtouns, farmsteads and Pitcarmick-type buildings • Associated shielings
Learable, Sutherland	• Soils: Arkaig Association • Parent Material: Drift derived from schists, gneisses, granulites and quartzites, principally of the Moine series.	• 16th C Charters • Good documentation from late 17th - late 18th C • Clearances documented 1813-1816.	• Straight and reverse-S plough rig • Cultivation terraces • Some subdivision • Some prehistoric remains beneath • Lynchets	• Head-dyke - relatively late feature	• 2 clusters rectangular buildings • Some round-ended buildings leveled into the slope and 2m broader than the rectangular ones
Southdean, Borders	• Sedimentary rocks of Upper Old Red Sandstone & Carboniferous ages. Intrusive/extrusive igneous facies of Cheviot Massif. Limestone, whinstone, sandstone have all been quarried.	• Lack of any detailed docs. relating to settlement of forest in 13th-15th C. • 1541 Rental earliest doc. • Maps of Pont, Roy (1747-55) & Stobie (1770)	• Curved & reverse-S plough rig	• Assart dyke with external ditch • Head dykes	• Farmsteads, peles, homesteads, round-ended and rectangular buildings • Some stone-walled • Some turf-walled
Waternish, Skye	• Horizontally bedded basalts. • Peat covered ridge up to 300m OD • High, rocky cliffs.	• Book of Dunvegan (Macleod, 1928) • Records of British Fisheries Society • Crofting Commission's 1883 record • Statistical Account • c. 1790 Estate map	• Extensive lazybedding, typically wiggly with steep edges • Extensive plough rig, typically curvi-linear • Rarely >50m long	• Some rig enclosed by earthen dyke • Most rig enclosed by head-dyke • Clusters of sub-circular fields enclosing 1ha with stone-faced earthen dykes 1.25m high	• Lots of townships • Several shieling huts - difficult to associate with resepctive townships.

Table 3.1 - Characteristics and information available for the sites considered for field work.

3.3.1 Method of sampling

The sampling strategy was developed to obtain undisturbed soil samples from polygons in as many field classes as possible at each site. Table 3.2 details the number of polygons sampled from each field class and the total number of pits dug to obtain samples. Soil sampling at Boyken concentrated on getting as many samples from each of the main field classes as possible. The wide range of extant cultivation remains at Badentarbat led to a slight shift in the emphasis of the soil sampling strategy at this site. Lazybeds, curvi-linear, reverse-S and straight rig and furrow were all present at this site and emphasis was given to sampling each of these types of cultivation remains.

	Field Class No.	Field Class Type	No. of polygons in field class	No. of polygons sampled	Total no. of soil pits dug
Boyken	1	Truncated, rig and/or lynchets	4	1	3
	2	Short rig	21	2	4
	3	No rig	27	5	7
	4	Lynchet/rig	1	0	0
	5	Lynchet only	2	1	2
	6	Long rig	1	0	0
	7	Outwith polygons	N/A	N/A	3
Badentarbat	0	Outwith polygons	N/A	N/A	3
	1	Short rig	24	5	5
	2	No rig	18	1	1
	3	Long rig	2	1	2
	4	Reverse-S rig	1	1	1
	5	Rig on steep slope	6	4	4

Table 3.2 - Soil sampling strategy for Boyken and Badentarbat sites.

The soil fieldwork at Boyken was carried out during two visits in 1995. The first was a 12 day visit in May as part of the 4-person archaeological team from AOC (Scotland) Ltd. Twenty trenches were dug during this visit, 9 of which were used for soil profile description and 8 for soil sampling (Figure 2.5). The remaining trenches were used to establish the chronology of, and relationship between, some of the features of the field system under question from the desk-top survey and to obtain material suitable for radiocarbon dating. A second visit was made between 10-14 July 1995 in order to complete the soil profile description and sampling work for this site. A further 11 soil pits were dug during this visit. One pit was aborted due to striking very shallow bedrock immediately beneath the surface but all soil profiles in the remaining 10 pits were described and soil samples were taken.

It proved impossible to collect undisturbed soil samples for making soil thin sections using standard Kubiena tins measuring 8cm x 5cm x 5cm due to the very stony, friable nature of the soils at Boyken. Large monoliths were therefore carefully carved out of the side of each soil pit using small trowels and a large kitchen knife to cut through any roots. Each monolith represented a column of the entire soil profile from the surface to the B horizon. A number of large monolith tins (Dimensions: 50cm x 15cm x 10cm and 25cm x 15cm x 10cm) were borrowed from AOC Scotland Ltd and used where possible to transport these samples back to the laboratory for impregnation. However, it did not always prove possible to cut monoliths which neatly fitted into these large tins. In these cases, the monoliths were carefully wrapped in newspaper and bubblewrap and secured with masking tape. Each sample was marked with the orientation, the depth range and the appropriate trench number and field unit number as well as the date of sampling. All trenches were backfilled at the end of each field visit.

The fieldwork at the Badentarbat site was also carried out during 1995. The archaeological fieldwork was successfully completed during a visit from the 12th-26th August, 1995. Eighteen trenches were dug during this period with nine of these being used for soil profile description and sampling. A second visit to the site was made between 26th November -1st December, 1995 to complete the soil fieldwork. A further 6 soil pits were dug, described and sampled during this period.

It was possible to use standard Kubiena tins for collecting samples from this site as the soils were predominantly peats, loamy peats and loamy sands. Continuous sampling down through the profile was not always possible due to the great depths of some of the pits (up to 85cm). Prior to undertaking the fieldwork, it had been agreed that one hundred thin sections was the maximum number which could be successfully manufactured and described during this research project. The number of thin sections actually produced was one hundred and twenty-six for two main reasons. Firstly, the Badentarbat soil profiles were generally much deeper than those at Boyken and, therefore, required a greater number of samples to provide a representative sample of all the horizons contained in each profile. Secondly, difficulties were experienced in producing good quality thin sections from the peat samples from Badentarbat. These difficulties shall be discussed more fully in Chapter 4. However, these problems encouraged the collection of extra samples during the second visit to Badentarbat to ensure the availability of sufficient good quality thin sections for the micromorphological description and analysis.

3.3.2 Soil pit descriptions

Detailed soil pit descriptions and diagrams for all trenches at both sites are provided in Appendix 2. Representative examples from each site shall be given here to facilitate discussion. Horizon notation is according to the Soil Survey Field Handbook (Hodgson, 1976). Soil texture was described in the field using MAFF guidelines (MAFF, 1988).

Boyken

Figure 3.1 is a photograph of the soil profile of Trench 13 in Polygon 22 (see Figure 2.5 for exact location.). The profile description is provided below.

Profile Description: Trench 13, Polygon 22 (Boyken)
Dimensions of trench: 1m x 1m x 0.36m

Horizon	Depth	Description
Ah1	0-8cm	Many roots, some small stones, distinct even boundary. Colour: 10YR/3/2 (very dark greyish brown) Structure: Fine subangular blocky Texture: Humose silt loam
Ah2/Ah1	8-19cm	Very mixed horizon, resulting in mixture of colours (appear to be from faunal activity and disturbance by bracken roots), many stones (small-medium), uneven indistinct boundary. Colour: 10YR/5/6 (yellowish brown), 10YR/3/2 (very dark greyish brown) Structure: Fine-medium subangular blocky Texture: Silty clay loam
Bw	19-36cm	Very stony (almost gritty, small-large), some roots. Colour: 10YR/5/6 (yellowish brown) Structure: Medium subangular blocky Texture: Silty clay loam

The soils throughout the Boyken site were very homogeneous in nature. Most had a distinct top Ah horizon of 5-20cm thickness. The A horizon ranged in thickness from 8-35cm throughout the site. The deepest A horizons were found in Polygons 56 and 10 which contained high amplitude cultivation remains (Figure 3.2 shows Trench 6 in Polygon 10). A bAp horizon was found beneath the contemporary Ap horizons in each of these small polygons. Trench 1/56 contained a bAp horizon ranging from 7-11cm in thickness at a depth of approximately 40cm (Appendix 2). The bAp horizon in Trench 6/10 was at an approximate depth of 15cm and ranged in thickness from 14-28cm. The Bw horizon was located at a depth range of 6-50cm. The greatest depth of 50cm was again found in

Figure 3.1 - Trench 13 in Polygon 22, Boyken.

Figure 3.2 - Trench 6 in Polygon 10, Boyken.

Trench 1 in Polygon 56. It was not felt necessary for the purposes of this research to spend time digging through the particularly stony Bw horizon to the C horizon in every trench. However, the upper boundary of the Bw horizon of Trench 5 in Polygon 52 was located at a depth of only 18cm and weathered bedrock was found at a depth of 50cm. This evidence, coupled with the high shale content of the soils of the Bw horizon throughout the site, appear to suggest that the C horizon is located at no great depth below the surface.

All soils were in the 10YR hue range with only a few small areas falling in the 7.5YR hue category and the soil structure was consistently found to be fine-medium subangular blocky throughout the site. Soil texture was also found to be a uniform silty clay loam across the site, providing further evidence for the homogeneity of the soils at Boyken.

Three trenches deserve particular mention - Trenches 1, 5 and 6. Figure 2.5 illustrates the location of these trenches at the Boyken site and Appendix 2 provides full profile descriptions and schematic diagrams where appropriate.

Trench 1

The Ap horizons of Trench 1 in Polygon 56 have already been described in terms of depth and thickness. The top Ap horizon of this profile contained numerous charcoal fragments which were visible in the field. However, no evidence of similar inclusions was apparent in the bAp horizon immediately below the current A horizon. This was only one of two trenches which contained obvious evidence of charcoal in the soil profile.

Trench 6

Trench 6 in Polygon 10 also appeared to contain a bAp horizon. However, the current Ap horizon appeared to be only 8cm in thickness in comparison to the bAp horizon immediately below this which ranged in thickness from 14-28cm across the length of the pit profile. No charcoal fragments were evident in either of these horizons during field description.

Trench 5

The third trench of particular interest is Trench 5 in Polygon 52. This polygon contained no evidence of cultivation remains but a significant amount of charcoal was found at a depth of 30-35cm on the south side of the trench during excavation. It was considered possible to obtain a reasonably secure radiocarbon date for this material due to its specific location in the profile. Several charcoal fragments were also recorded in the Ah horizon from which this charcoal was taken. This Ah horizon was covered by a 29cm thick horizon of humose silty clay loam which could only be described as an Ah horizon. This was interpreted in the field, in consultation with Dr Ian Simpson, as a layer of inwashed material from further upslope. Polygon 52 is located on a particularly steep slope and it would seem justifiable to suggest that any exposure of the bare soil in this area would lead to significant downslope movement of sediment, especially when the high and often intense rainfall of this area is also considered.

Badentarbat

The soils of the Badentarbat site are a little more difficult to represent in a single example. The soil profiles found throughout this site can be broadly split into two categories: 1) those predominantly consisting of horizons of pure or loamy peat, and 2) those with virtually no peat horizons. The location of the trenches discussed here are shown in Figure 2.4 and the full profile descriptions and schematic diagrams, where appropriate, are given in Appendix 2.

Profiles with pure and loamy peat horizons

Trench 38, located in Polygon 50 is a typical soil profile from the first category(Figure 2.4 shows the exact location). Figure 3.3 illustrates the soil profile and the amplitude of the rig and furrow in this polygon. The soil profile description for this trench is as follows:

Profile Description: Trench 38, Polygon 50 (Badentarbat)
Dimensions: 2.0m x 1m x 0.68m

Horizon	Depth	Description
Of1	0-10 0-7	Many roots, no stones, gradual boundary. Colour: 10YR/2/2 (very dark brown) Structure: Massive Texture: Peat
Of2	7-10	Many roots, no stones, distinct even boundary. Colour: 10YR/2/1 (black) Structure: Massive Texture: Peat
Op/Ap	10-66	Many roots, no stones, distinct, abrupt and uneven boundary Colour: 7.5YR/2.5/1 (black) Structure: Massive Texture: Loamy peat
Bw	68-?	Many large stones, some roots, sandy. Colour: 10YR/4/3 (brown) Structure: Medium subangular blocky Texture: Loamy sand

The majority of the soil profiles at Badentarbat can be grouped under this category. The peat horizons (including pure peat, loamy peat and sandy peat) vary in total thickness from 18-85cm across the site. All these peat horizons are over a loamy sand Bw horizon. Again, it was not considered necessary for the purposes of this study to dig through this horizon to determine the depth at which the C horizon was located.

Trench 38 in Polygon 50 demonstrated some interesting features. The O horizons in the rig profile of this trench were found to have a maximum depth of 68cm to the Bw horizon compared with 43cm in the furrow but coring in other areas of this polygon revealed that some rig had O horizons which reached a depth of almost 1.0m. The rigs were very regularly spaced with narrow furrows. The nature of the rig and furrow in this area suggests that it is the product of cultivation with a plough rather than a *cas-chrom* (Chapter 1). This trench was dug from the centre of the furrow to the summit of the adjacent rig and measured approximately 2m in length. The Bw horizon is much stonier in nature under the furrow, suggesting that the erosive effects of water movement within the furrow have removed relatively more fine grain material from this area than from under the rig. This area was particularly wet underfoot, even after the exceptionally long, hot summer of 1995, providing an indication of the importance of water movement in this area.

Figure 3.3 - Photograph of Trench 38 in Polygon 50, Badentarbat

Several fragments of charcoal, provisionally identified as *Betula sp.*, were found towards the bottom of the O horizons in the furrow. These were collected for radiocarbon dating in an attempt to get a reasonably secure date for the onset of peat growth in the area. The results are given in Section 3.4.2. No further evidence of charcoal fragments or other types of anthropogenic manuring was found in the O horizons of the rig profile.

Trench 32

Another trench grouped under this category which merits special mention is Trench 32, located in Polygon 7 (Figure 2.4). This trench was dug between the summits of two adjacent rigs which were interpreted in the field as being spade-dug cultivation remains, commonly known as "lazybeds". This interpretation was based on the uneven nature of the crests of the rigs which appear to be a series of short, rather disjointed sections rather than the smooth linear apex which would be expected from the use of a plough. The rig also end rather abruptly at the edge of the *Allt an Fhealing* stream which it can be argued would be particularly difficult to achieve when using a plough (Figure 3.4). The cultivation remains in this polygon are irregularly spaced throughout, providing further evidence to support the lazybed interpretation. However, measurements from this trench revealed that the furrow was 3m in

Figure 3.4 - Photograph of Trench 32 in Polygon 7, Badentarbat

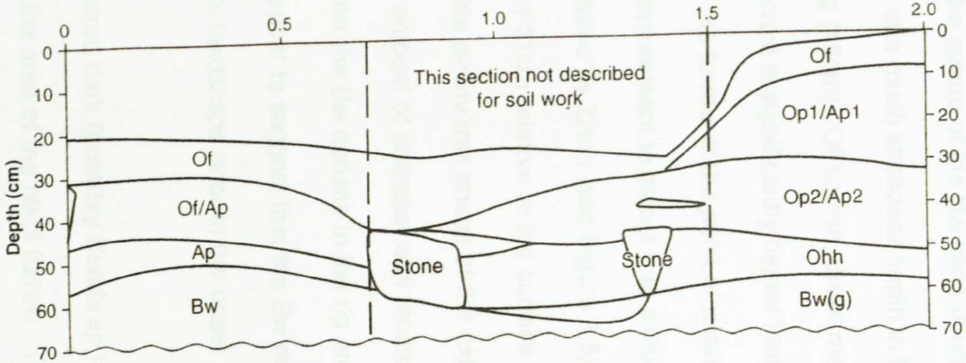

Figure 3.5 - Schematic diagram of soil profile of Trench 32 illustrating difference in height between rig and furrow, Badentarbat.

width with a distance of 4.5m between the adjacent rig summits. The amplitude of the rig was measured at a maximum of 0.29m in this trench although this measurement should be treated with caution given that infilling of the furrow may have occurred since abandonment. Measurement of the amplitude of other rig in this polygon gave an average measurement of 0.5m. The rig was also found to be asymmetrical with a much steeper scarp face on the north side which would also seem to favour the interpretation of these cultivation remains as lazybeds dug by a *cas-chrom* rather than plough rig (Chapter 1).

The most interesting aspect of Trench 32 was the nature of the Bw horizon underneath the peat (Appendix 2). The Bw horizon was found to be at a much shallower depth in the profile under the existing furrow (9cm) than under the existing rig (49cm). Of course, these measurements are measured from 0cm at the surface and the rig crest is significantly higher than the furrow. However, the difference in height between the surface of the furrow at the point of measurement and the surface of the rig can be added to the furrow profile measurement to gain a true picture of the depth of this mineral Bw horizon. This difference was measured as 22cm (see Figure 3.5). The Bw horizon in the furrow profile is, therefore, located at a depth of 31cm relative to the surface of the rig and at a depth of 49cm in the rig profile which appears to create an inverse image of the existing rig and furrow found on the surface of the landscape. A significant amount of charcoal was recorded and sampled in the top 5cm of the Bw horizon in the furrow profile whilst the Bw horizon in the rig profile had virtually no evidence of organic inclusions. This would appear to suggest that the Bw mineral horizon provides evidence of previous agricultural activity in this landscape prior to the onset of peat formation.

A thin yet distinct layer of flattened and weathered bark (possibly *Betula* sp.) was also recorded between the peat and mineral Bw horizons in the area of the relict furrow . This may suggest that the two phases of agricultural activity interpreted from this trench were separated by a period of abandonment when the landscape was colonised by shrubs and trees. Trench 36 was also found to contain a similar layer of bark between the O and Bw horizons. Radiocarbon dates from the charcoal sampled in this trench are discussed in Section 3.4.2.

Trench 46

Trench 46 in Polygon 22 is located towards the south-east of the Badentarbat site in an extensive open area of lazybed near the post-Improvement fields (Figure 2.4 shows exact location of trench and Figure 3.6 shows nature of the lazybedding) and extends from the crest of one rig to the centre of the adjoining furrow. The trench measured 2m in length and the rig had an amplitude of 35cm. The BG horizon was located at a depth of 60cm below the surface of the rig (Appendix 2). Two distinct peat horizons, separated by a 10cm thick loamy sand lens were identified beneath the 8 cm Of layer in the rig (see Figure 3.7). The Op/Ap horizon had a sandy peat texture and was black (10YR/2/1) in colour. The sand lens immediately below this layer from 27-37cm depth was only evident in the rig profile (see Figure 3.8). This would suggest that the sand has been deliberately introduced to the soil as wind or water-borne sand is unlikely to have resulted in such small-scale localised deposition. It is suggested that this sand may have been introduced as part of past manuring practises.

Profiles with non-peaty horizons

The second category of soil profiles found at the Badentarbat site can be represented by the following description:

Profile Description: Trench 42, Polygon 44.
Dimensions: 3m x 1m x 0.4m

Horizon	Depth (cm)	Description
Of	0-3 0-5	Many fine-medium roots, no stones, distinct even boundary. Colour: 10YR/2/2 (very dark brown) Structure: Massive Texture: Peat
Ap	3-40 5-25	Many fine roots, many small-medium stones, some black mottles, abrupt and even boundary Colour: 7.5YR/3/2 (dark brown) Mottles 10YR/2/1 (black) Structure: Fine-medium subangular blocky Texture: Sandy clay loam
Bw(g)	40-? 25-?	Some fine roots, many small-large stones, highly weathered. Colour: 7.5YR/3/3 (dark brown) Structure: Coarse subangular blocky Texture: Loamy sand

Figure 3.6 - Photograph of Polygon 22 showing the distinct lazybeds, Badentarbat

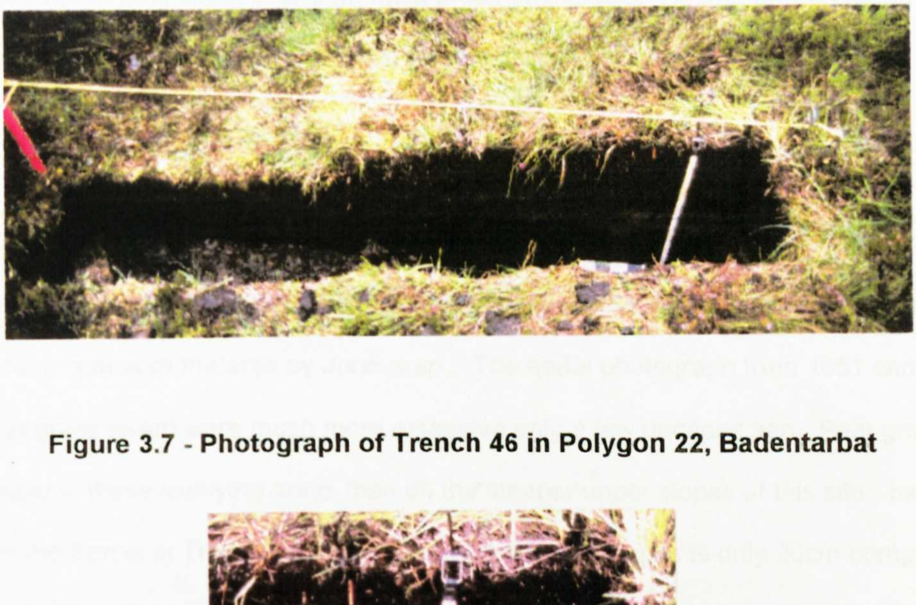

Figure 3.7 - Photograph of Trench 46 in Polygon 22, Badentarbat

Figure 3.8 - Detail of rig profile of Trench 46 in Polygon 22, Badentarbat

The amplitude of the rig in this trench was very much smaller, at only 0.15m, than that found on the peat soils. They were also much broader with a distance of *circa* 6m between adjacent rig summits (Figure 3.9). However, excavation of this trench revealed the multi-crested nature of the rig with adjacent crests being separated by an approximate distance of 1m. This would appear to suggest that the precise location of each rig has not been constant through time. This constant shifting of the rig may also partly explain the relatively small amplitude of these cultivation remains. These regularly spaced, straight rig are interpreted as originating from plough cultivation rather than by use of the *cas-chrom* (Chapter 1). Despite being multi-crested, each crest is continuous and smoothly linear in contrast to the "wiggly" rig described in Trench 32 in Polygon 7 above.

The lack of any significant O horizon in an area dominated by peat soils, would tend to suggest that these areas have either had the peat removed prior to cultivation or that they have been under fairly continuous cultivation until much later than most areas on this site. Neither interpretation has been conclusively proved by the fieldwork evidence but the latter interpretation is not favoured for several reasons.

These areas are located at the foot of relatively steep slopes close to the *Allt an Fhealing* burn. They have poor drainage conditions due to their position and shallow slopes which is demonstrated by the progressive colonisation of the area by *Juncus sp.*. The aerial photograph from 1951 shows that the areas of better grass sward were much more extensive only a few decades ago. Peat growth is likely to be more rapid in these low-lying areas than on the steeper upper slopes of this site. Indeed, the peat horizon under the furrow in Trench 43 on the upper east-facing slopes is only 20cm compared with 30cm in Trench 38 on the lower east-facing slopes. The palynological record for this site has also been studied by Dr Jane Bunting and Dr Richard Tipping and is discussed fully in Section 3.4.2 but the summary interpretation provides useful information in this context.

The record from a sediment core taken from the lochan on site (Figure 2.4) has identified that there was probably two phases of fairly intensive human activity on this site separated by a phase of relatively low activity and peat growth. It is, therefore, considered unlikely that such poorly drained areas would be the first choice for continuous arable cultivation in such circumstances. If the

Figure 3.9 - Polygon 44 in which Trench 42 was located, Badentarbat

Figure 3.10 - Photograph of Trench 44 in Polygon 35, Badentarbat

continuous cultivation interpretation is correct, it is to be expected that the mineral soils would require substantial amounts of manure to maintain their fertility. However, very little in the way of evidence for continuous and concerted efforts to manure this mineral soil was found.

A fragment of burnt bone and a sherd of black glazed ware, dating from no earlier than the 19th century, retrieved from the furrow of Trench 42 were the only indications of human input. Several small black concretions were observed in the Ap horizon which were originally thought to be fragments of charcoal. However, this did not prove to be the case and they were finally interpreted as manganese concretions due to the poor drainage conditions in the profile. This was not confirmed through subsequent chemical analysis in the laboratory and merely remains as an interpretation. This evidence, nevertheless, seems to suggest that these mineral soils have not received substantial and sustained anthropogenic inputs any earlier than the 19th century but is there evidence to support the suggestion that these areas were stripped of their peat overburden prior to a late phase of cultivation?

It might be argued that the relatively deep peat accumulations found on the lower slopes of this site presented the best local resource of peat for fuel and building materials. However, evidence of peat-cutting is more commonly found on the upper slopes. Many of the settlement structures are also aligned along the western head-dyke on these upper slopes and it would seem sensible to have your source of fuel and building material as close to the settlement as possible. If intensive peat-stripping did occur in the low-lying areas, why were similar areas of deep peat, such as the lower slopes of Polygon 50 (Trench 38), not similarly exploited? It might be expected that such localised activity would result in these areas appearing as depressions in the landscape. This is not the case. There is virtually no evidence to support this possible explanation for the existence of these areas of mineral soils. However, there also appears to be little evidence to dismiss it. Without further, more extensive excavation and field survey of the nature and extent of these areas, it is impossible to provide a plausible explanation.

Trench 44

Trench 44 in Polygon 35 is located in a similar area to that of Trench 42 and, again, the rigs have a shallow amplitude of only 0.12m (Figure 2.4). Several fragments of coal, a piece of slate and two sherds of white glazed ware were also found in this trench. Further evidence was also found to support the interpretation of the shifting nature of these cultivation remains with time. The excavation identified a shallow feature underneath the rig profile in this trench which has been interpreted by the archaeologists as a possible relict furrow (Figure 3.10). The Bw horizon in this trench was much stonier than that found in Trench 42 which may be attributed to the increased water movement through the relict furrow.

Trench 54

Trench 54 was located in a small enclosure on the upper slopes in the north-west of the site. The soils contained within this enclosure appeared raised above the level of those immediately outwith. Although there was no obvious rig and furrow to be seen within this structure, it was thought possible that this enclosure might contain a plaggen soil. However, shallow bedrock was hit on several occasions before a trench could be dug adjacent to a small circular indented structure immediately inside the eastern retaining wall. The three horizons of the resulting profile were described as a sandy clay loam Ap horizon of 43cm depth overlying a 9cm thick loamy sand bAp horizon on to a Bw horizon at 52cm depth also with a loamy sand texture. However, the description of the upper 43cm deep layer as an Ap horizon is given with some reservations given that several areas of this enclosure obviously could not have the same characteristics due to the presence of bedrock only a few centimetres below the surface. This enclosure obviously served some purpose other than that of a mere stock enclosure but this purpose will probably not be ascertained without further detailed archaeological excavation. The trench in this enclosure was dug and described during the visit in late November 1995 and was not studied in detail during the archaeological fieldwork in August 1995.

3.4 Archaeological fieldwork

The archaeological fieldwork was carried out to provide additional information to aid the interpretation of the two sites and also answer some questions raised during the desk-top classification of these sites. It became apparent from the detailed examination of the survey maps of both Boyken and Badentarbat that several of the built field boundaries were not contemporary and were superimposed one on top of the other. This clearly has implications for the interpretation of a site as a "field system" (see Chapter 2 for discussion). It was agreed that archaeological field survey could provide important information on the chronology of the built elements at both sites. Radiocarbon dating of material obtained from these built elements was seen as a useful method of gaining an appreciation of the length of occupation of the sites. It was also hoped that dateable material may be found in sufficiently secure contexts and in sufficient quantities within the actual polygons to provide information on the dates of certain agricultural activities. However, this proved only to be possible in one trench at the Boyken site and two at Badentarbat. Evidence of past land-use practises was also sought through archaeological survey and excavation and an attempt was made to define the nature and extent of masking factors on each site.

The archaeological fieldwork involved 3 methods of exploring the landscape:

1. Small test trenches were used to establish the nature of soil profiles at certain points in the landscape.

2. Larger trenches, up to a maximum of 5m x 5m, were used to gain information on the stratigraphy of certain built structures and their relationships to each other and the cultivation remains contained within them as well as providing the possibility for collecting dating samples from sealed contexts.

3. Small scale detailed surface mapping of the dykes and enclosures in certain areas created a more detailed record of the chronology of these elements than could be ascertained from the existing survey maps created by the RCAHMS.

3.4.1 Stratigraphy of field elements

The archaeological field survey and excavation was carried out by two trained archaeologists from AOC (Scotland) Ltd and the information given here is taken from the report written by Mr Rod McCullagh for Historic Scotland. The stratigraphy of various features of the historic agricultural landscape at both sites was examined either by excavation or by detailed field mapping of the surface features. Excavation was used in an attempt to establish the relationship between cultivation remains and the built structures surrounding such areas. The relationship between certain areas of rig and furrow and substantial stone cairns was also explored in this way. The stratigraphy of the various sections of built dyke was ascertained by detailed field survey mapping.

Boyken

Seven trenches were excavated primarily to try and answer the questions on the stratigraphic sequence of different elements within the landscape raised by the desk-top field classification. Unfortunately, several of these trenches failed to provide conclusive evidence upon which to base an interpretation of the stratigraphic relationships of the elements being explored.

Relationship between cultivation remains and built structures

Trench 1 in Polygon 56 was dug across the lower retaining wall of this polygon along the line of axis of the rig contained within it in order to explore the relationship of the rig and furrow with the boundary. It was also hoped that this trench would provide dateable material to give an indication of the approximate date of construction of the dyke which was also part of the substantial linear bank which ran through the eastern part of this site. Neither proved to be possible due to the high biological and chemical activity within the soils. Although several of the features explored appeared substantial on the surface, preservation of the soils contained within them proved to be poor. The soils contained high numbers of worms and other small invertebrates as well as being invaded in many areas by dense covers of bracken.

The desk-top field classification of the Boyken site survey map identified a few furrows in the upper complex of polygons on the eastern side of the site which did not appear to respect the surrounding enclosure dykes (Figure 2.5). Two of these, located in Polygon 35, appeared to run through the western boundary dyke of Polygon 38. However, inspection of these features casts doubt on this interpretation and the interpretation of these features as the wheel ruts of vehicles is favoured. Several lumps of burnt lime were also discovered in upcast molehills in this area and several of the enclosure banks displayed regularly spaced breaches. Examination of the soil profile in Trench 8 cut across the boundary dyke between Polygon 38 and 39 showed an irregular lower boundary to the A horizon (Appendix 2). This evidence, taken together, led to the interpretation that this area had been subjected to relatively modern ploughing and fertilisation. The current land-owner confirmed that burnt lime had been used as a top dressing up until as late as 1970 but he was adamant that the area had not been ploughed within his living memory. Although this interpretation is far from conclusive, it does provide some justification for doubting the accuracy of the survey map during the classification exercise.

Stratigraphy of built structures

Trenches 12 and 15 in Polygon 22 were dug in order to answer questions about the origins of the "lynchets" identified by the RCAHMS during their survey. As discussed in Chapter 2, these features are generally created by downslope movement of sediment due to human activities disturbing and often baring the soil surface upslope. However, the features identified in Polygon 22 as "lynchets" were orientated perpendicular to the slope contours and also roughly parallel to each other. Examination of the cross section of one of these features exposed in Trench 15 demonstrated that the "lynchet" was in fact a small turf bank. These were interpreted as possible banks for dividing up the land in Polygon 22 into strips under a run-rig type system. This is generally regarded as an earlier form of land division than the types of enclosure demonstrated at Boyken. Trench 12 was cut through the intersection of one of these features with the surrounding built enclosure to Polygon 22. Examination of this trench showed that the "lynchet" or putative turf dividing wall did, indeed, pre-date the enclosure wall for this polygon. Similar features were present in Polygon 28. Polygons 29 and 30 had also been mapped as containing lynchets although the orientation in this case was parallel to the slope contours as would normally be expected of such features. However, excavation of one of these features in Polygon 30 confirmed that these were also structures of a similar construction to those in Polygon 22. The persistence of such slight features in the landscape would tend to suggest that subsequent agricultural activity in this area has been minimal or at least has not penetrated the soil surface to any great depth.

A previously unidentified structure was discovered during this fieldwork underneath the upper boundary wall of Polygon 26. A small quarry had been mapped at this site but the archaeologists from AOC (Scotland) Ltd interpreted this feature as the platform of a small rectangular structure, bisected by a narrow track and with the upper boundary dyke of Polygon 26 overlying what may be considered the front gable of the structure. This structure appeared to be much more simple in construction than the structures in the other settlement clusters at Boyken. It was considered likely that clear evidence for chronological sequencing of the various features would be present at this location as well as offering the possibility of stratigraphically secure material for radiocarbon dating. Trench 17 was therefore dug across this feature and the overlying dyke and two layers of dateable material were recovered and sent for analysis. The results of this analysis are discussed in Section 3.4.2. Excavation, however, was not the only method used to unravel the chronological sequence of the built structures.

Detailed surface mapping of several of the boundary dykes in the upper eastern complex of polygons was undertaken to try and establish the chronological sequence of these features. The classification study had interpreted several of these irregularly shaped polygons as residuals from early land divisions which had been overlain by later reorganisation of the land. The identification of this stratigraphic sequence was based on "subtle changes of direction, disturbances, superimposition of bank alignments and the intersection of quarry gullies" (McCullagh, 1996, p.9). This fieldwork confirmed the suspicions raised during the desk-top classification study that this complex area of polygons was actually a palimpsest of several periods of land reorganisation rather than one contemporary field system layout. For example, the boundary separating Polygons 44 & 48 from Polygons 45 & 50 was found to be later than the boundary shared by Polygons 45 & 50 which was, in turn, later than the two boundaries separating Polygons 43 & 44 and 43 & 47. There was no conclusive evidence for palimpsest of the latter two boundaries which may indicate that they are contemporary. It would, therefore, appear that the doubts raised during the classification exercise about the validity of treating this site as one contemporary field system are justified.

Badentarbat

Relationship between rig and furrow and stone cairns

Three trenches were dug to explore the relationship between mapped rig and furrow and adjacent stone cairns (Figure 2.4). Trench 31 was excavated in Polygon 51. However, the mapped stone cairn proved to be little more than a slight accumulation of stones around an earthfast boulder at the downslope terminal of a rig. This suggests that the rig and furrow and the cairn are contemporary. However, no artefacts were found to give an indication of the age of these features and, although a fragment of peat was found under the rig terminal, it was too weathered to provide samples for dating. However, the presence of such peat under the rig does appear to indicate that improvement of peat land was part of the agricultural activities associated with the formation of this area of rigged landscape.

Trenches 41 and 45 explored similar relationships in Polygons 47 and 36, respectively. Again, examination of these trenches appeared to indicate that the rig and cairns were contemporary in both cases. However, artefacts were found in each of these trenches which give an indication of the age of these features. A fragment of brown thin-walled glass was found in Trench 41 and Trench 45 provided a piece of white glazed ware which both indicate that these areas were in use in relatively modern times, certainly no earlier than the 18th Century.

Relationship between cultivation remains and built structures

Trench 35 sought to establish the relationship between a section of dyke and the rig and furrow contained within (Figure 2.4). It was dug through the boundary dyke between Polygons 4 and 5. This section of dyke was interpreted from the detailed surface mapping exercise (discussed below) to be a possible remnant of a boundary of earlier origin than the existing head-dyke. The rig from Polygon 4 exposed by this trench was shown to abut the top course of stones in the dyke. The dyke had also acted as a revetment and had accumulated a large amount of soil behind its upslope face which presumably means that the rig, abutting the top course of stonework and sitting on this thick accumulation of soil, is later than the construction of the dyke. This is merely an indication of the last phase of land use within this polygon and does not rule out the possibility that other forms of cultivation were associated with the dyke's construction. However, no evidence for this former cultivation was found in the trench profile.

Trench 39 was cut through a substantial section of the head-dyke which constitutes the north-western part of the boundary for Polygon 50. It was hoped that this trench might provide information on the sequence of the head-dyke construction on this site. Unfortunately, this did not prove to be the case. However, the presence of an *in situ* layer of peat preserved beneath the dyke did provide dateable material to provide a date for the onset of peat in the area and a *terminus post quem* (TPQ) for the dyke construction. The presence of a gully on the upslope side of the dyke also allowed a tentative interpretation of the relative chronology of the cultivation remains in Polygons 50, 4 and 5. Such gullies associated with dyke construction have been noted elsewhere on the site and they have been interpreted as a means of land drainage which avoids the loss or disruption of tracts of cultivable land.

If this interpretation is accepted, then it can be argued that the construction of a drainage gully on the outside of the boundary dyke of Polygon 50 indicates that the land within this new enclosure was considered more important for cultivation than the land contained in Polygons 4 and 5. This may indicate that either Polygons 4 and 5 did not exist during the construction and early use of Polygon 50 or that they did not contain land under contemporaneous cultivation. This suggests that the arable use of Polygons 4 and 5 may be later than that evident in Polygon 50. However, the dates calculated from the charcoal retrieved from Trench 38 in Polygon 50 and the interpretation of the rig form in this polygon as being relatively modern suggest that Polygon 50 may more accurately be said to have a longer agricultural history than Polygons 4 and 5 (see Section 3.4.2).

Chronology of the built structures

Detailed surface mapping of the boundary dykes at this site was carried out in order to establish whether the head-dyke was actually the substantial, contemporary structure that it seemed from the survey map. Figure 3.11 illustrates the findings of this survey. Each section of dyke which displayed different characteristics to the dyke on either side was identified and allocated a dyke segment number. The characteristics of the dyke construction were noted for each segment. It was also noted whether or not the segment of dyke abutted or articulated with adjacent segments.

It was observed during this survey that the head-dyke on the western side of the site was much more substantial than that found on the east. The post-Improvement activity on the eastern side of the site may play some part in producing this difference and, certainly, there was evidence of the dyke having been disrupted and robbed out during the construction of later buildings on this side.

There is a clear distinction between the nature of the landscape layout to the north of the site and that to the south. This observation was made during the desk-top classification study and it was hoped that the date of origin of these two parts of the site could be provided by the archaeological fieldwork. Were they contemporaneous or did one pre-date the other? The surface mapping exercise led to the interpretation that the northern enclosed landscape was earlier than that of the more open landscape to the south of the site. This may be an over-simplistic view given that some of the evidence for the chronology of dyke construction on the eastern part of the site has been eradicated by post-

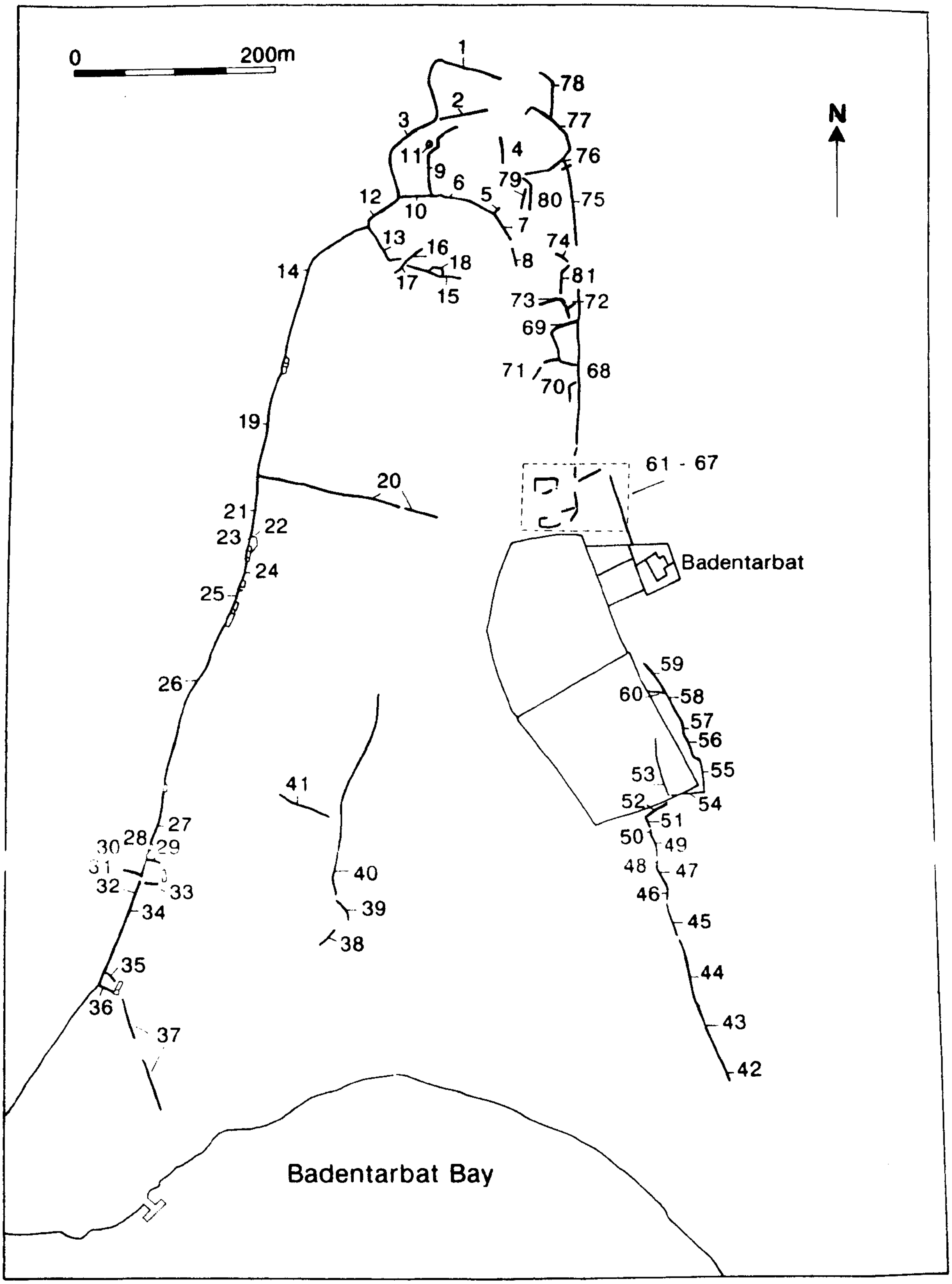

Figure 3.11 - Results of detailed archaeological survey of head-dyke, Badentarbat. (after McCullagh, 1996)

improvement activity. The test pit soil survey undertaken by Dr Stephen Carter, then employed by AOC (Scotland) Ltd., during his visit to the site in August identified the land now enclosed and used as horse paddocks as some of the best on the site. It must be considered that the best land is likely to have been among the first areas utilised during the initial occupation of this site and that the evidence for this has been obliterated by the horse paddocks of today. This interpretation is interesting in the context of previous studies of Scottish field systems where it has generally been considered that open run-rig landscapes were the primitive precursor to the enclosed agricultural landscape (Butlin, 1964). Dodgshon (1993), however, argues that an adjustment of settlement from a dispersed to a nucleated form may not have occurred in some West Highland areas of Scotland until the late medieval period and may also have been associated with a shift from the use of field enclosures to one based on runrig open fields. The evidence from this research appears to uphold this argument.

It is also argued from this survey exercise that the head-dyke either lost its function or was not completed before the site was abandoned for arable agriculture. The variety of forms of dyke construction found on the western part of the head-dyke seems to suggest that it never really formed a consistent barrier and research of the historical documentation from the 18th century shows only sporadic attention was given to the upkeep of the dyke.

3.4.2 Dating

All routine radiocarbon dating analyses were carried out by the Scottish Universities Research and Reactor Centre in East Kilbride. Liquid scintillation counting methods are used and calendrical dating is estimated using the calibration curves of the University of Washington Quaternary Isotope Laboratory Radiocarbon Dating Program 1987 (Pearson & Stuiver, 1986; Stuiver & Pearson, 1986). All samples are corrected for ^{13}C fractionation and the estimate of error includes an estimation of the errors associated with both radioactive measurement and reproducibility in the laboratory (Smart & Frances, 1991). Accelerator Mass Spectrometry (AMS) was carried out at the radiocarbon dating laboratory of the University of Arizona to date the small sample of charcoal from Trench 38 at Badentarbat. Only the calibrated age ranges at the 2 standard deviation level (2σ) are given here.

Boyken

Only three samples of dateable material were obtained from the Boyken site. Two are from the base of the stratigraphy exposed in Trench 17 during the excavation of a previously unrecorded house platform overlain by the boundary dyke of Polygon 26 and the third is the relatively large quantity of charcoal found at the base of the A horizon in Trench 5 located within Polygon 52 (Figure 2.5 shows location of trenches).

The two Trench 17 samples are charcoal samples which came from vertically adjacent contexts (GU-4420 overlies GU-4419) towards the base of the stratigraphy which present a means of dating either the use of the settlement structure or the approximate date of construction. They also provide a *terminus post quem* (TPQ) for the construction of the boundary dyke around Polygon 26. The results from these samples were as follows:

GU-4420 660 ± 60 $\delta^{13}C = -26.8‰$
Calibrated Age range
2σ cal AD 1260-1410, cal BP 690-540

GU-4419 630 ± 50 $\delta^{13}C = -26.2‰$
Calibrated Age range
2σ cal AD 1270-1410, cal BP 680-540

The close correlation between the calibrated dates would appear to indicate that the charcoal samples may be contemporaneous in age, if not in date of deposition and that the boundary dyke for Polygon 26 was built some time after the early 15th century. These dates do not provide conclusive evidence for either the date of construction or occupation of the settlement structure but merely provide evidence that these events occurred sometime between these dates and the construction of the boundary dyke.

The sample of charcoal taken from the A horizon of Trench 5 in Polygon 52 at a depth of 30-35cm was taken in the hope that a date could be obtained which pertained to the most recent phase of landuse in this area. Field survey revealed that the complex of polygons at the top of the slope on the eastern part of the site overlay the upper boundaries of the group of Polygons 50-54 (Figure 2.5). Polygons 50-54 have been interpreted as a series of temporary stock enclosures. The later polygons at the top of the hill have been dated, using circumstantial evidence, to the mid-18th century. An earlier date was therefore expected for the sample taken from Polygon 52. The dating results are as follows:

GU-4421 860 ± 50 $\delta^{13}C = -26.6‰$
Calibrated Age range
2σ cal AD 1030-1270, cal BP 920-680

This early date from Polygon 52 appears to confirm the interpretation that this group of polygons (50-54) is of a relatively early origin. However, this date can only be associated with the last probable period of soil disturbance in this area and cannot be used to provide a date for the surrounding boundary dyke. If the interpretation of these polygons as a set of stock enclosures is correct, then it is reasonable to assume that soil disturbance would be minimal under this type of use. The date provided by this charcoal sample could indicate either of two earlier activities on this site: 1) it represents the date of burning of vegetation to clear the area for the building of the stock enclosures, or 2) it represents a period of arable agriculture prior to the construction of the stock enclosures seen today. Given the very steep nature of the slope in this area, prolonged exposure and disturbance of the soil during arable cultivation, especially in the wet climate of this area, is likely to result in considerable downslope movement of the soil and associated crops. The first interpretation is thus considered the more likely of the two.

These dates seem to suggest that the Boyken site was in use during the early part of the 2nd millenium AD which corresponds to the early medieval period. However, other circumstantial evidence across the site, such as the large circular defensive earthwork thought to date from the Iron Age on the western fringes of the site and the burnt lime found in the upper complex of polygons to the east, suggest that this site has been used in a variety of ways over a much more extensive period of time.

Badentarbat

Dateable material was much more abundant at Badentarbat and 20 samples were collected and analysed. The presence of deep peat and sediment layers in the small lochan on the site also provided an excellent opportunity for further study of the palaeoenvironmental data for this site in order to determine the long term landscape changes which have taken place in this area. Sediment core analysis using X-radiography, pollen analysis and radiocarbon dating and diatom analysis were also carried out at this site by other researchers during the period of this research. The dates obtained from the sediment core study shall be considered along with the radiocarbon dating programme from the field system work.

Trench 32

A sample of charcoal was dated from the top 5cm of the sub-mineral soil in Trench 32 in Polygon 7 (Figure 2.4). The surface of this sub-mineral horizon appeared to have a rig and furrow morphology similar to that found at the surface with the mineral soil rig located under the current furrow evident in the overlying peat layer. This charcoal sample was interpreted as a possible anthropic inclusion during a proposed earlier phase of agricultural activity and may provide a TPQ date for the overlying rig in the upper peat profile. The following results were obtained for this sample:

GU-4416 4130 ± 50 $\delta^{13}C = -25.3‰$
Calibrated Age range
2σ cal BC 2889-2509, cal BP 4838-4458

This was a surprisingly early date which would appear to indicate that this site has been in use since prehistoric times. However, other evidence in the form of embanked roundhouses and sub-peat cairns does exist to further corroborate the presence of human activity in this area at this time.

Trench 33

Another date was obtained from charcoal in a sub-peat mineral soil horizon below the boundary dyke for Polygon 7 (Trench 33 - Figure 2.4). The 18cm peat layer which overlay this mineral horizon but which was sealed by the boundary dyke was also sampled for dating. Three samples at 1cm intervals were taken from the upper and lower boundaries of this peat column. The humic and humin fractions of these samples were dated where possible and can be seen from Table 3.3 to be very similar. These results can therefore be regarded as dating the actual age of the peat.

The charcoal sampled from the mineral soil beneath the peat in this trench has also given a very early date but is approximately 500 years older than the charcoal found in Trench 32. The pollen analysis carried out by Bunting and Tipping (unpublished) on local pollen assemblage zones B1 and B2 (lpaz) from the sediment core which span these early dates produced from the field system work, indicates that there is little clear evidence for human activity within the catchment at this time. Charcoal fragments are present at relatively low levels in lpaz B1 (6670-5230 BP) but decrease in lpaz B2 (5230-3890 BP). A marked increase in charcoal fragments, which may indicate human presence in the area, is not seen in the core until lpaz B3 (3890-3240 BP). This appears to suggest that the charcoal associated with the sub-mineral soils in Polygon 7 may not be due to human activity in the area. However, the morphology of the mineral soil horizon inTrench 32 seems to contradict this interpretation and it must be remembered that the dating of charcoal merely dates the period of initial burning and not of its subsequent use. It therefore seems reasonable to propose a "broad brushstroke" interpretation of Neolithic/Bronze Age human activity at this site.

The long gap between the date for the charcoal in the lower context boundary of Trench 33 and that for the basal peat samples in the upper context requires careful consideration during interpretation. This is best done by also considering the results from Trenches 37 and 39 and then discussing them in relation to the findings from the pollen analysis work. The results for Trenches 37 and 39 are as follows:

Sample No.	**Distance from upper context boundary (cm)**	**Fraction**	**Uncalibrated date and error at 1σ level**	**$\delta^{13}C$ (‰)**	**Calibrated Age range at 2σ level**
GU-4422 - 3305/1	1	Humic	520 ± 50	-28.6	cal AD 1305-1449 cal BP 645-501
-	2	-	Not dated		
GU-4423 - 3305/3	3	Humic	770 ± 50	-28.4	cal AD 1170-1290 cal BP 780-660
-	4-15	-	Not sampled		
GU-4424 - 3305/4	16	Humic	1850 ± 50	-28.4	cal AD 60-316 cal BP 1890-1634
GU-4546 - 3305/4	16	Humin	1870 ± 50	-28.6	cal AD 29-250 cal BP 1930-1700
-	17	-	Not dated		
GU-4425 - 3305/6	18	Humic	2520 ± 60	-28.7	cal BC 810-410 cal BP 2759-2359
GU-4547 - 3305/6	18	Humin	2490 ± 50	-28.7	cal BC 800-410 cal BP 2749-2359
GU-4417 - 3306	lower context boundary	Charcoal	4490 ± 80	-25.5	cal BC 3491-2920 cal BP 5440-4869

Table 3.3 - Radiocarbon dates obtained from sampled material under boundary dyke of Polygon 7 (Trench 33), Badentarbat. See Figure 2.4 for location of trench.

Trench 37

This trench was cut through the boundary dyke between Polygons 3 and 7 (Figure 2.4). The peat samples were obtained from a 5cm thick layer of peat buried beneath the stone coursework of this fairly substantial dyke which was thought to be undisturbed. The samples which were sent for radiocarbon dating represent the upper, middle and basal slices from this layer (Table 3.4). It was hoped that these dates would give us a date for the onset of peat growth and also a TPQ for construction of the dyke.

Trench 39

The peat sampled in this trench was also located under a boundary dyke on the downslope side. The layer was 13cm thick and the dated samples represent the upper and basal boundaries of the peat column. The acquisition of radiocarbon dates indicating the onset of peat growth and a TPQ for construction of the dyke were again the main aims of this sampling programme.

Sample No.	**Distance from upper context boundary (cm)**	**Fraction**	**Uncalibrated date and error at 1σ level**	**$\delta^{13}C$ (‰)**	**Calibrated Age range at 2σ level**
GU-4426 - 3708/7	1	Humic	1150 ± 50	-29.0	cal AD 770-990 cal BP 1180-960
3708/8	2	-	Not dated		
GU-4427 - 3708/9	3	Humic	950 ± 50	-28.9	cal AD 990-1210 cal BP 960-740
GU-4548 - 3308/9	3	Humin	1090 ± 70	-28.8	cal AD 780-1030 cal BP 1170-920
3708/10	4	-	Not dated		
GU-4428 - 3708/11	5	Humic	1310 ± 60	-28.9	cal AD 630-870 cal BP 1320-1080
GU-4549 - 3708/11	5	Humin	1510 ± 50	-28.9	cal AD 420-640 cal BP 1530-1310

Table 3.4 - Radiocarbon dates obtained from peat column sealed under boundary dyke between Polygons 3 & 7 (Trench 37), Badentarbat. (Figure 2.4 gives trench location).

The basal peat dates for Trench 37 are much later than the remarkably similar dates for Trenches 33 and 39 (Table 3.5). McCullagh (1996) proposes that these dates may not indicate the actual date for the onset of peat growth but merely mark the cessation of human activity which allowed peat growth to occur. This human activity need not necessarily have been in the form of intensive arable agricultural practises. It is considered likely that pastoral farming was predominantly practised between the dates for the mineral soils and overlying peats and that peat growth was inhibited through the practise of turf or peat-stripping for fuel or possibly for manure for the little arable cultivation that may have been in progress. There is no evidence in the prehistoric archaeological record at this site to confirm the hypothesis of such use of the surface peat or turf layers. However, Trench 39 was recorded as having

Sample No.	Distance from upper context boundary (cm)	Fraction	Uncalibrated date and error at 1σ level	$\delta^{13}C$ (‰)	Calibrated Age range at 2σ level
GU--4429 - 3903/13	1	Humic	840 ± 50	-28.9	cal AD 1040-1270 cal BP 910-680
3903/14	2	-	Not dated		
GU-4430 - 3903/15	3	Humic	1380 ± 50	-29.1	cal AD 590-751 cal BP 1360-1199
-	4-10	-	Not sampled		
GU-4431 - 3903/16	11	Humic	2070 ± 50	-29.0	cal BC 332-cal AD 20 cal BP 2281-1930
GU-4550 - 3903/16	11	Humin	2190 ± 60	-28.8	cal BC 390-100 cal BP 2339-2049
3903/17	12	-	Not dated		
GU 4432 - 3903/18	13	Humic	2490 ± 50	-29.3	cal BC 800-410 cal BP 2749-2359
GU-4551 - 3903/18	13	Humin	2510 ± 60	-29.2	cal BC 810-410 cal BP 2759-2359

Table 3.5 - Radiocarbon dates from peat column sealed under boundary dyke of Polygon 50 (Trench 39), Badentarbat. See Figure 2.4 for location of trench.

evidence of a possible turf layer sandwiched between the mineral and peat horizons which would appear to suggest that the local landscape was open grassland rather than cultivated arable land. This interpretation is supported by the evidence from lpaz B4 (3240-930 BP) from the sediment core studied by Bunting and Tipping (1997). This zone is seen to contain pollen evidence which has been interpreted as indicating localised human activity, possibly with some animal grazing. Heather and sweet gale pollen increases from around 2900 BP which may suggest that blanket peat was present and spreading in the area and the observed decline in bracken spores also seems to suggest that the vegetation is moving from dry vegetation communities to that of wetter blanket bog around this time. The proposed date for the onset of peat growth in this area is relatively close to those obtained for the basal peat layers of Trenches 33 and 39. The later date from the basal peat layers from Trench 37 may indicate some localised, intensive human activity of longer duration in this area of the site.

The variety of dates obtained from the upper samples of the peat layers from these three trenches may seem, at face value, to indicate different ages of construction for the overlying dykes which nevertheless roughly span the early Medieval period. However, there is no way of establishing whether these upper layers represent the true upper extent of the peat surface or whether a significant part of the upper peat layer has been lost either before or during the construction of the boundary dykes. The inverted dates for the two upper samples in Trench 37 would appear to suggest that some disturbance of the peat horizon has occurred, at least at this location but this evidence cannot be extrapolated for Trenches 33 and 39. It is therefore impossible to state with any great confidence that the radiocarbon dates from these upper peat layers can be closely associated with the dyke construction.

The peat growth in these 3 shallow layers appears to be very slow with a growth rate of 0.008 $cmyr^{-1}$ for Trenches 33 and 37 and 0.006 $cmyr^{-1}$ for Trench 39. It seems unlikely that such shallow and slow-growing peat would be found particularly useful as a source of fuel although it may conceivably have been used for manure or building materials. However, the pollen data from Ipaz B6 (c. 770-420 BP) suggests that there may have been some localised woodland regeneration happening during this period. Bunting suggests that this may be due to decreased human activity but this is contradicted by other pollen evidence from this zone. An alternative proposed interpretation is that turf-stripping of blanket peat may have been exposing drier soils in which trees could regenerate. Although, the alleged peat disturbance in these trenches has not led to the exposure of the more freely draining sub-mineral soils, this may easily have occurred in other areas where greater peat accumulations occurred. The growth rate of peat in these trenches is very much slower than that calculated from the sediment core evidence (0.04 $cmyr^{-1}$) over the same period but this core represents an area of low-lying blanket bog rather than the blanket peat sampled from the slopes of the field system and no conclusions can be drawn from this difference. The similar growth rates for Trenches 33 and 37 are not unexpected given that they are located on similar slopes and quite close to each other. Trench 39 is located on a much steeper slope on the western fringes of the site which may account for the slower rate of peat growth in this area.

Trench 38

Trench 38 is located in the lower slopes of Polygon 50 which is partially bounded by the dyke bisected by Trench 39 (Figure 2.4). A small sample of *Betula sp.* charcoal was sampled from the base of the deep peat layer in the soil profile. This was dated at the radiocarbon laboratory of the University of Arizona using AMS techniques as:

AA-19624 300 ± 80 $\delta^{13}C = -26.6‰$
Calibrated Age range
2σ cal AD 1440-1955, cal BP 510-0

This is a particularly late date which seems to contradict the interpretation that Polygon 50 is earlier in origin to the adjacent Polygons 4 and 5 based on the evidence from Trench 39. However, the long, regular and curvilinear morphology of the rig and furrow located in Polygon 50 had been interpreted by the author as characteristic of plough cultivation during a relatively late phase of activity. This interpretation was also based on the waterlogged nature of the soils of the lower slopes of this polygon which were regarded as undesirable for arable agriculture unless extraordinary circumstances necessitated their use. Such extraordinary circumstances may have occurred during periods of rapid population growth when the maximum amount of land was needed under arable cultivation to meet consumer demand. Rapid population increases in this area are documented in the Old Statistical Accounts of 1794 and 1845. Censuses of 1755, 1794 and 1831 show the population of the parish of Lochbroom to increase from 2211 to 3500 to 4615, respectively. This late date from the charcoal may merely indicate the last phase of land use. If this interpretation is to be accepted, however, it must also be considered that the entire 66cm deep peat accumulation was disturbed during the last phases of cultivation to account for the location of the dated charcoal sample.

Grass and cereal-type pollen grains increase in quantity in lpazs B6 (*c.*770-*c.*420 BP) and B7 (*c.*420-*c.*140 BP) in the sediment core, suggesting that human activity was common at Badentarbat during this period. Interestingly, no pollen grains of oats (*Avena*) were recorded but all grains which were categorised as "cereal-type" grains had diameters from 9-11µm which suggests that they come either from aquatic grasses or from barley (*Hordeum*). Charcoal fragments were also seen to increase in number in lpaz B7 which may also reflect local human activity.

The dates for these latter local pollen assemblage zones are estimates derived from the radiocarbon dates already received. Three further samples from the upper *c.*150cm of the sediment core were obtained in September 1997 and the results are still awaited. However, comparison of the information for this site with the historical documentation record would appear to suggest that the age estimates are out by no more than 70-80 years.

Summary

From these results, it would appear that both sites have been subject to human activity over substantial, although not necessarily continuous, periods of time. Although dateable material was scarce at Boyken, a picture of the history of the site can be gained by also considering the field evidence. This history appears to span from at least the Iron Age through to the mid-18th century and, indeed, the area is still used for animal grazing today. An early form of land division has been identified in the western half of the site where the land was divided into a series of parallel strips separated by low earthen banks. No date can be provided for this form of land division but it has been superseded by a later phase of land reorganisation which dates from some time after the early 15th century. Evidence of early Medieval activity is provided by the charcoal sample analysed from Trench 5 in the eastern half of the site and the presence of burnt lime along with the chronology of the enclosure banks in the upper eastern complex of polygons indicates that human activity also occurred on this site in the 18th century. However, this evidence cannot be interpreted as illustrating the continuous use of the site throughout this period. Nor can it be used to demonstrate that the Boyken site was only used sporadically over this period.

The Badentarbat site, however, provides more conclusive evidence for its sporadic use through time. Badentarbat appears to have experienced an even longer history of human activity which has been demonstrated by the radiocarbon dating and pollen analysis work to have consisted of two phases of human activity separated by a period of less intensive use when peat growth was predominant. The first phase has been dated to have occurred between approximately 5500 - 2500 BP and the second from *circa* 1000 BP to virtually the present day. Certainly, there appears to be evidence for agricultural activity on this site in the mid-late 18th century, both from the radiocarbon and historical documentation records. It would, therefore, seem reasonable to suggest that the cultural landscapes seen today merely reflect the nature of the last phase of use with its associated vestiges of former human activity and it may be more accurate to term such sites not as "field systems" but as "evolving landscapes".

4. Soil Micromorphology: Thin section preparation, description and methods of analysis

4.1 Introduction

The third, and major, phase of this research was the laboratory preparation, description and analysis of the one hundred and twenty-six undisturbed soil samples collected from the Boyken and Badentarbat sites. Full description of one soil thin section can take even expert soil micromorphologists several hours to complete. This project applied the technique of soil micromorphological description for a specific purpose: to identify signatures in the soil which may indicate human influence in the past. With such a large number of slides, it was necessary to devise a description system which targeted the soil features which were most likely to provide this evidence in order to allow the maximum number of slides to be described. Two methods of soil thin section description were carried out to establish the level of detail required to obtain the necessary micromorphological information. The rationale and methods used are described in this chapter. The results of the micromorphological work were quantitatively analysed using a range of statistical tests and procedures.

4.1.1 Thin Section Preparation

The preparation of soil thin sections from undisturbed soil samples taken in the field comprises a number of stages. The soils have to be impregnated with a resin in order to obtain solid blocks of soil which can then be cut, bonded on to prepared glass slides and lapped to an appropriate thickness. The standard method of soil thin section preparation used at Stirling University is detailed in Appendix 3. Slight modifications had to be made to these standard procedures in order to produce good quality slides from the Boyken and Badentarbat soil samples.

4.1.2 Method - Boyken

Due to the stony nature of the soils at Boyken, it was impossible to use standard Kubiena tins to obtain undisturbed samples for soil thin section preparation. Large monoliths of the entire A horizon, and occasionally also part of the B horizon, were extracted from each soil pit for preparation in the laboratory. Each monolith sample was carefully extracted from its packaging on to a metal tray, keeping a note of the orientation of the sample at all times. Smaller blocks of soil were carved from this large monolith using a scalpel and small knife. The number of soil blocks taken from each monolith for impregnation was dependent on a number of factors: the number of horizons which comprised the monolith sample, the stoniness and friability of the sample and the maximum size of soil block which could be accommodated in the desiccator during the impregnation process. The upper size limit for these soil blocks was 15cm x 10cm x 10cm.

A heavy duty aluminium foil carton with a perforated base had to be made to measure for each soil block. Each block was carefully transferred to the corresponding foil carton which was marked with the correct identification details and the orientation. The samples were then placed in plastic basins which also had the identification and orientation details for each sample marked on the side. The impregnation process was considerably slowed because only one or two samples could be impregnated in the desiccator apparatus at one time, compared with the usual 5 Kubiena tin samples. The large blocks also took longer to cure and required much more sawing and trimming to produce slices which fitted on the glass slides. The polishing, bonding and lapping of the slides and soil took the normal amount of time. Each slide was engraved with the Trench No./Polygon No. and the orientation. Fifty-two slides were produced for the Boyken site. Table 4.1 provides the slide identification details and the depth in the profile which each corresponds to. Some slides contained more than one horizon or areas with distinctively different features. These have been indicated by the use of additional terms such as "upper" and "lower".

4.1.3 Method - Badentarbat

The peaty soils of the Badentarbat site allowed undisturbed soil samples to be taken using Kubiena tins. However, many of the samples had a very high peat content which required special treatment. Some organic matter may be destroyed or affected by prolonged submersion in acetone. Oven- and air-drying also causes significant shrinkage of peaty samples, thus affecting the soil structure. The acetone vapour exchange method was therefore employed (Murphy, 1986). The removable bases of the tins were replaced with perforated ones and the samples were raised from the bottom of the plastic

Trench No/ Polygon No.	Slide A Depth (cm)	Slide B Depth (cm)	Slide C Depth (cm)	Slide D Depth (cm)	Slide E Depth (cm)	Slide F Depth (cm)
1/56	**Upper** 30.0-38.5 **Lower left** 35.0-38.5	40.0-48.5	**Upper** 7.0-11.5 **Lower** 11.5-15.5	**Upper** 14.0-18.0 **Lower** 18.0-22.0	23.0-31.0	-
5/52	16.0-23.5	20.0-27.5	5.0-14.0	15.0-23.0	-	-
6/10	4.0-12.0	17.5-26.5	30.0-39.0	35.0-44.0	-	-
8/38	7.5-17.5	-	-	-	-	-
11/36	3.0-11.0	15.0-23.5	27.0-36.0	-	-	-
13/22	**Upper** 6.0-11.5 **Lower** 11.5-15.0	11.0-20.0	-	-	-	-
19/47	**Upper** 0.0-4.0 **Lower** 4.0-7.0	10.0-18.5	24.0-32.0	32.0-40.5	34.5-43.0	44.0-52.0
20/22	2.0-10.5	19.0-27.0	-	-	-	-
21/22	7.0-13.0	24.0-32.0	-	-	-	-
22/outwith	2.5-10.0	16.0-23.5	27.0-34.0	-	-	-
23(1)/outwith	2.0-9.5	11.0-18.0	26.0-34.5	-	-	-
23(2)/outwith	1.0-9.0	16.0-24.0	-	-	-	-
25/30	**Upper** 2.0-5.0 **Lower** 5.0-10.0	15.0-20.0	24.0-31.0	-	-	-
26/30	2.0-10.5	16.0-24.0	-	-	-	-
27/38	6.0-14.0	19.0-27.5	-	-	-	-
28/47	2.0-10.0	21.0-30.0	-	-	-	-
29/52	9.0-15.5	19.0-27.5	-	-	-	-
30(1)/outwith	5.0-12.5	18.0-25.5	-	-	-	-
30(2)/outwith	1.0-8.5	17.0-25.0	-	-	-	-

Table 4.1 - Notation details and corresponding depths for the 52 soil thin sections from Boyken. The location of each trench is illustrated in Figure 2.5.

tubs used during the acetone exchange process. Acetone was poured into the tubs to a level just below the perforated bases of the soil samples. The tubs were sealed and placed in a fume cupboard to allow the acetone vapour to impregnate the peaty soil samples and exchange with the water held in the pore spaces. The samples acquired during the late November visit to Badentarbat were considerably wetter than those taken during the visit in August 1995 and took much longer to fully excnange their water content with acetone. The mineral soil samples were processed using the standard methods described in Appendix 3 but the peat samples also required modifications to the impregnation process.

The peats had very low porosity which made it difficult to impregnate them under vacuum using the standard resin mixture given in Appendix 3. These samples were therefore transferred into deep foil cartons after the acetone exchange process had been completed. The resin mixture was modified to produce a thinner consistency which would more easily infiltrate the small pore spaces in the samples. The modified recipe was:

B & K Crystic (polyester) resin	180ml
B & K MEPK LA3 Catalyst	0.9ml
"FSA" pure acetone	180ml
Keystone Keyplast Blue A dye	0.6mg

This mixture was poured over the samples until each was submerged under at least 5cm of resin mixture. The samples were then placed in a fume cupboard and topped up daily until the level of the resin mixture remained stable for a period of at least 48 hours. They were left to cure for several weeks. Many of the samples took much longer than normal to cure to solid blocks and several had to have a sticky outer layer of semi-hardened resin removed to reveal the properly cured soil block which then had to be left for a further few days in daylight to fully harden. No reason for this was established but the resultant blocks appeared to be just as well impregnated as those not experiencing these difficulties. The rest of the procedure followed the standard method described in Appendix 3 except that only abrasive in ethanol solution was used during lapping of the thin sections.

However, difficulties were still experienced with the pure peat samples during the final stages of the thin section preparation process. Some areas of the soil thin section lapped off much more rapidly than others. It often took three or more attempts to produce a slide of reasonable quality. At first, it was thought that the differential lapping rate may be due to areas of poor impregnation. However, repeat attempts at making a slide from the same block often resulted in similar differential lapping but in different areas of the slide. This suggests that this problem is due to some other factor but no solution has been found, despite similar problems with peaty samples from other sites. Several slides could not be lapped down to 35µm thickness without losing large areas of the soil sample. It was considered more important to have as large an area as possible in each thin section available for micromorphological description than to try to achieve the optimum thickness of 35µm for only some areas. Several of the thin sections of peaty soils from Badentarbat are thus much thicker in order to preserve as many of the soil features as possible. Seventy-four slides were produced and the identification details and corresponding depth in the profile of each slide is given in Table 4.2.

4.2 Soil Micromorphological Description

Soil micromorphology was first introduced in 1938 by Kubiena as an additional technique for the classification of soils. Since then, soil micromorphological techniques have been used in a number of different applications. It has been increasingly used to understand and research the effects of modern agriculture on soils (Drees *et al*, 1994;Jongerius, 1983; Koppi *et al*, 1992; Munyankusi *et al*, 1994; Torrentó & Solé-Benet, 1992). Similarly, it has been applied to the study of much older anthropogenic soils (Bryant & Davidson, 1996; Davidson & Simpson, 1984; Dockrill & Simpson, 1994; Gebhardt, 1993; Macphail *et al*, 1990; Shiel & Askew, 1988, Simpson, 1993; Simpson, 1997) and is increasingly used as a tool for interpreting archaeological sites and landscapes (Allen & Macphail 1987; Barclay *et al*, 1995; Courty *et al*, 1991; Davidson *et al*, 1992; Dockrill *et al*, 1994; Goldberg, 1983; Macphail, 1986; Macphail *et al*, 1990; Romans & Robertson, 1983a). With so many different applications of soil micromorphological techniques over the years, several methods of description of soil thin sections have evolved.

Kubiena used soil micromorphology to identify and interpret genetic processes to aid soil classification. This system was commonly used until the introduction of new descriptive methods by Brewer in 1964 which attempted to eradicate any need for interpretation and was based on pure morphological description of the soil structure and fabric. The mineralogical bias to these systems for soil thin section description was gradually rectified with the publication of methods for the description of organic matter during the sixties and seventies (Babel, 1975; Barratt, 1969, Jongerius & Schelling, 1960). Other systems were devised and published, most notably Fitzpatrick (1984). However, the increasing number of researchers working in soil micromorphology and applying it to an ever-growing range of fields resulted in the use of a vast array of descriptive terms. An attempt was therefore made, through an International Working Meeting set up as a Sub-Commission of the International Society of Soil Science, to standardise and limit both the terminology used in soil thin section description and the method of description used. This work resulted in the publication of the Handbook for Soil Thin Section Description in 1985 written by Bullock *et al*. This is now the internationally accepted reference text for soil thin section description although many micromorphologists still also refer to the earlier texts. The Bullock *et al* (1985) reference has been used to create an adapted system for soil thin section description for this research.

The subjective nature of soil micromorphology has been a major criticism of the technique. The publication of a glossary of micromorphological terms (Jongerius & Rutherford, 1979) and the use of reference plates and diagrams in the Handbook (Bullock *et al*, 1985) served to at least partially address this problem but the heterogeneous nature of soils cannot be comprehensively covered in any one text and doubts still remained as to whether different micromorphologists would actually produce similar descriptions of the same features. A "round-robin" experiment was thus set up in the early 1980s with three main aims: to assess the degree of similarity between descriptions of soil thin sections by different micromorphologists, to identify the reasons for any differences that were found, and to test the usefulness of the Handbook for Soil Thin Section (Murphy *et al*, 1985).

Seven experienced micromorphologists from five different countries and six different institutes were asked to describe the same seven slides which represented a range of soil types. The description of each slide had to be achieved in a few hours, which is the normal time taken for the full description of a slide by an experienced micromorphologist. The results were then collated and analysed for similarities and differences between the corresponding descriptions. Although several variations were found between corresponding descriptions, these were generally thought to be due to certain individuals specialising in specific fields such as mineralogy and faecal matter. However, the descriptions generally concurred and it was agreed that the Handbook (which had yet to be published at this stage) provided a "good framework for comprehensive descriptions" (Murphy *et al*, 1985, p.35), although a few improvements were also suggested, such as a change to the description of coarse/fine related distributions and allowing greater flexibility for the coarse/fine limits. It was also stressed that, as Brewer had emphasised in his book of 1964, features in soil thin sections should be described first in terms of their size, shape and distribution and interpreted later. This is particularly difficult for features such as spheroidal excrement which is grouped under the heading "Pedofeatures" in the Handbook. To be able to distinguish these features as pedofeatures rather than a type of soil microstructure requires a

Trench No./ Polygon No.	Slide A Depth (cm)	Slide B Depth (cm)	Slide C Depth (cm)	Slide D Depth (cm)	Slide E Depth (cm)	Slide F Depth (cm)
32/7	0.0-18.0	18.0-26.0	26.0-34.0	34.0-42.0	42.0-50.0	**Upper** 50.0-50.5 **Lower** 50.5-58.0
32(Furrow)/7	**Upper left** 10.0-12.5 **Upper right** 10.0-15.0 **Lower left** 12.5-18.0 **Lower right** 15.0-18.0	**Upper** 22.0-24.5 **Lower** 24.5-30.0	-	-	-	-
34/3	10.0-18.0	18.0-26.0	-	-	-	-
34(Furrow)/3	**Upper** 6.0-8.0 **Lower** 8.0-14.0	-	-	-	-	-
36/5	13.0-21.0	21.0-29.0	29.0-37.0	37.0-44.0	44.0-52.0	-
38/50	20.0-28.0	26.0-34.0	33.0-41.0	41.0-49.0	49.0-57.0	-
42/44	8.0-16.0	16.0-24.0	24.0-32.0	-	-	-
43/40	10.0-18.0	18.0-26.0	26.0-34.0	24.0-42.0	-	-
44/35	5.0-13.0	17.0-25.0	29.0-37.0	-	-	-
45/36	7.0-15.0	11.0-19.0	16.0-24.0	24.0-32.0	-	-
46/22	7.0-15.0	15.0-23.0	**Upper** 24.0-29.0 **Lower** 29.0-32.0	**Upper** 32.0-38.0 **Lower** 38.0-40.0	**Top left** 40.0-43.0 **Lower** 43.0-48.0	-
47/31	11.0-19.0	22.0-30.0	28.0-36.0	32.0-40.0	-	-
49/Outwith	3.0-11.0	**Upper** 11.0-15.0 **Lower** 15.0-19.0	**Upper** 19.0-22.0 **Lower** 22.0-27.0	-	-	-
50/Outwith	3.0-11.0	11.0-19.0	19.0-27.0	**Upper** 27.0-31.5 **Lower** 31.5-35.0	-	-
51/22	2.0-10.0	17.0-25.0	32.0-42.0	46.0-54.0	**Upper** 59.0-61.0 **Lower** 61.0-67.0	72.0-80.0
51(Furrow)/22	12.0-20.0	40.0-48.0	-	-	-	-
52/29	10.0-18.0	20.0-28.0	30.0-38.0	39.0-47.0	**Upper** 50.0-52.5 **Middle** 52.5-58.0 **Lower** 52.5-58.0	-
52(Furrow)/29	20.0-28.0	**Upper** 30.0-34.5 **Lower** 34.5-38.0	-	-	-	-
53/Outwith	(1) 2.0-10.0	10.0-18.0	**Upper** 18-19.5 **Middle** 19-22.5 **Lower** 21.5-25	26.0-34.0	-	-
54/45	5.0-13.0	15.0-23.0	22.0-30.0	32.0-40.0	-	-

Table 4.2 - Notation details and corresponding depth in profile for all 74 soil thin sections from Badentarbat. The location of each trench is illustrated in Figure 2.4.

degree of interpretation, otherwise nothing would ever be recorded under this category of pedofeatures. There are, therefore, still a number of potential problem areas which have still to be fully addressed and soil micromorphology remains a subjective technique, albeit with some controls.

The use of image analysis in soil micromorphology has made some attempt to reduce the subjectivity of this method (Bryant & Davidson, 1996; Bui, 1991; Torrentó & Solé-Benet, 1992; Terribile & Fitzpatrick, 1992; Terribile & Fitzpatrick, 1995; Tovey *et al*, 1992). It was hoped that image analysis could be used in this project to identify, quantify and measure certain features but prolonged problems with the hardware and software and the complex nature of the significant soil features in the thin sections made this goal impossible to achieve within the research period. Manual description of the slides, using the Handbook for Soil Thin Section Description (Bullock et al, 1985), was undertaken at two levels of detail.

All slides were described at the first level of description using a recording system devised and adapted from the Handbook and a recording system used by Simpson (see Simpson,~~(~~1997), p. 372 for an example). Analysis of the results from the first level of description identified certain features which may provide some evidence for different uses of the sampled soils. A selected range of slides representing as many field class types as possible was then described in more detail during the Level 2 description using a 1cm grid sampling method on each slide. This second level of description aimed to serve two purposes. Firstly, more detailed information on the features targeted from the Level 1 description was sought to aid the interpretation of their origin and use. Secondly, certain features had been identified from the Level 1 description as being significantly different between slides sampled from different field classes. The detailed grid system for description in the second level aimed to test whether this was still true at a more detailed level of inspection or whether within-slide variation became more significant at this detailed level of examination. The results of the comparison of the two levels of description should give an indication of the level of detailed observation required to obtain the necessary information for informed interpretation.

4.3 Level 1 Micromorphological Description

4.3.1 Method of Recording - Level 1

The system for soil thin section description given in the Handbook (Bullock *et al*, 1985) is necessarily very detailed and comprehensive. Using this system, the full description of a single slide takes an experienced micromorphologist several hours and may be even longer if more than one horizon is represented. However, this project aims to use soil micromorphological description for a very specific purpose - to look for evidence of past agricultural activity within the sampled soils- and it was thought to be more appropriate to describe a limited number of relevant features rather than spend time describing features which had not been shown by previous research to be of any great significance to agricultural activity. Previous studies have shown that certain features may be interpreted as indicating human influences in the development of the soil.

Studies of the effects of modern farming on the physical properties of soil have shown that soil porosity can either be reduced by modern ploughing and harrowing (Drees *et al*, 1994) or that the pore size distribution varies between tilled and untilled soils (Torrentó & Solé-Benet, 1992). Gebhardt (1992) has studied the effects of a range of different cultivation implements, including ancient tools such as ards and hoes, and different manuring practises on soil microstructure under experimental conditions. She concluded that different microstructures were produced by the different management techniques. Pedofeatures, such as clay coatings, have been interpreted as the product of mechanical transportation (Bullock *et al*, 1985) and are often recorded in cultivated soils (Jongerius, 1983). Microstructure, the nature of the groundmass b fabric and the related distribution of fine/coarse mineral material (c/f limit 10μm) was therefore recorded during this research as well as a wide range of pedofeatures including silty, limpid and pure clay coatings and infillings and amorphous and cryptocrystalline nodules, coatings and infillings. Although the inclusion of organic manures was not shown in Gebhardt's study to affect microstructure, it did result in an increase in organic fragments incorporated in the soil.

Ancient buried soils and plaggen soils have been found to contain organic inclusions such as enhanced quantities of coarse and fine organic matter, bone, charcoal, ash, seaweed and turf, which have been interpreted as indicative of anthropogenic manuring practises in the past (Courty *et al*, 1989; Dockrill &

Simpson, 1994; Pape, 1970; Shiel & Askew, 1986; Simpson, 1997). A range of organic material at various stages of humification was therefore included in the recording system along with fungal spores, charcoal and bone. Soils with enhanced organic matter content also show marked increases in faunal activity which are indicated by an increased abundance of mamillate and spheroidal excrement. These two parameters were also described and recorded in the Level 1 description. Mineral inclusions have also been identified in peaty plaggen soils in Ireland in the form of calcareous sand (Conry, 1969, 1971).

The practise of including sand in the manuring regime of the peaty soils at Badentarbat was considered likely, both because of the coastal location and because of evidence found in the historical literature for such practises being common in this area. It was thus thought important to record the presence of calcium carbonate and a range of minerals including quartz, feldspar, sandstone and siltstone and to describe the basic distribution of the coarse mineral material in each slide. The fine mineral material was also described in terms of its type, colour and limpidity to provide some information on the history and evolution of the soil with which to compare the coarse mineral material. A further inorganic material, this time of biological origin, has been found useful in interpreting and understanding past environmental conditions and is often associated with pastoral farming activities. Phytoliths are produced by the action of plant cells taking up silica. The formation of phytoliths is most common in the grasses, cereals and equisetaceous plants, although they do occur in lower concentrations in heath and tree species. They are frequently associated with domestic wastes (Courty *et al*,1 989). These were also recorded during the Level 1 description. Depletion pedofeatures may also provide some information about the environment under which the soil has developed.

Evidence of the loss of iron or manganese from the groundmass immediately lining pores and voids indicates that the soil may have been subjected to periodic and/or prolonged waterlogging. Such waterlogging currently occurs at Badentarbat and it was thought likely that such features may show varying abundances, especially between the peaty and sandy clay loam soils identified during the fieldwork. Depletion pedofeatures were thus recorded. A recording sheet was devised (Figure 4.1) along with a set of descriptive codes in order to speed up the recording process.

Several of the features were described in terms of their frequency within each slide. The frequencies were split into classes with a percentage range associated with each . Appendix 4 provides details of all codes used for recording the soil micromorphological data. The presence of textural pedofeatures was rare. However, on the rare occasions where they were identified, they always constituted less than 1% of the entire slide which was almost impossible to estimate accurately. Bullock *et al* (1985) suggest the use of a different scale of abundancy for textural pedofeatures from rare (<2%) to very abundant (>20%). However, as these features never constituted more than 1% of any slide, it was decided that it was more appropriate to define a set of categories which gave a means of comparing the relative abundance of textural pedofeatures between slides. These categories could not be quantified accurately and were therefore described merely in descriptive terms of frequency (Appendix 4).

Fine mineral material was defined as having a grain size of <10µm and was described in terms of type, colour and limpidity. Codes were allocated to the standard descriptive terms used in Bullock *et al* (1985) and are summarised in Appendix 4. The descriptions for the basic distribution of the coarse mineral material, nature of the groundmass b-fabric and the related distribution of the coarse and fine mineral material follow the Handbook guidelines (Bullock *et al*, 1985). The codes associated with each description are given in Appendix 4.

There are 22 types of microstructure detailed in the Handbook for Soil Thin Section Description (Bullock *et al*, 1985). This extensive list was reduced to the 15 types considered most likely to be present in the slides to be described and were coded as detailed in Appendix 4. The predominant type of each micromorphological parameter within a slide was recorded. It is acknowledged that there may be more than one type of related distribution within a single soil thin section but this would be recorded during the Level 2 descriptive work where a description of certain features within every second 1cm square on a grid placed over the slide would be recorded. This could then be compared with the more general level of description used during the Level 1 descriptive work to test the accuracy of soil thin section description at the less detailed level.

SECTION	SUB SECTION	COARSE MINERAL							FINE MINERAL			COARSE ORGANIC					FINE ORGANIC					PEDO FEATURES								MICROSTRUCTURE	BASIC DISTRIBUTION	GROUNDMASS B FABRIC	RELATED DISTRIBUTION
		QUARTZ	FELDSPAR	SANDSTONES	SILTSTONES	PHYTOLITHS	BONE	$CaCO_3$	TYPE	COLOUR	LIMPIDITY	FUNGAL SPORES	LIGNIFIED TISSUE	PARENCHYMATIC TISSUE	ORGAN RESIDUE	CHARCOAL	FUNGAL SPORES	AMORPHOUS (BLACK)	AMORPHOUS (YELLOW / ORANGE)	AMORPHOUS (REDDISH / BROWN)	CELL RESIDUE	SILTY CLAY COATINGS & INFILLINGS	CLAY COATINGS & INFILLINGS	LIMPID CLAY COATINGS & INFILLINGS	AMORPHOUS & CRYPTO - CRYSTALLINE NODULES	AMORPHOUS & CRYPTO - CRYSTALLINE COATINGS & INFILLINGS	EXCREMENT (MAMILLATE)	EXCREMENT (SPHEROIDAL)	DEPLETION				

Figure 4.1 - Example of recording sheet used during Level 1 description

Description of each slide took approximately forty-five minutes to one and a half hours, depending on the number of horizons represented, using this system of description and recording. The results were subsequently entered into a spreadsheet in the SPSS software package for statistical analysis.

4.3.2 Hierarchical Cluster Analysis - Level 1

Hierarchical Cluster Analysis (HCA) has already been discussed in Chapter 2 in relation to the analysis of the field data. Exactly the same methods were applied for the analysis of the Level 1 soil thin section description data and will not be repeated in detail in this chapter. Gower's coefficient of similarity was again calculated on the raw Level 1 data, using the methods described in Section 2.3.6, as it consisted of interval, nominal and ordinal data which could not be input directly into the HCA procedure to produce valid results. The similarity coefficients derived from the raw data were, therefore, used during the HCA process and the significant stages in the clustering process were identified using the methods explained in Section 2.3.7. Again, the subjectivity of this type of statistical analysis is a major criticism but the consistent approach adopted for the various stages of classification in this research project should enable valid comparisons to be made between the results obtained at each stage.

4.3.3 Statistical Analysis - Level 1

Although the statistical analysis of the field system classification results has been discussed earlier in Chapter 2, the Level 1 soil micromorphological data was actually the first set of data to be statistically analysed during this research. Many statistical tests require certain criteria to be met before the results obtained can be considered valid. The assumption that the data to be analysed has a normal distribution is the most common of these. Raw data with a non-normal distribution should, therefore, be manipulated to achieve a normal distribution pattern before applying the appropriate statistical test (Clarke, 1980). This may be achieved by applying a number of methods of data transformation - inversion, multiplying by a certain power and calculating the square root or natural logarithm being the most common. None of the raw data from the Level 1 descriptive work was normally distributed and no transformation method could be found to achieve a normal distribution for the raw data. Several days were spent trying to achieve this goal with no success.

Despite these problems, each variable was tested for any significant differences between both the field classes and the soil thin section classes obtained from the HCA procedures using a one-way analysis of variance (ANOVA) and the residuals stored, plotted and tested for normal distribution. Several variables were found to be significant at the 95% confidence interval. However, despite several of the residual plots appearing to produce fairly straight lines which may be regarded as demonstrative of normal distribution, the results from the Ryan-Joiner statistical test for normality were insignificant for all variables using a 95% confidence interval. Unfortunately, the computer was incapable of testing more than two variables at a time using the multivariate ANOVA test and this test was thus abandoned. Whilst it was acknowledged that these results were of no real statistical significance, lack of time dictated that decisions on the features to be further described in the Level 2 description work had to be made before any further statistical analysis could be attempted. These features were therefore selected using a combination of the one-way ANOVA results and the knowledge gained from previous studies (Chrystall, unpublished; Gebhardt, 1992; Conry, 1971; Simpson, 1997). The results of the Level 2 work and further post-hoc analysis of the Level 1 work was carried out at the end of the soil thin section description work using suitable distribution-free non-parametric statistics.

4.4 Level 2 Micromorphological Description

4.4.1 Method of recording - Level 2

From the analysis of the Level 1 data discussed in Section 4.4.3, a range of micromorphological features were selected which appeared to vary significantly between at least two classes from the field and/or Level 1 soil thin section classifications (Table 4.3).

Distinctive Micromorphological features from Level 1 description		
Badentarbat site only	**Boyken site only**	**Both sites**
Cell residue Related distribution Sand Quartz	Mamillate excrement Spheroidal excrement	Microstructure

Table 4.3 - Micromorphological features from the Level 1 descriptive work which are statistically significantly different (95% C.I.) between two or more Level 1 thin section and/or field classes, using one-way ANOVA.

The quantity of cell residue, mamillate and spheroidal excrement, sandstone and quartz was estimated to the nearest 5% in each 1cm square examined. The basic distribution of each of these features was also described. It was considered important to record the shape of the individual sandstone and quartz grains and their referred distribution to the soil surface. Differences in the shape of mineral grains is often used to help establish their origin and method of transport. Rounded grains are regarded as illustrative of transport by water whilst more angular grains may indicate aeolian transport. More rounded grains may also indicate prolonged *in-situ* disturbance by ploughing or digging. It was also thought that the distribution of these grains in relation to the soil surface may provide evidence of anthropogenic input and cultivation activity.

Evidence of increased bioturbation is often the only remaining evidence in ancient agricultural soils of past anthropogenic activity (Courty *et al*, 1989) but it was also considered possible that there was a relationship between the quantity of cell residue present in the soils and also the type of soil microstructure. This could be further explored and analysed at this detailed level of description. As discussed earlier, differences in microstructure and related distribution have been used as indicators of anthropogenic soil disturbance in many studies. It was, therefore, considered important to describe these features in greater detail in order to establish whether the variations identified between slides from different field classes during the Level 1 work was more distinct than variation between the 1cm grid squares described in each slide during Level 2 work. This was tested for all the parameters used in the Level 2 work.

Again, a set of codes and a spreadhseet were devised to speed recording (Figure 4.2) and the magnification at which each feature was to be described was determined. It took several attempts to find a suitable method of overlaying a grid pattern on the soil thin sections without affecting the optical properties of the features contained in the slide. The solution proved to be cheap, simple and effective. A piece of fish pond plastic mesh with a 1cm mesh size was cut to the size of the slides and secured using Blu-tac™. Each grid square with at least 50% of its area covering the soil sample was numbered consecutively from 1, starting at the top left corner across to the top right corner before moving down one square and continuing the numbering sequence to the left. Every second square was described for each soil feature and its depth in the soil profile recorded.

Note: % - To nearest 5%

Site:					Quartz (x40)				Sandstone(x40)			Cell residue (x100)		Mamillate Excrement (x20)		Spheroidal Excrement (x20)			
Field Class	Section	Sub section	Grid square	Depth from surface	%	Basic distribution	Referred (Surface)	Shape	%	Basic distribution	Referred (Surface)	%	Basic distribution	%	Basic distribution	%	Basic distribution	Microstructure (x20)	Related distribution (x20)

Basic Distribution:
0=None present
1=Random
2=Clustered
3=Linear
4=Banded
5=Fan-like
6=Interlaced

Referred Distribution:
0=None present
1=Unreferred
2=Perpendicular
3=Parallel
4=Inclined
5=Radial
6=Concentric

Shape:
1=Rounded
2=Sub-rounded
3=angular
4=Sub-angular

Microstructure:
As for Level 1

Related Distribution:
1=Monic
2=Gefuric
3=Chitonic
4=Enaulic
5=Close porphyric
6=Open porphyric

Figure 4.2 - Example of recording sheet used for Level 2 micromorphological description

The second level of description was carried out on a selection of slides which represented the different field classes at each site. As discussed in Section 4.1.2, several of the peaty thin sections from the Badentarbat site proved problematic to manufacture and had proved difficult to describe for certain small features such as phytoliths due to their over-thickness in places. The selection process for the Level 2 description therefore avoided the worst slides where possible, and all the thin sections taken from each selected trench were included. It was agreed that a maximum of 40-45 slides could be further described in the time available and that an approximately equivalent number from each site should be examined. Table 4.4 details the slides chosen for the Level 2 description.

Boyken			**Badentarbat**		
Field Class	**Slides**	**No. of Slides**	**Field Class**	**Slides**	**No. of Slides**
1	11/36A-C, 5/52A-D	7	0	49A-C	3
2	1/56A-E	5	1	36A-E, 44A-C	8
3	Not sampled	0	2	54A-D	4
4	26/30A-B	2	3	46A-E	5
5	Not sampled	0	4	1 Polygon only - not selected	0
6	13/22A-B	2	5	42A-C	3
7	22A-C, 30(1)A-B	5			
Total No. of Slides		21	Total No. of Slides		23

Table 4.4 - Soil thin sections selected for the Level 2 descriptive work. Note: Field Class 7 (Boyken) and Field Class 0 (Badentarbat) are areas outwith the field system.

4.4.2 Hierarchical Cluster Analysis - Level 2

The raw Level 2 data was treated in exactly the same way as the field system and Level 1 data. The raw data was entered into an SPSS spreadsheet and converted to similarity coefficients using Gower's Coefficient of Similarity equation written as a macro in the DOS version of Minitab. This proved to be a very long process, however, as each file contained approximately 420 cases. The Minitab spreadsheet had to be increased to the maximum size of 4,000,000 cells and it took approximately 12 hours each to run the Gower macro for the Boyken and Badentarbat Level 2 data. Huge output files for each site were also produced during the HCA procedure carried out in SPSS on the Level 2 data.

4.4.3 Statistical Analysis - Level 2

The Level 2 data was analysed in three different ways: 1) the Level 2 data was analysed for differences between the Level 2 groups obtained during the classification of the Level 2 data, 2) the Level 2 data was grouped by the Level 1 classification group memberships and analysed for any differences, and 3) the Level 2 data was grouped according to its membership of the field classification classes and analysed for any differences in the soil features between the different field classes. Each method of grouping the Level 2 data was analysed in the same way using the Kruskal-Wallis One-way Analysis of Variance by Ranks for multiple comparison between treatments for the ordinal and interval data and cross-tabulation using Chi-square tests for the nominal data as described in detail in Chapter 2, Section 2.3.8. These non-parametric statistical tests are distribution-free and were selected as the most appropriate statistical tests for analysing this data in consultation with Dr Kate Howie, a lecturer in statistics in the Mathematics Department. The mean and median for each class was also calculated to check for any obvious similarities or differences between the classes.

5. Level 1 Soil Micromorphological Description: Results and Analysis

5.1 Introduction

This chapter presents the analysis of the results of the Level 1 micromorphological description described in Chapter 4. The raw data is presented in Appendix 5. The analysis of the results and the associated interpretation for each site are dealt with separately in the first instance. The chapter concludes with a comparison of the results and interpretations for both sites (Figure 1.3). The objective of the analysis of the results is to determine whether quantitative statistical techniques can identify micromorphological features which can be shown to be associated with certain types of field class.

Fifty-two soil thin sections were produced and described from the Boyken site. Six of these slides either spanned two distinct soil horizons or contained areas of soil which were distinctly different to the rest of the sample. Each distinct region was therefore described separately. Seventy-four slides from Badentarbat were described during the Level 1 descriptive work. Fifteen of these slides contained more than one distinct soil region which resulted in a total of ninety-one individual descriptions. The data recorded from the Level 1 description were input into an SPSS spreadsheet which allowed the data to be coded and displayed using either the codes or the actual descriptions. This raw data is presented in code form in Appendix 2 for conciseness. The definitions of the codes are provided in Appendix 4. It is only possible to assign each variable an 8-digit name in SPSS and thus several of the parameters measured or described have had to be abbreviated. The full title of each parameter is given in the sample recording sheet shown as Figure 4.1 in Chapter 4 and the variables have been presented in the same order in the SPSS spreadsheet.

5.2 Analysis - Boyken

Five of the parameters described during the Level 1 description of the Boyken slides did not show any variation between the slides: the type of b-fabric, the basic distribution of coarse mineral content and the limpidity, colour and type of fine mineral material were found to be constant for all samples. These variables were therefore not used for the Hierarchical Cluster Analysis (HCA) of the Level 1 raw data. The results from the HCA procedure were analysed in a similar way to those for the field classification work described in Chapter 2, Section 2.3.8. Again, the coefficient jumps in the agglomeration schedule were ranked from the 1st to the 5th largest. These corresponded to the raw Level 1 data being grouped as 1, 2, 3, 5 and 8 groups, respectively. The first stage in the HCA procedure invariably produces the largest coefficient jump and was therefore disregarded. The second stage of the procedure led to the data being grouped as one very large group of 48 members and one with only 4 members. The third stage merely led to the splitting of the smaller group at stage two into two groups with 1 and 3 members, respectively. Although stage 4 split the large group of 48 members into 2 smaller groups, the agglomeration schedule showed that this stage produced only a very insignificant jump in coefficient. Stage 5 split the raw data into 5 groups with 3, 1, 12, 31 and 11 members in each respective group. Stage 8, which produced the 5th largest coefficient jump, split the data into 8 groups but 3 of these had only very small memberships of 1, 1 and 2, respectively. Such small groupings of the data are difficult to analyse statistically and it was felt that such a high proportion of the total groups having such a limited membership would prove very difficult to analyse for any differences using statistical tests. The field classification had identified 6 different types of field class for Boyken. Of these 6 classes, only 4 were sampled in the field as 2 of these classes contained only 1 member each. Samples taken from areas outwith the classified field system were allocated to an additional field class not included in the classification procedure, Field Class 7. The samples described during the Level 1 soil thin section description therefore came from 5 field class types. The 5 cluster solution to the HCA of the Level 1 raw data was thus selected for analysis and comparison with the field classification results. The slides which comprised each of these 5 groups are summarised in Table 5.1.

It is clear from Table 5.1 that the raw Level 1 data was not conveniently grouped according to the field class from which each sample came during the Hierarchical Cluster Analysis. It is therefore necessary to establish which parameters characterise each cluster in order to gain some understanding of the HCA process. Analysis of the data using the Kruskal-Wallis one-way analysis of variance by ranks to identify parameters which significantly differ (95% C.I.) between two or more classes showed that several parameters were important in the classification procedure. The two smaller clusters (1 and 2) were too small to provide any significant results apart from defining a difference between the organic

Level 1 Cluster	Slides grouped in Level 1 Cluster (Trench/Polygon No.)	Field Class from which soil sample was obtained
1	1/56A Upper & Lower left	Field Class 2
	19/47B	Field Class 3
2	1/56B	Field Class 2
3	1/56C Upper & Lower, 1/56D Upper & Lower, 1/56E, 6/10A,	Field Class 2
	5/52A&B, 29/52A&B	Field Class 3
	30(1)A&B	Field Class 7
4	13/22A Upper, Lower & B, 20/22A, 21/22A	Field Class 1
	6/10B-D, 8/38A, 27/38A&B	Field Class 2
	5/52C&D, 11/36A&B, 19/47A Upper & Lower, 28/47A	Field Class 3
	25/30A Upper and Lower, 26/30A&B	Field Class 5
	22A-C, 23(1)A&B, 23(2)A&B, 30(2)A&B	Field Class 7
5	20/22B, 21/22B	Field Class 1
	11/36C, 19/47C-F, 28/47B	Field Class 3
	25/30B&C	Field Class 5
	23(1)C	Field Class 7

Table 5.1 - Membership for the 5 cluster solution from the Hierarchical Cluster Analysis of the Level 1 raw data - Boyken Level 1. See Figure 3.5. for location of trenches.

residue content of the slides grouped in Clusters 1 and 3. Although none of the results from the cross-tabulation of the nominal data were statistically significant, some trends could be inferred from examination of the results. Observations could also be made by comparing the median of each parameter for every cluster and checking the validity of apparent differences by doing simple manual cross-tabulation and percentage calculations of the raw data.

From this range of analyses, it was possible to establish not only which parameters were significantly different between clusters in statistical terms but also to identify trends in the clustering where 50% or more of the members in a particular cluster displayed the same characteristic for a parameter which was different to one or more of the other clusters. Table 5.2 summarises the differentiating characteristics for each cluster. Table 5.3 gives the median for each cluster of all the micromorphological parameters which are measured for content by frequency class. Where an equally high number of cases are grouped under 2 frequency classes, the median is given as the midway point between the 2 classes, following basic arithmetic rules. This results in some medians not being whole integers which does not accord with the ordinal nature of the frequency classes, with each covering a range of percentage content. However, it does serve to highlight where a certain parameter may not be a distinguishing feature for only one cluster. The median depth in the soil profile of each cluster is also provided and shall be discussed in greater detail at the end of this section.

Level 1 Clusters - Boyken	Interval/Ordinal data	Nominal data
Cluster 1	Quartz Sandstone Siltstone Bone Amorphous black material Silty clay coatings	-
Cluster 2	Feldspar Sandstone Siltstone Bone Clay coatings Limpid clay coatings Amorph & cryptocrystalline coatings	Related distribution
Cluster 3	Organic residue Charcoal Amorphous black material Spheroidal excrement	Microstructure
Cluster 4	Organic residue Spheroidal excrement Depth	-
Cluster 5	Lignified tissue Parenchymatic tissue Organic residue Amorph red brown material Cell residue Mamillate excrement Spheroidal excrement Depletion pedofeatures	Microstructure

Table 5.2 - Micromorphological parameters identified from the Level 1 soil thin section description which characterise each cluster from the others - Boyken Level 2.

Clusters 1 and 2 contain 3 and 1 members, respectively. The differentiating parameters have therefore mainly been identified from examining the raw data and the medians for each cluster. It is clearly very easy to identify trends when dealing with such small numbers. However, apparent trends for a specific parameter in these small clusters were always compared with the larger clusters and only parameters which showed a distinct difference to all other clusters have been included. These small clusters appear to be predominantly distinguished from the others by their mineral content.

Cluster 1

The slides grouped in Cluster 1 only show a statistically significant difference in organic residue content when compared with Cluster 3. However, the cluster medians for this parameter in Table 5.3 suggest that the organic residue content of the slides in Cluster 1 is very similar to that in Clusters 2 and 5, as they all have a median of 0 (0%). Simple cross-tabulation of the organic residue data

	Medians per Level 1 cluster (Frequency class)				
Level 1 micromorphological parameters measured by content	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Quartz	6	6	5	5	5
Feldspar	1	3	1	1	1
Sandstone	4	5	3	3	3
Siltstone	4	5	3	2	3
Phytolith	1	0	1	1	1
Bone	1	1	0	0	0
$CaCO_3$	0	0	1	1	1
Multi-cell fungal spore	1	1	1	1	1
Lignified tissue	1	0	1	1	0
Parenchymatic tissue	2	1	2	2	1
Organic residue	0	0	2	1	0
Charcoal	0	1	0.5	0	0
Single cell fungal spore	1	1	1	1	1
Amorphous black material	4	3	2.5	1	1
Amorphous yellow orange material	1	1	1	1	1
Amorphous red brown material	2	1	1	1	0
Cell residue	2	1	2	2	1
Silty clay coatings	1	1	0	0	0
Clay coatings	0	2	0	0	0
Limpid clay coatings	0	2	0	0	0
Amorph. & cryptocrystalline nodules	3	3	2	2	2
Amorph. & cryptocrystalline coatings	1	3	1	1	1
Mamillate excrement	3	4	3	3	2
Spheroidal excrement	2	2	3.5	3	1
Depletion	0	1	1	0	1
Depth (cm)	30	40	15	7	24

Table 5.3 - Cluster medians for interval/ordinal data from Level 1 descriptions - Boyken

confirms this but if the proportion of slides in each cluster which have an organic residue content which corresponds to frequency classes 1 and above is calculated, then we see that a smaller proportion of the Cluster 1 slides meet this criterion. This is by no means conclusive evidence, however, when such a small sample is being considered.

	No. of slides per frequency class of organic residue content				
Level 1 Clusters	0 (0%)	1 (1%)	2 (1-5%)	3 (5-15%)	% slides with >0% organic residue
Cluster 1	2	1	0	0	33
Cluster 2	1	0	0	0	0
Cluster 3	0	1	9	2	100
Cluster 4	8	19	4	0	74
Cluster 5	6	5	0	0	45

Table 5.4 - Cross-tabulation of organic residue data - Boyken Level 1.

Although no other micromorphological parameters for Cluster 1 are statistically different to the other clusters, slides grouped in Cluster 1 can be shown to contain higher quartz, sandstone and siltstone contents than Clusters 3, 4 and 5 from simple cross-tabulation (Tables 5.5-5.7).

	No. of slides per frequency class of quartz content			
Level 1 Clusters	**4 (15-30%)**	**5 (30-50%)**	**6 (50-70%)**	**% slides with >50% quartz**
Cluster 1	0	1	2	67
Cluster 2	0	0	1	100
Cluster 3	2	8	2	17
Cluster 4	1	30	0	0
Cluster 5	0	9	2	18

Table 5.5 - Cross-tabulation of quartz content data - Boyken Level 1.

Two of the three slides in Cluster 1 are in frequency class 6 (50-70%) for quartz content. This is a much higher proportion than for Clusters 3, 4 and 5 but the only slide grouped in Cluster 2 also has the same quartz content.

	No. of slides per frequency class of sandstone content				
Level 1 Clusters	**2 (1-5%)**	**3 (5-15%)**	**4 (15-30%)**	**5 (30-50%)**	**% slides with >15% sandstone**
Cluster 1	0	1	2	0	67
Cluster 2	0	0	0	1	100
Cluster 3	5	6	0	1	8
Cluster 4	12	9	10	0	32
Cluster 5	3	8	0	0	0

Table 5.6 - Cross-tabulation of sandstone content data - Boyken Level 1.

Similarly, two of the three Cluster 1 slides have a sandstone frequency of 4 (15-30%). However, both Clusters 2 and 3 have slides which have been described as containing 30-50% sandstone fragments (Frequency Class 5).

	No. of slides per frequency class of siltstone content					
Level 1 Clusters	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**4 (15-30%)**	**5 (30-50%)**	**% slides with >15% siltstone**
Cluster 1	0	0	0	2	1	100
Cluster 2	0	0	0	0	1	100
Cluster 3	2	3	6	1	0	8
Cluster 4	5	11	7	8	0	26
Cluster 5	0	3	7	1	0	9

Table 5.7 - Cross-tabulation of siltstone content data - Boyken Level 1.

None of the Cluster 1 slides have a siltstone frequency less than class 4 (15-30%). In comparison, the siltstone content of the majority of the slides in Clusters 3-5 is no greater than 15% (Frequency Class 3). Again, it is only the single slide in Cluster 2 which has an equally high siltstone content.

Cluster 1 contains the only slides which contain 15-30% (Frequency class 4) of amorphous black material. All other slides contain less than 15% (Table 5.8). This is reflected in the cluster medians for this parameter shown in Table 5.3.

	No. of slides per frequency class of amorphous black material content				
Level 1 Clusters	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**4 (15-30%)**	**% slides with >5% amorphous black material**
Cluster 1	1	0	0	2	67
Cluster 2	0	0	1	0	100
Cluster 3	1	5	6	0	50
Cluster 4	26	5	0	0	0
Cluster 5	11	0	0	0	0

Table 5.8 - Cross-tabulation of amorphous black material - Boyken Level 1.

Cluster 2

No statistically significant results were obtained from a comparison of this cluster with any other because of the small size of Cluster 2. However, several observations can be made from the cross-tabulation of various micromorphological parameters. Whilst the single slide in Cluster 2 has a similar quartz content to those in Cluster 1 (Table 5.5), it also contains the highest recorded sandstone (Table 5.6), siltstone (Table 5.7) and feldspar (Table 5.8) content of any of the 56 slides described.

	No. of slides per frequency class of feldspar content				
Level 1 Clusters	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**% slides with >5% feldspar**
Cluster 1	1	2	0	0	0
Cluster 2	0	0	0	1	100
Cluster 3	0	12	0	0	0
Cluster 4	1	29	1	0	3
Cluster 5	0	10	1	0	9

Table 5.9 - Cross-tabulation of feldspar content data - Boyken Level 1.

Similarly, this slide also contains the highest recorded content of pure and limpid clay coatings and amorphous and cryptocrystalline coatings (Tables 5.10-5.12, respectively). These characteristics are reflected in the related distribution of the fine and coarse mineral material in this slide which is described as gefuric. Again, this is the only slide to be described with this type of related distribution at Boyken.

	No. of slides per frequency class of pure clay coating content			
Level 1 Clusters	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**% slides with >0% pure clay coating**
Cluster 1	2	1	0	33
Cluster 2	0	0	1	100
Cluster 3	11	1	0	8
Cluster 4	31	0	0	0
Cluster 5	9	2	0	18

Table 5.10 - Cross-tabulation of pure clay coating content data - Boyken Level 1.

	No. of slides per frequency class of limpid clay coating content			
Level 1 Clusters	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**% slides with >0% limpid clay coating**
Cluster 1	2	1	0	33
Cluster 2	0	0	1	100
Cluster 3	12	0	0	0
Cluster 4	31	0	0	0
Cluster 5	10	1	0	9

Table 5.11 - Cross-tabulation of limpid clay coating content data - Boyken Level 1.

	No. of slides per frequency class of amorphous & cryptocrystalline coating content				
Level 1 Clusters	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**% slides with >1% amorph. & cryptocrystalline coatings**
Cluster 1	0	2	1	0	33
Cluster 2	0	0	0	1	100
Cluster 3	5	7	0	0	0
Cluster 4	7	23	1	0	3
Cluster 5	5	5	1	0	9

Table 5.12 - Cross-tabulation of amorphous & cryptocrystalline coating data, Boyken Level 1.

Clusters 1 and 2 also include 3 of the 4 slides which contain traces of bone. The fourth slide is located in Cluster 3. However, none of these slides contain more than 1% of this micromorphological feature.

Cluster 3

Six of the twelve slides grouped in Cluster 3 contain 5-15% of amorphous black material (Table 5.8). This represents two thirds of the total number of slides from the Boyken site which also record this level of amorphous black material. The others are grouped in Clusters 1 and 2. The Kruskal-Wallis one-way analysis of variance by ranks test results indicate that the amorphous black material content of the slides in Cluster 3 are statistically different from those grouped in Clusters 4 and 5. This appears to be supported by the cluster median results in Table 5.3.

Similarly, 50% of the slides in Cluster 3 contain a trace (up to 1%) of charcoal fragments (Table 5.13). Although this parameter is not shown by the Kruskal-Wallis test results to be significantly different to any other clusters, these cases do represent 43% of the total number of slides from the Boyken site which are described as containing charcoal fragments. This may indicate that charcoal content is one of a group of parameters used to differentiate this cluster from the others.

	No. of slides per frequency class of charcoal content		
Level 1 Clusters	0 (0%)	1 (1%)	% slides with >0% charcoal
Cluster 1	2	1	33
Cluster 2	0	1	100
Cluster 3	6	6	50
Cluster 4	26	5	16
Cluster 5	11	0	0

Table 5.13- Cross-tabulation of charcoal content data - Boyken Level 1.

Cluster 3 also contains the highest amounts of organic residue which make it statistically different (95% C.I.) to Clusters 1, 4 and 5 using the Kruskal-Wallis one-way analysis of variance by ranks test. These findings are supported by the cluster median data (Table 5.3) as Cluster 3 has a cluster median of 2 (1-5%) for organic residue content compared to 1 (1%) for Cluster 4 and 0 (0%) for Clusters 1, 2 and 5. The cross-tabulation data provides further evidence to support the Kruskal-Wallis test results (Table 5.4). From Table 5.4, it can be shown that Cluster 3 is the only cluster where all the cases contain at least a trace (1%) of organic residue.

Examination of the medians of spheroidal excrement content between clusters (Table 5.3) reveals that Cluster 3 contains the highest amount of this micromorphological feature but it is not statistically different to the spheroidal excrement content of the slides in Cluster 1, 2 and 4. It is, however, found to differ significantly (95% C.I.) from the slides in Cluster 5. This finding can be further explored by checking the raw spheroidal excrement data using simple cross-tabulation. The results in Table 5.14 show that Cluster 3 does, indeed, have the highest proportion of cases with a spheroidal excrement content greater than 5%. However, Cluster 4 contains the only slide which has a recorded spheroidal excrement content of 6 (50-70%) and it has the second highest percentage of cases with >5% content of this pedofeature. This confirms that the Kruskal-Wallis test results are valid. The low spheroidal excrement content of the single slide in Cluster 2 produces the greatest difference between Cluster 3 and any other cluster but this cannot be regarded as statistically valid due to the very small size of Cluster 2.

	No. of slides per frequency class of spheroidal excrement content							
Level 1 Clusters	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**4 (15-30%)**	**5 (30-50%)**	**6 (50-70%)**	**% slides with >5% spheroidal excrement**
Cluster 1	1	0	1	1	0	0	0	33
Cluster 2	0	0	1	0	0	0	0	0
Cluster 3	0	1	1	4	2	4	0	83
Cluster 4	0	2	10	9	8	1	1	61
Cluster 5	4	2	4	1	0	0	0	9

Table 5.14 - Cross-tabulation of spheroidal excrement content data - Boyken Level 1.

Seven of the twelve slides in Cluster 3 are also described as having a subangular blocky microstructure. Whilst this type of microstructure is not unique to this cluster, it is the only cluster in which >50% of the members display this characteristic. However, this merely represents 30% of the total number of slides from the Boyken site which have a subangular blocky structure and cannot be taken as conclusive evidence for this being an important factor in the grouping of the slides in Cluster 3.

Cluster 4

Cluster 4 is the largest cluster which groups 31 of the 58 descriptions together. It can be observed from the cluster medians (Table 5.3), that this cluster contains the second highest amount of organic residue. However, the statistical analysis of this parameter shows that the quantity of organic residue in Cluster 4 is only statistically different to that of Cluster 3. This would suggest that the organic residue content of the slides in Cluster 4 is closer to that of Cluster 5 than to Cluster 3, rather than being midway between the two which is what may be assumed from preliminary examination of the median data. The cross-tabulation of the organic residue content data given in Table 5.4 shows that Clusters 4 and 5 have fairly similar distribution patterns. However, the percentage of slides in each of these clusters with >0% organic residue differs by 29%, compared to only a 26% difference between Clusters 3 and 4. This obviously casts doubt on the Kruskal-Wallis test results but some evidence that these results may be valid can be obtained by considering the percentage of cases in each cluster which contain more than 1% organic residue rather than the previously calculated 0% threshold (Table 5.15). From this calculation, it can be seen that there is a 79% difference between the values for Clusters 3 and 4, compared to a difference of only 13% between Clusters 4 and 5.

Percentage of slides per Level 1 cluster containing >1% organic residue				
Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
0	0	92	13	0

Table 5.15 - Difference in Level 1 clusters with >1% organic residue - Boyken.

The opposite seems to be true for spheroidal excrement content. It would appear that the spheroidal excrement content of slides in Clusters 3 and 4 are quite similar and cannot be distinguished as being statistically different. However, a statistically significant difference can be detected between Clusters 4 and 5. This finding is supported by the cluster median results given in Table 5.3 and the percentage of slides per cluster which contain >5% spheroidal excrement given in Table 5.14. From Table 5.14, it can be shown that there is a 52% difference between Clusters 4 and 5 and only a 22% difference between the spheroidal excrement content of Clusters 3 and 4.

Cluster 5

The slides grouped in Cluster 5 contain the least amounts of lignified tissue, with only 2 of the 11 slides containing any at all (Table 5.16). The amount of lignified tissue in the slides grouped in Cluster 5 differs significantly (95% C.I.) to that of the slides in Clusters 3 and 4. From Table 5.16 it can be shown that, although not found to be statistically significantly different to Cluster 5, Cluster 2 has 67% of its cases containing 1% of lignified tissue. This percentage value is much closer to that for Clusters

3 and 4 than to the value of 18% for Cluster 5. The single slide in Cluster 2 also contains no lignified tissue but cannot be used as conclusive evidence for rejecting lignified tissue content as a significant factor used in the clustering procedure. The 9 slides in Cluster 5 which contain no lignified tissue represent 60% of the total number of slides from Boyken which meet this criterion.

	No. of slides per frequency class of lignified tissue content			
Level 1 Clusters	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**% slides with >0% lignified tissue**
Cluster 1	1	2	0	67
Cluster 2	1	0	0	0
Cluster 3	0	9	3	100
Cluster 4	4	20	7	87
Cluster 5	9	1	1	18

Table 5.16 - Cross-tabulation of lignified tissue content data - Boyken Level 1.

The slides in Cluster 5 also contain the least amounts of parenchymatic tissue, spheroidal excrement and mamillate excrement which are found to be significantly different (95% C.I.) to Clusters 3 and 4 for all parameters. The cluster medians for each of these parameters is given in Table 5.3. From this, it can be seen that Clusters 2 and 5 actually have similar cluster medians of 1 (1%) for parenchymatic tissue content. It also shows that Clusters 1, 3 and 4 all have a cluster median of 2 (5-15%) for parenchymatic tissue content. This would suggest that Cluster 1 should also significantly differ from Cluster 5 for this parameter. However, simple cross-tabulation of the data again reveals differences and similarities between the clusters which cannot be ascertained from cluster medians alone (Table 5.17). The information provided in this table shows that Clusters 1, 2 and 5 do not contain any slides which have a parenchymatic tissue content >5%. In comparison, 25% and 29% of the slides in Clusters 3 and 4, respectively, contain >5% parenchymatic tissue.

	No. of slides per frequency class of parenchymatic tissue content						
Level 1 Clusters	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**4 (15-30%)**	**5 (30-50%)**	**% slides with >5% parenchymatic tissue**
Cluster 1	0	1	2	0	0	0	0
Cluster 2	0	1	0	0	0	0	0
Cluster 3	0	0	9	1	0	2	25
Cluster 4	0	4	18	8	1	0	29
Cluster 5	3	8	0	0	0	0	0

Table 5.17- Cross-tabulation of parenchymatic tissue content data - Boyken Level 1.

The cluster medians for spheroidal excrement data appear to confirm that Cluster 5 contains the least amounts of spheroidal excrement and that Clusters 3 and 4 show the greatest difference to the value for Cluster 5. The cross-tabulation results given in Table 5.14, however, do not completely support the findings from the Kruskal-Wallis statistical tests. From this table, it can be shown that Cluster 1 also has a considerable proportion (33%) of its cases with >5% spheroidal excrement content which suggests that a comparison between Clusters 1 and 5 should also give a statistically significant result. However, if the threshold is raised to >15%, then it can be shown that none of the slides grouped in Clusters 1, 2 and 5 contain this level of spheroidal excrement compared to 50% and 32% of the slides in Clusters 3 and 4, respectively (Table 5.18).

Percentage of slides per Level 1 cluster containing >15% spheroidal excrement				
Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
0	0	50	32	0

Table 5.18 - Difference in clusters with >15% spheroidal excrement - Boyken Level 1.

The mamillate excrement content of the slides grouped in Cluster 5 is found to differ significantly from that of Clusters 3 and 4. Once again, the cluster median data in Table 5.3 suggests that Cluster 1 should also show a statistically significant difference for this parameter as it has the same median value as Clusters 3 and 4. Similarly, the single slide in Cluster 2 has the highest cluster median value of 4 (15-30%) which would prove significant if the membership of this cluster were greater. Recourse to the cross-tabulation of the mamillate excrement data provides enough detailed information to establish that the Kruskal-Wallis test results may be accepted (Table 5.19). Calculations of the percentage of slides per cluster which contain >1% of mamillate excrement shows that there is a 30% difference between the values for Clusters 4 and 5 and a 36% difference between Clusters 3 and 5. This compares with only a 3% difference between Clusters 1 and 5. The values for Clusters 2 and 5 also give a difference of 36% but the small size of Cluster 2 makes it difficult to accept this as conclusive evidence.

The slides which contain the least organic residue, amorphous red brown material and cell residue are also grouped in Cluster 5. However, Cluster 5 is only found to differ significantly in organic residue content from Cluster 3 from the Kruskal-Wallis test results. This is supported by the cluster median results in Table 5.3, although the proportions of each cluster which contain >0% and >1% organic residue detailed in Tables 5.4 and 5.15 also appear to show that there is a substantial difference in the values for Clusters 4 and 5, too. However, if the cross-tabulation is further scrutinised, it can be seen that Cluster 3 is the only cluster to have any slides with an organic content of 5-15%. This may be the reason for the Kruskal-Wallis results.

	No. of slides per frequency class of mamillate excrement content					
Level 1 Clusters	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**4 (15-30%)**	**5 (30-50%)**	**% slides with >1% parenchymatic tissue**
Cluster 1	1	0	1	0	1	67
Cluster 2	0	0	0	1	0	100
Cluster 3	0	2	5	5	0	100
Cluster 4	2	9	17	1	2	94
Cluster 5	4	6	1	0	0	64

Table 5.19 - Cross-tabulation of mamillate excrement content data - Boyken Level 1.

Again, there is only found to be a significant difference between the content of amorphous red brown material in Clusters 3 and 5. However, the cluster median results (Table 5.3) suggest that there should also be a significant difference between Cluster 5 and Clusters 1, 2 and 4, given that the medians for the latter three clusters are 2 (1-5%), 1 (1%) and 1 (1%), respectively. Cluster 3 also has a median of 1 (1%) and Cluster 5 of 0 (0%). Cross-tabulation of the data does not provide conclusive evidence to support the Kruskal-Wallis results either (Table 5.20). The biggest difference in the percentage of cases in each cluster which contain >1% amorphous red brown material is between Clusters 2 and 5 (67%). Given that a comparison of Cluster 1 with Cluster 3 produced a statistically significant result for organic residue content, it could be assumed that Cluster 1 contains sufficient members to make a valid statistical comparison using the Kruskal-Wallis one-way analysis of variance by ranks test for all parameters. However, this does not appear to be the case. The results of this test must, therefore, be regarded with caution. However, the observation can be made from the cross-tabulation of the amorphous red brown material data that over 50% of the slides grouped in Cluster 5 contain no amorphous red brown material. In comparison, none of the slides in Clusters 1-3 contain any amorphous red brown material and only 22% of the slides in Cluster 4 contain 0% of this feature.

Level 1 Clusters	No. of slides per frequency class of amorphous red brown material content 0 (0%)	1 (1%)	2 (1-5%)	% slides with >1% amorphous red brown material
Cluster 1	0	1	2	67
Cluster 2	0	1	0	0
Cluster 3	0	8	4	33
Cluster 4	7	21	3	10
Cluster 5	6	5	0	0

Table 5.20 - Cross-tabulation of the amorphous red brown material content data - Boyken Level 1.

The cell residue content of Cluster 5 is only found to differ significantly from Clusters 3 and 4. Again, from the cluster median data, it appears that Cluster 1 should also therefore be significant as it has the same cluster median of 2 (1-5%) as Clusters 3 and 4. However, from the cross-tabulation data (Table 5.21), it can be seen that Clusters 1, 2 and 5 contain no slides which have a cell residue content of 3 (5-15%). The Kruskal-Wallis test results may, therefore, be considered valid.

Level 1 Clusters	No. of slides per frequency class of cell residue content 0 (0%)	1 (1%)	2 (1-5%)	3 (5-15%)	% slides with >5% cell residue
Cluster 1	0	1	2	0	0
Cluster 2	0	1	0	0	0
Cluster 3	0	2	9	1	8
Cluster 4	0	11	16	4	13
Cluster 5	1	9	1	0	0

Table 5.21 - Cross-tabulation of the cell residue content data - Boyken Level 1.

The amount of depletion pedofeatures contained in the slides in Cluster 5 are found to differ significantly to that contained in the slides from Cluster 4. The cluster median results (Table 5.3) would again suggest that there should also be a significant difference between Clusters 1 and 5 as Cluster 1 has the same median as Cluster 4. This also appears to be the case when the cross-tabulation results are examined and the percentage of slides in each cluster which contain >0% of depletion features is calculated (Table 5.22). The difference in percentage values between Clusters 1 and 5 is 49% compared with 47% for a similar comparison of Clusters 4 and 5. It can, therefore, merely be noted that Cluster 5 has the highest proportion of slides (4 out of 11) with a 5-15% (Frequency class 2) content of depletion features. Only one other slide from the Boyken samples demonstrates this frequency of depletion features. This may indicate that the relatively high frequency of depletion features in the slides in Cluster 5 is an important factor used to differentiate this cluster from the others.

	No. of slides per frequency class of depletion pedofeature content			
Level 1 Clusters	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**% slides with >0% depletion pedofeatures**
Cluster 1	2	1	0	33
Cluster 2	0	1	0	100
Cluster 3	5	7	0	58
Cluster 4	20	10	1	35
Cluster 5	2	5	4	82

Table 5.22 - Cross-tabulation of depletion pedofeature content data - Boyken Level 1.

Ten out of the 11 slides grouped in Cluster 5 also have a spongy microstructure. Although this merely represents 38% of the total number of slides from Boyken with this type of microstructure, it may be one of the parameters used to distinguish the slides in this cluster from all others.

Depth in soil profile

The depth of each slide from the surface of the soil profile was also recorded during the Level 1 description work. However, this was not entered as a parameter for consideration during the HCA procedure. It was, nevertheless, considered possible from a knowledge of general soil properties, that the differentiating characteristics used to define each cluster may be associated with the depth of the described samples in the soil profile. The homogeneous nature of the soils across the Boyken site was considered a possible controlling factor which may allow differences in micromorphological features associated with depth in the profile to be more important in the clustering process than those associated with different soil types. The recorded depth data was, therefore, analysed in the same manner as the other micromorphological parameters in order to check for any possible relationship between the cluster characteristics and the depth from which the slides came in the soil profile.

The Kruskal-Wallis one-way analysis of variance by ranks test only gave a statistically significant result, at the 95% confidence level, between Clusters 4 and 5. The median depth of each cluster was also calculated and is given at the bottom of Table 5.3 in centimetres. Again, the small cluster sizes of Clusters 1 and 2 presents problems for analysis of this kind. The three slides grouped in Cluster 1 come from depths of 10cm, 30cm and 30.5cm. This appears to provide little evidence to support the theory that the characteristics used to cluster this group of slides together are associated with the sampling depth in the soil profile. The single slide grouped in Cluster 2 comes from a depth of 40cm in Trench 19 in Polygon 47. The only other slide to come from a similar depth is grouped in Cluster 5 and comes from 44.5cm below the surface of Trench 1 in Polygon 56. A comparison of the recorded characteristics for these 2 slides shows there to be little correlation between the two sets of data. However, the soil sampled in Trench 19 comes from a sealed location under the boundary dyke of Polygon 47 and is the only example of an illuviated podzol found and sampled from the Boyken site. It is, therefore, not surprising that there are few similarities in the micromorphological properties of these 2 slides, despite coming from similar depths.

The 12 slides grouped in Cluster 3 all come from 23cm depth or above in the sampled soil profiles with 50% coming from 15cm or above. Although no significant difference was found between the depth data for this cluster and any other, this observation may provide some clues for the existence of certain characteristics in these slides and their subsequent clustering during the HCA process.

The slides grouped in Cluster 4 are generally found to be samples taken from the highest regions of the soil profiles (Table 5.23). Whilst a statistically significant difference in depth was only found between Clusters 4 and 5, the median depth for Cluster 4 is 7cm compared to 30cm for Cluster 1, 40cm for Cluster 2, 15cm for Cluster 3 and 24cm for Cluster 5. Cluster 4 is, however, the largest cluster with 31 members and the depth range of the described sections in this cluster is 0-35cm. Closer examination of the raw data, nevertheless reveals that, of the 31 descriptions comprising this group, only 3 come from sections taken below a depth of 17.5cm and 17 of the slides are from 8.5cm depth and above. It may be that some relationship can be suggested between certain parameters and the depth in the profile from which the sample originates.

The slides in Cluster 5 cover a 15-44cm depth range with six of the eleven slides in this group taken from 18-26.5cm. This gives rise to the median of 24cm for this cluster (Table 5.3). Only one slide comes from a depth of <18.0cm and the slide taken from a depth of 44cm is the deepest sample from

	No. of slides in each depth range from the surface of soil profile (cm)					
Level 1 Clusters	0-8.5	9.0-17.5	18.0-26.5	27.0-35.5	36.0-44.5	% slides at >17.5cm depth
Cluster 1	0	1	0	2	0	67
Cluster 2	0	0	0	0	1	100
Cluster 3	3	4	5	0	0	42
Cluster 4	17	11	0	3	0	10
Cluster 5	0	1	6	3	1	91

Table 5.23 - Cross-tabulation of depth data - Boyken Level 1.

the entire Boyken site. With the exception of the single slide in Cluster 2, therefore, Cluster 5 has the highest proportion of slides at a depth of >17.5cm.

A summary table is provided to indicate the relative amounts and type of each parameter which appears to have been used to create each cluster. Only the nominal characteristics, such as microstructure, which show a substantial clustering of one type in one cluster are indicated. As discussed above, not all of the relative differences in micromorphological feature content between clusters are statistically significant but it is considered a useful point of reference for the differences between the clusters and for assessing which parameters have been used most in the hierarchical cluster analysis procedure. Eight parameters which were recorded are not included in this table as they did not show sufficient variability to feature in the clustering process. These micromorphological parameters are: phytolith, bone, $CaCO_3$, multi-cell and single-cell fungal spore content, silty clay coatings and frequency of amorphous and cryptocrystalline nodules.

From the evidence provided and on the basis of what is a detailed "deconstruction" of the classification, Clusters 1 and 2 appear to be characterised by a high mineral content. They also contain evidence of disturbance in the form of amorphous material, and both clay and amorphous and cryptocrystalline coatings. The particularly high mineral content of the slide grouped in Cluster 2 has resulted in a gefuric related distribution which is unique amongst the Boyken samples. Cluster 3 contains slides with high amounts of organic material and spheroidal excrement and a substantial number of these slides also contain traces of charcoal. Cluster 4 contains moderate amounts of organic residue and spheroidal excrement and a large proportion of the slides come from shallow depths in the soil profiles. The slides grouped in Cluster 5 contain the least amounts of organic material and both spheroidal and

Micromorphological parameters	Differentiating characteristics per Level 1 cluster - Boyken				
	Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
Quartz	2nd highest	Highest	2nd lowest (≅5)	Lowest	3rd lowest (≅3)
Feldspar	Lowest	Highest	2nd lowest	3rd lowest	2nd highest
Sandstone	2nd highest	Highest	2nd lowest	3rd lowest	Lowest
Siltstone	2nd highest (≅5)	Highest (≅1)	Lowest (≅5)	3rd lowest	2nd lowest (≅3)
Lignified tissue	3rd highest	Lowest	Highest	2nd highest	2nd lowest
Parenchymatic tissue	3rd lowest	2nd lowest	2nd highest	Highest	Lowest
Organic residue	2nd lowest	Lowest	Highest	2nd highest	3rd lowest
Charcoal	3rd highest	Highest	2nd highest	2nd lowest	Lowest
Amorphous black material	Highest	2nd highest	3rd highest	3rd lowest	Lowest
Amorphous red brown material	Highest	2nd lowest	2nd highest	3rd highest	Lowest
Cell residue	3rd highest	2nd lowest	2nd highest	Highest	Lowest
Pure clay coatings	2nd highest	Highest	2nd lowest	Lowest	3rd highest
Limpid clay coatings	2nd highest	Highest	Lowest (=4)	Lowest (=3)	3rd highest
Amorphous & cryptocrystalline coatings	2nd highest	Highest	Lowest	2nd lowest	3rd lowest
Mamillate excrement	2nd lowest	Highest (≅3)	2nd highest(≅2)	3rd highest	Lowest
Spheroidal excrement	3rd highest	Lowest	Highest	2nd highest	2nd lowest
Depletion pedofeatures	Lowest	2nd highest	3rd highest	2nd lowest	Highest
Microstructure	-	-	Subangular blocky	-	Spongy
Related distribution	-	Gefuric	-	-	-
Depth	3rd deepest	Deepest	2nd shallowest	Shallowest	2nd deepest

Table 5.24 - Summary of differentiating characteristics of each Level 1 cluster - Boyken. Note: The ordinal data is presented for each cluster relative to the others. Some parameters have similar values in 2 clusters. The cluster with the similar value for that parameter is given in round brackets. Only the nominal characteristics which show a large grouping either per cluster and/or in terms of the site total for that characteristic are shown.

mamillate excrement whilst a very high proportion contain evidence of depletion and have a spongy microstructure.

5.3 Interpretation of Level 1 Results - Boyken

The interpretation of the Boyken samples is made simpler by the fact that there is one soil type found across the site. Freely draining brown soils showing some evidence of podzolization dominate this area. The evidence for podzolization does not generally include the presence of an Ea horizon, except in the case of the profile described and sampled from Trench 19 situated across the boundary bank of Polygon 47 (Figure 2.5), and there is very little variability in the colour of the A horizon. The 1:250,000 Soil Survey of Scotland map describes the soils in this area as brown forest soils from the Ettrick association derived from the drifts of Lower Palaeozoic greywackes and shales. The high content of shale in the soils and the shallow nature of the soil horizons suggest that this soil is not particularly well developed and may not yet have reached a dynamic equilibrium with the surrounding environment (Bridges, 1978). Although all the slides demonstrate a substantial mineral content, the three slides grouped in Clusters 1 and 2 during the Level 1 HCA have particularly high mineral contents.

The 2 slides grouped in Cluster 1 come from very different contexts. Slide 1/56A is taken from the Ap horizon at a depth of 30-38.5cm in Polygon 56. This polygon is a small rectangular area with distinct rig and furrow adjacent to a settlement structure (Figure 2.5) which was interpreted during the archaeological excavation as a garden plot. The second slide in this cluster, slide 19/47B, comes from a trench put across the soil boundary bank of polygon 47. The purpose of this trench was to sample what may be the natural soil of this area as it was sealed underneath the oldest boundary bank in this upper complex of polygons. The profile exposed in this trench provided the only evidence of a true podzol with a distinct Ea horizon. The area surrounding this trench was the wettest on site and marshy, sedge-dominated vegetation was rapidly colonising the area. The early stages of peat formation were also evident with a thin iron pan identified at 5cm depth in the profile.

Although these 2 slides come from very different contexts, they are both characterised by their relatively high mineral content and the presence of clay coatings. The presence of clay coatings indicates that there has been some translocation of the fine soil fraction. Soil taxonomists and pedologists studying pedogenic processes have tended to concentrate on "natural, mature" soils (Bridges, 1978) rather than those affected by human activities. The terms "lessivage" (Duchaufour, 1977) and "pervection" (Paton, 1982) have thus been used by pedologists to describe the mechanical eluviation of clay without chemical alteration associated with the downward movement of water in a natural soil profile (White, 1987). However, micromorphological study of soils under modern agriculture has found that clay coatings and infillings can also be created from surface or internal slaking in ploughed soils (Jongerius, 1970, 1983). The term "agricutan" was coined by Jongerius (1970) to describe this phenomenon. Macphail *et al* (1987) associated the occurrence of textural coatings and infillings at certain depths with the type of cultivation implement used. Maximum deposition of the fine soil fraction at a depth of 4-5cm in buried cultivation ridges at a Neolithic barrow mound at Strathallan (Barclay, 1983) was interpreted as evidence of hoe cultivation (Romans and Robertson,1983b). Buried soils sampled from a nearby Neolithic henge demonstrated a similar maximum deposition but at a depth of approximately 12cm. This was interpreted as the result of cultivation with an ard. Impure and dusty clay coatings and infillings containing silt and sand grains have been interpreted at several sites as evidence of anthropogenic activity (Bullock *et al*, 1985; Courty & Federoff, 1982; Scaife & Macphail, 1983; Slager & Van der Wetering, 1977) whilst limpid clay coatings, often displaying micro-lamination, are interpreted as the result of the illuviation of clay. The presence of clay coatings has, therefore, been interpreted in the past as evidence of tillage as well as natural pedogenic processes (Courty *et al*, 1989).

Slide 1/56A contained rare silty clay coatings only. From previous studies and interpretations, this would appear to suggest that these textural pedofeatures are a result of past cultivation practises. This slide is from a depth of 30-38.5cm in the soil profile and a depth of 25-33.5cm in the Ap horizon. Whilst these coatings are not numerous enough to establish a maximum rate of deposition within this profile, the interpretation of Macphail *et al* (1987) may be tentatively applied to suggest that the occurrence of coatings at this depth represents the disturbance produced by the use of a plough or foot spade. However, Macphail *et al* (1987, p653) caution that, on sloping sites, "the effects of erosion and the layered redeposition of colluvium may complicate" the pattern of accumulation of textural pedofeatures at a certain depth associated with the implement used. Certainly, this trench is situated on a slope and the rig and furrow run perpendicular to the contours which may have led to increased erosion of the bare, cultivated soil. Nevertheless, the interpretation that the textural pedofeatures described in this slide result from past agricultural activity is further supported by the high amounts of amorphous black fine organic material found in this slide. This suggests that this soil has received increased amounts of organic material. Charcoal fragments were also found throughout the Ap horizon. In addition, two late 17th or early 18th century pipe bowls were also found in this trench which suggests that domestic waste and hearth material may have been used as a manure on this small cultivated plot of land.

It is harder to justify applying the same interpretation to slide 19/47B, however. Only rare dusty and limpid clay coatings were found in this slide and the organic material content was low. This slide is, therefore, interpreted as representing the natural pedogenic process of illuviation. The presence of amorphous and cryptocrystalline nodules and coatings and a distinct Ea horizon further supports the interpretation that the clay coatings may also be associated with the cheluviation of aluminium and iron which is a principal process in podzolization (White, 1987).

Slide 1/56B, which constitutes Cluster 2, also has a very high mineral content and contains the greatest number of clay coatings. These features result in this slide demonstrating the only gefuric related distribution from the Boyken samples. This slide comes from the bAp horizon at a depth of 40-48.5cm. Although there is sufficient field evidence to call the horizon a buried Ap horizon, influenced by anthropogenic activity, the micromorphological evidence would suggest that the clay coatings are most likely the product of both the downward percolation of water and the mechanical disturbance by cultivation implements. The clay coatings in this slide are predominantly dusty and limpid in nature, although rare silty clay coatings are also described. Limpid clay coatings, in particular, are interpreted as evidence of illuviation of clay particles rather than mechanical disturbance. However, less pure clay coatings demonstrating reduced birefringence can be created due to the turbulent flow of water through the soil. This can occur after the soil has been exposed by cultivation (Courty *et al.*, 1989). It is argued that the extremely high mineral content of this sample may be due to erosion of the fine fraction after loss of the vegetation cover through ploughing. However, no clear accumulation of soil was found behind the downslope boundary of Polygon 56 to support the theory of downslope movement of the soil fine fraction. Again, the evidence for past agricultural activity is provided by the presence of charcoal fragments and substantial amounts of amorphous black organic material.

As well as the predominantly dusty and limpid clay coatings, amorphous and cryptocrystalline nodules and coatings are also frequent in this slide. This suggests that water movement is a significant factor in the development of this soil. Trench 1/56 is situated on the lower slopes of the site close to a line of natural springs. It may, therefore, be that groundwater fluctuations are common at this depth in the profile which has resulted in the relatively high amounts of amorphous and cryptocrystalline pedofeatures. However, rapid downward percolation of water due to the free-draining nature of the soil must also provide a possible explanation for the presence of these amorphous and cryptocrystalline pedofeatures. It is considered likely that rapid overland and throughflow would occur from the steep slopes above this trench which would decrease on encountering the less steep lower slopes around Trench 1/56, even with the continuous grass cover present today. Percolation is likely to become the dominant pathway for soil water in this area, washing the fine clay particles down the profile to form clay coatings (Ward and Robinson, 1990).

Almost all of the slides grouped in Cluster 3 come from trenches situated within polygons. Only two come from a trench dug outwith a bounded area. Of those taken from within polygons, 4 are from polygons containing rig and furrow and 4 are from Polygon 52 which does not have similar surface features. However, a charcoal layer of *Corylus avellana* (hazel) was found at a depth of 30-35cm in Trench 5/52 which was dated to the early medieval period and has been tentatively interpreted as an early phase of vegetation clearance by burning. This charcoal layer is covered by a thick layer of sediment which was interpreted in the field as inwash material (Simpson, pers. comm.). It is argued that the subsequent baring of the soil surface on such a steep slope in an area of relatively high precipitation could easily result in rapid washing of the surface material downslope. There is, therefore, some evidence to suggest that significant anthropogenic activity has occurred equally within the non-rigged polygons as within those clearly displaying rig and furrow formations today.

The two slides also incorporated in this group which come from Trench 30, situated between the complex of polygons numbered 51-54 and those numbered 32-50, do not appear to hold with the interpretation that Cluster 3 represents the grouping of slides from polygons which have undergone some degree of human disturbance. No clear explanation can be proposed for this. However, two separate monoliths were taken from this trench in order to check the extent of localised, natural soil variability. It is interesting to note that the slides from the second monolith have been grouped in Cluster 4 and, therefore, can be considered to be more similar to slides from other polygons than to the slides taken from the first monolith in Trench 30. It may be that the micromorphological evidence for anthropogenic activity throughout the site is so slight that it is no more important than natural variability. Certainly, examination of the depths from which the slides occur reveals that there is an apparent relationship between this and some of the clusters produced during the HCA procedure. This suggests that the micromorphological characteristics used to group the slides are distinctive of the different pedogenic processes which operate throughout a soil profile, rather than any distinct differences in land use.

There is, however, some evidence to suggest that the slides grouped in Cluster 3 differ in certain micromorphological parameters which may be considered indicative of anthropogenic influences. For example, the slides in this cluster contain the highest amounts of organic residue and contain significantly more amorphous black material than those in Clusters 4 and 5. The Cluster 3 slides also contain relatively high quantities of spheroidal excrement. All of these features are indicative of high faunal activity which is often the only remaining evidence of former anthropogenic activity (Courty *et al*, 1989). Whilst many of the slides grouped in Cluster 4 come from the upper Ah horizon of the soil profiles sampled, the majority of those grouped in Cluster 3 come from the upper few centimetres of the lower Ah or Ap horizons. The spheroidal excrement in these samples are interpreted as the product of the activity of beetle larvae (Figure 5.1) and *Oribatid* mites. These meso-fauna are generally most active in the upper few centimetres of the profile, close to the source of organic material. Courty *et al* (1989) state that micromorphological features produced by biological activity and disturbance may persist in soil with high structural stability over long periods as long as other pedological processes have not eradicated this evidence. It may, therefore, be possible that much of the spheroidal excrement found in these slides is a "relict" feature of the biological activity at the previous soil surface when the A horizon was directly influenced by vegetation and human activities such as manuring.

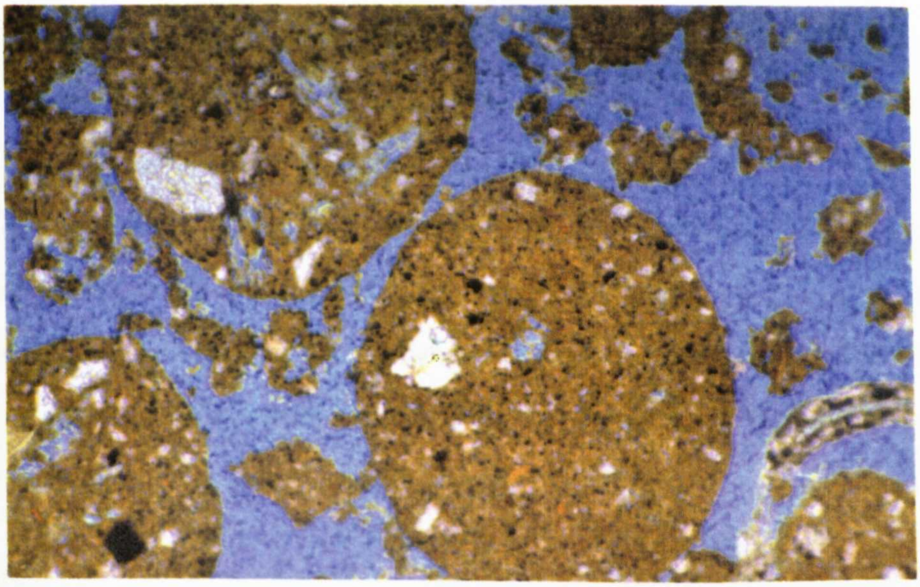

Figure 5.1 - Spheroidal excrement of beetle larvae, Slide 29/52B, Cluster 3, Boyken. (Magnification x4, PPL)

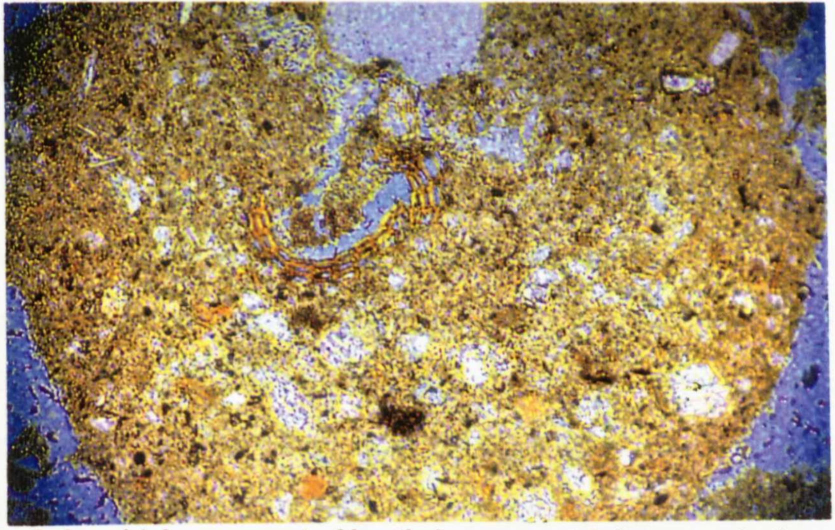

Figure 5.2 - Spheroidal excrement of beetle larvae containing organic tissue, Slide 30(2)A, Cluster 4, Boyken. (Magnification x10, PPL)

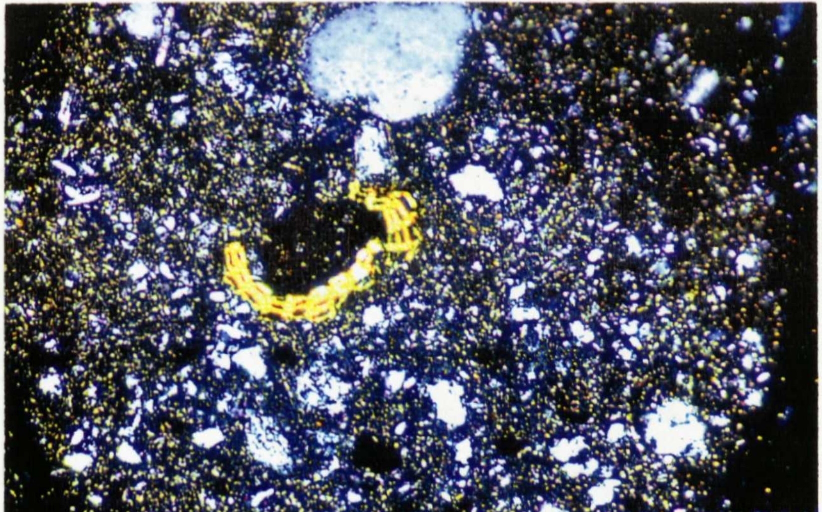

Figure 5.3 - As for Figure 5.2 but using XPL.

Cluster 4 is the largest of the five clusters created during the HCA process. The vast majority of these slides are sampled from A horizons within the top 15-20cm of the soil profile. Only the 3 slides from Trench 6 in polygon 10 can be said to come from a polygon containing obvious rig and furrow. All the other slides grouped in this cluster represent a variety of different polygons and locations throughout the Boyken site. The grouping together of samples from such a diverse range of locations does not lend itself to an interpretation associating the micromorphological evidence common to all of these slides with a specific type of anthropogenic activity.

The only micromorphologically distinct characteristics of this group of slides which could be shown through the statistical analysis were moderate amounts of organic residue and spheroidal excrement. However, the organic residue content of this cluster is only significantly different to that of Cluster 3 and is actually quite similar to the organic residue content of the Cluster 5 slides. In contrast, the spheroidal excrement content of the Cluster 4 slides is more similar to that of the slides in Cluster 3. Fifteen of the 31 slides grouped in Cluster 4 cover at least part of the top 10cm of the soil profile. Again, the spheroidal excrement identified in these samples was from three different types of soil fauna - beetle larvae, *oribatid* mites and *enchytraeids*. All of these organisms live in the surface soil layers which are rich in organic material and move horizontally rather than vertically in the profile (Courty *et al*, 1989). Relatively high amounts of spheroidal excrement would, therefore, be expected in samples from the upper part of the A horizon (Figures 5.2 and 5.3).

The low amounts of organic residue may be due to the presence of micro- and meso-fauna in these upper layers. Significant faunal activity will result in the rapid mechanical and chemical breakdown of fresh organic material. Bacteria and microflora play a significant role in the chemical breakdown of organic material and are closely associated with the micro- and meso-fauna which produce the excrement that can be identified as evidence of faunal activity during micromorphological descriptions (Petersen & Luxton, 1982). The meso- and macro-fauna complete the first stages of the breakdown of organic material by physically breaking it down into small enough components for the micro-fauna to utilise (Anderson, 1988; Hole, 1981; Seastedt, 1984; Swift et al, 1979). If the input of organic material to the soil system is not enhanced by anthropogenic inputs, then it is possible that the rate of faunal breakdown of the fresh organic material will equal the rate of input to the system, resulting in relatively fewer organic residues within the top few centimetres of the soil profile. However, this is a tentative interpretation and it is hoped that the more detailed Level 2 descriptions using a $1cm^2$ grid will provide more accurate information on the distribution of both organic residues and spheroidal excrement with depth.

The majority of the slides grouped in Cluster 5 are sampled from the B horizon or the Ea horizon of Trench 19/47. These slides contain the least amounts of organic material of any kind as well as both spheroidal and mamillate excrement. This is consistent with what would be expected in the lower B horizons or eluviated Ea horizons of a soil profile. Depletion pedofeatures are highest in these slides. Not surprisingly, the highest frequencies of this type of pedofeature are found in the Ea horizon of the samples from Trench 19/47. All of this micromorphological evidence is consistent with what would be expected from the natural pedological processes associated with B horizons.

The clusters produced from the hierarchical cluster analysis of the Level 1 micromorphological data for Boyken thus generally appear to be indirectly grouped by depth, although this was not one of the parameters used in the procedure. Many of the micromorphological characteristics which have been identified during the statistical analysis as important in the creation of each cluster, appear to be a function of the natural pedological processes which occur at different depths in the soil profile. This is not surprising as any study of soils will normally identify different pedological influences with depth but it does suggest that any evidence of human activity which may occur in these soils needs to be fairly substantial before it can be identified using quantitative statistical analysis. There is some evidence to suggest that Clusters 1-3 are distinguishable from the others because of micromorphological features such as dusty clay coatings which suggest anthropogenic activity. However, the vast majority of the slides appear to have been grouped together according to depth in the soil profile rather than by anthropogenic influence.

It is interesting to note that the slides from the two trenches (1/56 and 19/47) which displayed the most distinct horizons have been allocated to different clusters during the HCA process. The five slides taken from Trench 1/56 are grouped in Clusters 1, 2 and 3 whilst the six slides from Trench 19/47 are grouped in Clusters 1, 4 and 5. The slides from each of the other trenches are spread across no more than 2 clusters, with several having all the slides grouped in one cluster. This is particularly true of the samples taken from the trenches outwith the bounded polygons. This may suggest that samples from trenches within polygons which display similar clustering patterns, such as Trenches 11/36 and 27/38 may be regarded as containing soils which have not been substantially modified or affected by human activity. This may be due to the type of activity practised in each polygon or it could equally be due to the short duration of human impacts. For example, polygon 36 may only have been used for pastoral activities such as stock penning whilst polygon 38 was only briefly brought into arable production. Certainly, the remains of rig and furrow mapped by the RCAHMS in polygon 38 were too slight to be identified during field work and this has been interpreted as an indication that this part of the Boyken site was not subjected to a prolonged period of cultivation.

The differences between the clusters created during the hierarchical cluster analysis of the Level 1 Boyken data are therefore interpreted as a combination of pedological processes at different depths in the profile which, in some cases, have been influenced by past anthropogenic activity.

5.4 Analysis - Badentarbat

The raw Level 1 data for Badentarbat were also processed using Gower's coefficient of similarity in Minitab and Hierarchical Cluster Analysis in SPSS. No bone or depletion pedofeatures were found in any of the slides and these two parameters were therefore omitted from the classification procedure. The top six coefficient jumps were ranked in descending order. The two largest coefficient jumps merely resulted in the data being split from one large group into two with 16 and 75 members, respectively. The third largest coefficient jump split the data into 4 groups with 14, 2, 18 and 57 members respectively. The small cluster with 2 members was split into two separate clusters during stage 5 to produce a 5 cluster solution which corresponded with the fourth largest coefficient jump. Stage 7 gave rise to the fifth largest coefficient jump to produce 7 clusters of 14, 1, 1, 11, 7, 37 and 20 members whilst Stage 6 resulted in the sixth largest coefficient jump to give 6 clusters of 14, 1, 1, 18, 37 and 20 members.

Five different field classes had been identified from the field system classification exercise. Areas from each of these field classes were sampled during the field work. Samples were also taken from areas outwith the field system which had not been included in the field system classification but which had subsequently been categorised as Field Class 0. The number of field classes sampled had partly provided the basis for selecting a cluster solution from the HCA of the Boyken Level 1 data and it was considered best to apply the same principles for selecting a cluster solution from the Badentarbat analysis. However, the 6 cluster solution was actually the smallest of the top six coefficient jumps and the 7 cluster solution was more significant. It was therefore decided to select the stage with the most significant coefficient jump which was closest to the number of field classes from which slides had been produced for the Level 1 soil thin section description. The 5 cluster solution was thus selected and the membership of each cluster is given in Table 5.3.

Level 1 Cluster	Slides grouped in Level 1 Cluster (Trench/Polygon No.)	Field Class from which soil sample was obtained
1	49A-C Upper, 50A-D, 53A-C	Field Class 0
	32A-F, 32(F)A Upper left & right, 34A&B, 34(F)A, 36A-E	Field Class 1
	46A-C Upper &E, , 51A-C,E-F, 51(F)A&B	Field Class 3
	52A-D, 52(F)A & B Upper	Field Class 4
	38A-E, 43A-D	Field Class 5
2	49C Lower, 53C&D	Field Class 0
	32(F)A Lower left & right & B	Field Class 1
	54A-D	Field Class 2
	46C Lower, 46D Upper & 46E	Field Class 3
	52E, 52(F)B Lower	Field Class 4
	45D	Field Class 5
3	32(F)B Lower	Field Class 1
4	44A-C, 47A-D	Field Class 1
	46D Upper	Field Class 3
	42A-C, 45A-C	Field Class 5
5	51D	Field Class 3

Table 5.25 - Grouping of Badentarbat slides using the 5 cluster solution from the HCA process on the raw Level 1 soil thin section description data. See Figure 3.4 for location of each trench.

The clustering of the Level 1 raw data for Badentarbat also does not correspond to the field classes from which the soil samples came. Analysis of the data was undertaken using the same methods as for Boyken to establish which parameters had been used to produce this clustering pattern. Table 5.26 summarises the parameters which differentiate each cluster from the others. The cluster median for each measured parameter was also calculated and is given in terms of frequency class in Table 5.27.

Level 1 Clusters - Badentarbat	Interval/Ordinal data	Nominal data
Cluster 1	Quartz Feldspar Large fungal spores Lignified tissue Parenchymatic tissue Amorphous & cryptocrystalline nodules Amorph & cryptocrystalline coatings	B-fabric Microstructure Related distribution
Cluster 2	Amorphous black material	-
Cluster 3	Cell residue Amorph & cryptocrystalline coatings	Basic distribution Microstructure Mineral colour Mineral type
Cluster 4	Sandstone Amorph & cryptocrystalline nodules Amorph & cryptocrystalline coatings Mamillate excrement Spheroidal excrement	B-fabric Microstructure
Cluster 5	Quartz Feldspar	Limpidity Mineral colour Mineral type

Table 5.26 - Micromorphological parameters identified from the Level 1 soil thin section description which characterise each cluster from the others - Badentarbat

	Medians per Level 1 cluster (Frequency class)				
Level 1 micromorphological parameters measured by content	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Quartz	4	6	7	6	1
Feldspar	2	3	3	4	0
Sandstone	0	1	0	2	0
Siltstone	0	1	0	0.5	0
Phytolith	1	1	0	1.5	1
Diatoms	1	0	0	0	0
$CaCO_3$	0	1	0	1	0
Multi-cell fungal spore	1	1	0	1	2
Lignified tissue	1	0	0	0.5	2
Parenchymatic tissue	3	1	0	1	5
Organic residue	1	1	0	1	1
Charcoal	0	0	0	1	2
Single cell fungal spore	1	1	0	1	2
Amorphous black material	3	1.5	1	3	4
Amorphous yellow orange material	2	1.5	2	1.5	3
Amorphous red brown material	2	1	0	1.5	2
Cell residue	3	1	0	1	3
Silty clay coatings	0	0	0	0	0
Clay coatings	0	0	0	0	0
Limpid clay coatings	0	0	0	0	0
Amorph. & cryptocrystalline nodules	0	1	2	2	0
Amorph. & cryptocrystalline coatings	0	1	3	2	0
Mamillate excrement	1	1	0	3	2
Spheroidal excrement	1	1	1	2	3
Depth (cm)	29	34	23	26	40

Table 5.27 - Cluster medians for interval/ordinal data from Level 1 descriptions - Badentarbat.

Cluster 1

The slides grouped in Cluster 1 generally contain small amounts of quartz and feldspar. However, the content of these minerals in Cluster 1 is only found to differ significantly from Clusters 2 and 4. Again, the small size of Clusters 3 and 5, with only one case in each, results in no significant results between these clusters and any of the others using the Kruskal-Wallis test. However, the cluster medians for quartz and feldspar indicate that, apart from the single slide which constitutes Cluster 5, Cluster 1 has the lowest cluster median for both quartz and feldspar (Table 5.27). Simple cross-tabulation of the data further supports the findings of the Kruskal-Wallis test results (Tables 5.28 and 5.29). From Table 5.28, it can be shown that only 10% of the slides grouped in Cluster 1 have a quartz content >50%. In comparison, 72%-100% of the slides in Clusters 2-4 contain this level of quartz content. The single slide in Cluster 5 merely contains up to 1% of quartz grains and is one of only 4 slides to contain such a low level of quartz. However, the other 3 are all grouped in Cluster 1.

	No. of slides per frequency class of quartz content							
Level 1 Clusters	1 (1%)	2 (1-5%)	3 (5-15%)	4 (15-30%)	5 (30-50%)	6 (50-70%)	7 (>70%)	% slides with >50% quartz
Cluster 1	3	14	10	8	16	6	0	10
Cluster 2	0	0	0	1	4	7	6	72
Cluster 3	0	0	0	0	0	0	1	100
Cluster 4	0	0	0	0	3	11	0	78
Cluster 5	1	0	0	0	0	0	0	0

Table 5.28 - Cross-tabulation of quartz content data - Badentarbat Level 1.

The cross tabulation of the feldspar data (Table 5.29) shows that, apart from the slide in Cluster 5, only Cluster 1 contains slides which have a feldspar content of no more than 1%. In contrast, a much higher percentage of the slides in Clusters 2-4 contain more than 5% of this mineral. This supports the findings of the Kruskal-Wallis tests.

	No. of slides per frequency class of feldspar content					
Level 1 Clusters	0 (0%)	1 (1%)	2 (1-5%)	3 (5-15%)	4 (15-30%)	% slides with >5% feldspar
Cluster 1	0	22	15	19	1	35
Cluster 2	0	0	3	9	6	83
Cluster 3	0	0	0	1	0	100
Cluster 4	0	0	1	1	12	93
Cluster 5	1	0	0	0	0	0

Table 5.29 - Cross-tabulation of feldspar content data - Badentarbat Level 1.

The Kruskal-Wallis one-way analysis of variance by ranks also detects a significant (95% C.I.) difference in the amount of multi-cell fungal spores contained in the slides in Clusters 1 and 2. However, the median for this parameter for both of these clusters given in Table 5.27 is 1 (up to 1%). Moreover, Cluster 4 also has a cluster median of 1 but is not found to differ significantly from Cluster 1 for this parameter. Analysis of the raw data by simple cross-tabulation shows subtle differences in the distribution pattern of the data for each cluster (Table 5.30) which cannot be appreciated from calculating the cluster median alone. From this table, it can be shown that 96% of the slides in Cluster 1 contain some multi-cell fungal spores. A similar percentage (93%) of the slides in Cluster 4 also contain some of these features. These values are much too close to be statistically significant. However, only 61% of the slides in Cluster 2 contain more than 0% multi-cell fungal spores which is a large enough difference to the value for Cluster 1 to produce a significant result. The single slide in Cluster 3 is the only other cluster to produce a large difference to the value for Cluster 1. Cluster 1 contains 15 of the total of 17 slides from the entire Badentarbat site which contain 1-5% of multi-cell fungal spores. The clustering of such a large proportion of these slides in one group suggests that this may be a significant factor in differentiating the slides in Cluster 1 from all others.

	No. of slides per frequency class of multi-cell fungal spore content			
Level 1 Clusters	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**% slides with >0% multi-cell fungal spores**
Cluster 1	2	40	15	96
Cluster 2	7	11	0	61
Cluster 3	1	0	0	0
Cluster 4	1	12	1	93
Cluster 5	0	0	1	100

Table 5.30 - Cross-tabulation of multi-cell fungal spore content data - Badentarbat Level 1.

The amount of lignified tissue also differs significantly between Clusters 1 and 2, according to the statistical analysis. However, the cluster median results would suggest that there should also be a significant difference between Cluster 1 and Clusters 3 and 5 for this parameter, given that they also differ to Cluster 1 by only one frequency class. Examination of the raw data using cross-tabulation provides a means of checking for differences with the small Clusters 3 and 5 which cannot be determined from the Kruskal-Wallis tests (Table 5.31). From Table 5.31, it can be observed that 8 out of the 10 slides from the Badentarbat site which contain 1-5% of lignified tissue are grouped in Cluster

1, whilst 15 of the 18 slides in Cluster 2 contain no lignified tissue at all. From the distribution pattern of the lignified tissue content data, it can be seen that Cluster 1 is the only cluster to have the majority of its slides with a lignified tissue content of 1 (up to 1%). In contrast, neither the slides in Cluster 3 nor Cluster 5 contain this frequency of lignified tissue. However, this is not conclusive evidence that there is any significant difference between the lignified tissue content of Cluster 1 and Cluster 3 and 5. It does, nevertheless, suggest that lignified tissue content is also a significant parameter in defining Cluster 1.

	No. of slides per frequency class of lignified tissue content			
Level 1 Clusters	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**% slides with >0% lignified tissue**
Cluster 1	14	25	8	58
Cluster 2	15	3	0	17
Cluster 3	1	0	0	0
Cluster 4	7	6	1	50
Cluster 5	0	0	1	100

Table 5.31 - Cross-tabulation of lignified tissue content data - Badentarbat Level 1.

The slides in Cluster 1 differ significantly in parenchymatic tissue content to the slides in both Clusters 2 and 4. The cluster median data (Table 5.27) shows that the Cluster 1 slides contain much more parenchymatic tissue than any other cluster, apart from Cluster 5 which only has a membership of one . Cross-tabulation of the raw data further confirms these findings. Three of the four slides which contain 30-50% of parenchymatic tissue are grouped in Cluster 1, with the fourth comprising Cluster 5. Even when the number of slides which contain more than 5% of this parameter are examined, 92% of the total number of slides from the Badentarbat site which demonstrate this frequency of parenchymatic tissue are found to be grouped in Cluster 1.

	No. of slides per frequency class of parenchymatic tissue content						
Level 1 Clusters	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**4 (15-30%)**	**5 (30-50%)**	**% slides with >5% parenchymatic tissue**
Cluster 1	0	5	17	21	11	3	61
Cluster 2	1	9	7	1	0	0	6
Cluster 3	1	0	0	0	0	0	0
Cluster 4	2	7	4	1	0	0	7
Cluster 5	0	0	0	0	0	1	100

Table 5.32 - Cross-tabulation of parenchymatic tissue content data - Badentarbat Level 1.

The slides in Cluster 1 show a significant difference (95% C.I.) in the amount of amorphous and cryptocrystalline nodules and coatings to Cluster 4. The cluster median values given in Table 5.27 for these parameters, however, suggests that Cluster 3 should also show significant difference as it has the same median for amorphous and cryptocrystalline nodules as Cluster 4 and an even higher value for coatings. Again, cross-tabulation provides a sufficient level of detail to be able to accept the findings of the Kruskal-Wallis tests (Table 5.33 and 6.34). Fifty-three percent of the slides in Cluster 1 contain no amorphous and cryptocrystalline nodules whilst only 2 of the 57 slides contain more than 1% of these features. When the proportion of cases in each cluster which contain > 5% amorphous & cryptocrystalline nodules is calculated (Table 5.33), it can be shown that only Cluster 4 contains slides with such a relatively high amount of these features.

	No. of slides per frequency class of amorphous & cryptocrystalline nodules				
Level 1 Clusters	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**% slides with >5% amorph. & cryptocrystalline nodules**
Cluster 1	30	25	2	0	0
Cluster 2	3	12	3	0	0
Cluster 3	0	0	1	0	0
Cluster 4	0	0	9	5	36
Cluster 5	1	0	0	0	0

Table 5.33 - Cross-tabulation of amorphous & cryptocrystalline nodules data - Badentarbat Level 1.

The cross-tabulation of the amorphous and cryptocrystalline coatings data shows a very similar pattern. However, the slide in Cluster 3 is recorded as containing 5-15% of these features. The remaining 3 slides from the Badentarbat site which contain this amount of amorphous and cryptocrystalline coatings are grouped in Cluster 4. This explains the cluster median results and also suggests that Cluster 1 differs from both Clusters 3 and 4 for this parameter.

Three of the nominal variables show trends for the clustering of the slides in Cluster 1, although none of these is statistically significant. Fifty-four of the fifty-seven slides grouped in this cluster have an undifferentiated b-fabric. Whilst not all slides with this type of b-fabric are to be found in this cluster, 87% of the total number of slides displaying this type of feature are. Similarly, 49 of the 57 slides have a spongy microstructure, which represents 92% of the total number of slides from Badentarbat which

	No. of slides per frequency class of amorphous & cryptocrystalline coatings				
Level 1 Clusters	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**% slides with >5% amorph. & cryptocrystalline coatings**
Cluster 1	30	24	3	0	0
Cluster 2	7	8	3	0	0
Cluster 3	0	0	0	1	100
Cluster 4	0	5	6	3	21
Cluster 5	1	0	0	0	0

Table 5.34 - Cross-tabulation of the amorphous & cryptocrystalline coatings data - Badentarbat Level 1.

have a microstructure of this type. All fifty-seven of the slides have a porphyric related distribution which corresponds to 84% of the total number of slides of this type sampled throughout the site. Although not conclusive, these results may indicate that these parameters play a substantial role in the grouping together of the slides in Cluster 1.

Cluster 2

Eighteen slides were grouped to form Cluster 2. Only one parameter can be identified as characteristic of this cluster alone. These slides contain low amounts of amorphous black material with only the slide grouped in Cluster 3 showing a similar trend. This is indicated by the similarity in the cluster median values for Clusters 2 and 3 for this parameter (Table 5.27). However, the Kruskal-Wallis test results merely show a significant difference between amorphous black material content of the slides in Clusters 1 and 2. The cluster median results indicate that there should also be a significant difference between Cluster 1 and Cluster 4, given that Cluster 4 has the same median (3 or 5-15%) as Cluster 1. However, simple cross-tabulation of the raw data for this parameter shows that the distribution patterns for Clusters 2 and 4 are very similar but Cluster 1 also contains slides with 30-50% content of amorphous black material (Table 5.35).

Although no other micromorphological feature can be shown to be exclusively characteristic of this cluster, statistically significant (95% C.I.) differences in amorphous and cryptocrystalline nodules and coatings are found between Clusters 2 and 4. These parameters are also shown to significantly differ between Clusters 1 and 4 but not between Clusters 1 and 2. This suggests that there is no real difference between this characteristic for Clusters 1 and 2 but that Cluster 4 differs significantly from

Level 1 Clusters	No. of slides per frequency class of amorphous black material content					% slides with >30% amorphous black material
	1 (1%)	2 (1-5%)	3 (5-15%)	4 (15-30%)	5 (30-50%)	
Cluster 1	4	10	30	9	4	23
Cluster 2	9	4	4	1	0	6
Cluster 3	1	0	0	0	0	0
Cluster 4	4	2	6	2	0	14
Cluster 5	0	0	0	1	0	100

Table 5.35 - Cross-tabulation of amorphous black material data - Badentarbat Level 1.

both. However, examination of the medians for each cluster for these parameters (Table 5.27) shows that the median for Cluster 1 is 0 (none present) and 1 (up to 1%) for Cluster 2. This may not be a statistically significant difference but analysis of the cross-tabulation of this data does show that the slides in Cluster 2 contain moderate amounts of amorphous and cryptocrystalline nodules and coatings compared to Clusters 1 and 4. If the proportion of slides in each cluster which contain 0% of amorphous and cryptocrystalline nodules and coatings is calculated (Table 5.36 and 6.37, respectively), then subtle differences can be shown between the distribution patterns of Clusters 1, 2 and 4 which cannot be detected from the calculations given in Tables 5.33 and 5.34.

Percentage of slides per Level 1 cluster containing 0% amorphous & cryptocrystalline nodules				
Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
53	17	0	0	100

Table 5.36 - Differences in Level 1 cluster with 0% amorphous & cryptocrystalline nodules - Badentarbat.

As discussed above, Cluster 1 contains low amounts of these amorphous and cryptocrystalline nodules with 53% of the slides in this group containing no nodules whilst only 17% of the slides in Cluster 2 contain none of these features. All the slides in Cluster 4 contain more than 1% amorphous and cryptocrystalline nodules (Table 5.33). Similarly, 53% of the Cluster 1 slides contain no amorphous and cryptocrystalline coatings compared to 39% of the slides in Cluster 2. Again, all slides in Cluster 4 contain at least a trace (up to 1%) of these features (Table 5.34).

Percentage of slides per Level 1 cluster containing 0% amorphous & cryptocrystalline coatings				
Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
53	39	0	0	100

Table 5.37 - Difference in Level 1 cluster with 0% amorphous & cryptocrystalline coatings - Badentarbat

No micromorphological features recorded as nominal data are found to show any distinctive differences between Cluster 2 and the others.

Cluster 3

Cluster 3 merely comprises one slide and therefore does not provide evidence of possessing distinctive micromorphological characteristics using the Kruskal-Wallis one-way analysis of variance by ranks test. Similarly, the results from the cross-tabulation of the nominal data for this cluster does not reveal any statistically significant results. However, examination of the raw data and the cross-tabulation results does allow certain distinctive features to be identified. The slide separated from the others to comprise Cluster 3 is one of only two slides from the Badentarbat site which contains no cell residue (Table 5.38). Conversely, it is one of only four slides which contain 5-15% of amorphous and cryptocrystalline coatings (Table 5.34).

	No. of slides per frequency class of cell residue content						
Level 1 Clusters	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**4 (15-30%)**	**5 (30-50%)**	**% slides with >1% cell residue**
Cluster 1	0	5	19	21	11	1	91
Cluster 2	1	10	5	2	0	0	39
Cluster 3	1	0	0	0	0	0	0
Cluster 4	0	8	6	0	0	0	43
Cluster 5	0	0	0	1	0	0	100

Table 5.38 - Cross-tabulation of cell residue content data - Badentarbat Level 1.

The features which appear to be truly unique to this cluster, however, are recorded as nominal data. This is the only slide to have a banded basic distribution of the coarse mineral material and which has a pure mineral fine fraction with a grey colour (mineral colour). Further, it is one of only three slides found on site that demonstrate a pellicular grain microstructure.

Cluster 4

Cluster 4 groups fourteen slides together which appear to have a number of distinguishing features. A statistically significant difference, at the 95% confidence level, is found between the sandstone content of Clusters 1 and 4. Again, the cluster medians given for this parameter suggest that there should also be a difference between Cluster 4 and Clusters 3 and 5 (Table 5.27). Cross-tabulation of the sandstone content data shows that Clusters 1, 3 and 5 do have similarly low sandstone contents (Table 5.39). In comparison, the slides in Cluster 4 have the highest occurrence of sandstone fragments of any of the clusters.

	No. of slides per frequency class of sandstone content					
Level 1 Clusters	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**4 (15-30%)**	**% slides with >1% sandstone**
Cluster 1	40	17	0	0	0	0
Cluster 2	7	9	1	1	0	11
Cluster 3	1	0	0	0	0	0
Cluster 4	1	5	4	3	1	57
Cluster 5	1	0	0	0	0	0

Table 5.39 - Cross-tabulation of sandstone content data - Badentarbat Level 1.

The slides in Cluster 4 also possess the highest amounts of amorphous and cryptocrystalline nodules (Table 5.33). The only five slides to contain more than 5% of nodules are grouped in this cluster. Similarly, 3 of the 4 slides from the Badentarbat site which contain more than 5% of amorphous and cryptocrystalline coatings are also grouped in Cluster 4 (Table 5.34). The remaining slide with this relatively high level of this feature is the single slide in Cluster 3.

The slides in Cluster 4 show a significant difference from both Clusters 1 and 2 in mamillate and spheroidal excrement content. The cluster medians for mamillate excrement content (Table 5.27) show that Cluster 4 has the highest median at 3 (5-15%), compared to a median of 1 (up to 1%) for both Clusters 1 and 2. However, it would also appear that there is a substantial difference in the mamillate excrement content of Cluster 3. Again, cross-tabulation of the raw data provides enough information to accept the Kruskal-Wallis test results (Table 5.40). Cluster 4 includes the only 3 slides from the site which contain more than 15% of mamillate excrement. The percentage of slides in each cluster which contain >1% of mamillate excrement given in Table 5.40 shows that Cluster 4, does indeed, show the greatest difference between Clusters 1-3 whilst there is only a 7% difference between the values for Cluster 4 and Cluster 5.

The cluster median data (Table 5.27) shows that Cluster 4 has a median of 2 (1-5%) whilst Cluster 5 has a median of 3 (5-15%) and Clusters 1-3 have a median of 1. As a statistically significant difference was found between Cluster 4 and Clusters 1 and 2, using the Kruskal-Wallis test, it would seem

	No. of slides per frequency class of mamillate excrement content					
Level 1 Clusters	0 (0%)	1 (1%)	2 (1-5%)	3 (5-15%)	4 (15-30%)	**% slides with >1% mamillate excrement**
Cluster 1	24	17	10	6	0	28
Cluster 2	8	4	6	0	0	33
Cluster 3	1	0	0	0	0	0
Cluster 4	0	1	5	5	3	93
Cluster 5	0	0	1	0	0	100

Table 5.40 - Cross-tabulation of mamillate excrement content data - Badentarbat Level 1.

reasonable to assume that there must also be an equally substantial difference between Cluster 4 and Clusters 3 and 5, given that the difference between the medians is the same for all comparisons of Cluster 4 with the other clusters. However, cross-tabulation of the data shows that the distribution pattern of the spheroidal excrement content data for Clusters 4 and 5 is more similar than a similar comparison of Clusters 3 and 4 (Table 5.41). The slides in Cluster 4 , therefore, appear to have a relatively high spheroidal excrement content in comparison to all clusters except Cluster 5.

	No. of slides per frequency class of spheroidal excrement content					
Level 1 Clusters	0 (0%)	1 (1%)	2 (1-5%)	3 (5-15%)	4 (15-30%)	**% slides with >1% spheroidal excrement**
Cluster 1	22	15	13	5	2	35
Cluster 2	6	8	3	1	0	22
Cluster 3	0	1	0	0	0	0
Cluster 4	0	4	4	6	0	71
Cluster 5	0	0	0	1	0	100

Table 5.41 - Cross-tabulation of spheroidal excrement content data - Badentarbat Level 1.

Although two thirds of the slides in Cluster 2 have a speckled b-fabric, all fourteen of the slides grouped in Cluster 4 have this type. This would seem to suggest that this characteristic, in combination with others, is a main differentiating factor for this cluster. Microstructure is possibly one of the features considered in combination with type of b-fabric during the HCA process to identify Cluster 4 as different to the others as all fourteen of the Cluster 4 slides also have an intergrain microaggregate microstructure. This represents only 58% of the total number of slides with this type of microstructure, however, and is by no means conclusive evidence. Indeed, as 6 slides with this combination of b-fabric and microstructure type are grouped in Cluster 2 rather than 4, it would suggest that both types of nominal data have been considered in combination with other interval and ordinal data to define the slides in Cluster 4 as more alike to each other than to any other group. Nine of the fourteen slides also have a gefuric related distribution which represents 69% of the total number of slides from the Badentarbat site which demonstrate this type of related distribution. This may, therefore, also be a parameter which is used in conjunction with the others identified to differentiate Cluster 4 from the others.

Cluster 5

Cluster 5, again, is merely one slide and thus does not prove significant in the statistical analysis of both the interval/ordinal and the nominal data. However, this slide is one of only four that contain only a trace (up to 1%) of quartz grains (Table 5.28). It is also the only slide from the Badentarbat site which does not contain any feldspar fragments (Table 5.29). In comparison to the slide grouped in Cluster 3, this is the only slide not to contain a fine mineral fraction which results in no limpidity, mineral colour or mineral type being recorded. Although none of these features can be shown to be statistically significant, the unique nature of this slide seems to suggest that it may not easily be grouped with other slides. Indeed, this slide and that defined as Cluster 3 remain as separate cases until very late in the HCA process.

Depth in soil profile

The maximum depth of each slide was recorded during the Level 1 description work but was not entered as a variable to be used during the HCA process. However, as discussed in Section 6.2 above, it was considered that the depth in the soil profile from which the slides came may be associated with the range of differentiating parameters used to identify the slides in each cluster as more alike to each other than to any of the other slides from the Badentarbat site. This does not appear to be the case at Badentarbat as depth in the soil profile was not found to be a statistically significant differentiating characteristic between any of the clusters.

The median depth of the slides in each cluster was calculated and is given in Table 5.27 in centimetres. From these results, it can be seen that there is only a 27cm difference between the shallowest and deepest median depths. It must also be noted that the 2 values which provide this maximum difference in depth belong to the 2 clusters which contain only one slide in each (Clusters 3 and 5). The values of 24cm for Cluster 3 and 46cm for Cluster 5 , therefore correspond to the minimum depth of actual slides rather than the composite values provided for Clusters 1, 2 and 4. The small range of median depths appears to support the findings of the Kruskal-Wallis one-way analysis of variance by ranks tests. This can be further verified by producing a simple cross-tabulation of the maximum depth of the slides in each cluster (Table 5.42).

	No. of slides in each depth range from the surface of the soil profile (cm)				
Level 1 Clusters	**0-20**	**21-40**	**41-60**	**61-80**	**% slides at >40cm depth**
Cluster 1	30	17	8	2	18
Cluster 2	5	10	3	0	17
Cluster 3	0	1	0	0	0
Cluster 4	8	6	0	0	0
Cluster 5	0	0	1	0	0

Table 5.42 - Cross-tabulation of depth data - Badentarbat Level 1.

From Table 5.42, it can be shown that the slides which constitute Clusters 3 and 5 occur in the same depth range of 21-40cm. It can also be shown that a large proportion of the slides in Clusters 1, 2 and 4 have been sampled from 21-40cm depth below the soil surface. Indeed, the distribution patterns for Clusters 1, 2 and 4 are very similar and are highlighted by the percentage of slides in each cluster which come from a depth of more than 40cm in the soil profile. Depth, therefore, does not appear to have a particular association with the range of features used to differentiate the clusters from each other.

A summary table, similar to that provided for the Boyken slides at the end of Section 6.2, is provided to indicate the relative amounts and type of each parameter which appears to have been used to create each cluster from the Badentarbat samples (Table 5.43). Again, only the parameters which are used to define at least one cluster are included and not all of the differences are statistically significant. Thirty-one different parameters were measured, described and entered into the hierarchical clustering analysis procedure for the Badentarbat slides. No bone fragments or depletion pedofeatures were recorded during the Level 1 description work and these parameters were thus omitted from the HCA procedure. Diatoms were found to be present in several of the Badentarbat slides, although none had been identified from the Boyken slides. This parameter was, therefore, measured for the Badentarbat slides. Twelve parameters have not been identified by the statistical analysis as important in defining each cluster. These are siltstone, phytolith, diatom, $CaCO_3$, organic residue, charcoal, single-cell fungal spore, amorphous yellow orange and amorphous red brown material content and the content of silty clay, pure clay and limpid clay coatings.

In summary, the slides grouped in Cluster 1 may generally be described as organic in nature, possessing the lowest amounts of quartz, feldspar and amorphous and cryptocrystalline nodules and coatings and the highest amounts of lignified tissue and large fungal spores. Cluster 2 appears to incorporate slides which are intermediate between the organic slides of Cluster 1 and the more mineral slides of Cluster 4. The Cluster 2 slides contain the least amounts of amorphous black material and have moderate relative amounts of amorphous and cryptocrystalline features. Cluster 3 contains only one slide which is characterised by its lack of organic material. It is the only slide to have a pure mineral fine fraction and a banded basic distribution of the coarse mineral material. The slides in Cluster 4 have a high sandstone content and also provide the greatest evidence for faunal activity. The higher mineral content in these slides leads to all the slides having an intergrain microaggregate microstructure and a speckled b-fabric. Cluster 5 merely contains one slide which is almost purely organic in origin. Virtually no coarse mineral fragments are found and there is no evidence of fine mineral material within this slide.

5.5 Interpretation of Level 1 Results - Badentarbat

The Badentarbat site contains a range of different soil types. Peats and loamy peats predominate but sandy clay loams are also common and loamy and peaty sand horizons and lenses are found in some profiles. The presence of sand in many of these soils is not surprising given that drifts derived from Torridonian sandstones and grits are the parent material in this area (Soil Survey of Scotland, 1982). The micromorphological characteristics of the 5 clusters produced during the HCA of the Level 1 data for Badentarbat have already been established. Attempts need to be made to establish the common link between the slides grouped in each cluster. Are these "distinctive" micromorphological features indicative of certain past anthropogenic activities or do they merely represent the natural pedological processes of the soils under certain environmental conditions? If natural pedological processes are

	Differentiating characteristics per Level 1 cluster - Badentarbat				
Micromorphological parameters	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
Quartz	2nd lowest	3rd highest	Highest	2nd highest	Lowest
Feldspar	2nd lowest	3rd highest	Highest	2nd highest	Lowest
Sandstone	3rd lowest	2nd highest	Lowest (=5)	Highest	Lowest (=3)
Mineral type	-	-	Mineral	-	None
Mineral colour	-	-	Grey	-	None
Limpidity	-	-	-	-	None
Multi-cell fungal spores	2nd highest (≅4, 5)	2nd lowest	Lowest	3rd highest (≅1, 5)	Highest (≅1,4)
Lignified tissue	2nd highest	2nd lowest	Lowest	3rd highest	Highest
Parenchymatic tissue	2nd highest	4th lowest (≅4)	Lowest	3rd lowest (≅2)	Highest
Amorphous black material	2nd highest	2nd lowest	Lowest	3rd lowest	Highest
Cell residue	Highest	2nd lowest	Lowest	3rd lowest	2nd highest
Amorphous & cryptocrystalline nodules	2nd lowest	3rd lowest	2nd highest	Highest	Lowest
Amorphous & cryptocrystalline coatings	2nd lowest	3rd lowest	Highest	2nd highest	Lowest
Mamillate excrement	2nd lowest	3rd lowest	Lowest	Highest	2nd highest
Spheroidal excrement	3rd lowest	2nd lowest	Lowest	Highest	2nd highest
Microstructure	Spongy	-	Pellicular grain	Intergrain microaggregate	-
Basic distribution of coarse mineral	-	-	Banded	-	-
B-fabric	Undifferentiated	Speckled	-	Speckled	-
Related distribution	Porphyric	-	-	Mainly gefuric	-
Depth	Deepest (≅2)	2nd deepest (≅1)	Shallowest	2nd shallowest	3rd shallowest

Table 5.43 - Summary of differentiating characteristics of each Level 1 cluster - Badentarbat. Note: The ordinal data is presented for each cluster relative to the others. Some parameters have similar values in 2 or more clusters. The cluster(s) with the similar value for that parameter is given in brackets. Only the nominal characteristics which show a large grouping either per cluster and/or in terms of the site total for that characteristic are shown.

indicated, are these produced under the present day environmental conditions or are they indicative of different conditions some time in the past?

Cluster 1 is the largest group which contains slides from 11 different trenches. These slides cover a range of depths from 0-80cm and are characterised by being highly organic. They also have a low mineral content, low frequency of amorphous and cryptocrystalline coatings and nodules and a high content of fungal spores. The single most strikingly common feature of these slides is their soil texture. All but two of the slides in this group have been sampled from horizons which have been described as having a peat or peaty soil texture (MAFF, 1988). Twenty-seven of the slides come from peat horizons whilst a further 18 are described as loamy peats. Peaty sands and sandy peats are also grouped in Cluster 1. This clearly explains why the high organic and low mineral contents are diagnostic features of this group of slides.

The low content of amorphous and cryptocrystalline coatings and nodules is not surprising given the low mineral content of these slides but it does indicate that poor drainage and anaerobic conditions are features of these organic horizons (Bullock *et al*, 1985). It is also worth noting that the highest frequency of amorphous and cryptocrystalline pedofeatures occurs in the samples from Trench 46. This is the only trench in this cluster which contains a sandy peat horizon above loamy peat layers. Three of the four slides from this trench are sampled from the sandy peat Op/Ap horizon. The top slide, from 7-15cm, contains 1% of amorphous and cryptocrystalline nodules and 1-5% of amorphous and cryptocrystalline coatings whilst the two slides from deeper in this horizon contain 1-5% of both types of amorphous and cryptocrystalline pedofeature. The fourth slide is sampled from the underlying loamy peat Ap2 horizon and merely contains 1% of amorphous and cryptocrystalline coatings. This clearly demonstrates that the frequency of amorphous and cryptocrystalline pedofeatures is closely associated with the mineral content of the soils.

The high numbers of fungal spores is much harder to interpret. Several different types of spores are present but these are not identified to any particular species. In most cases, only 1% of either single or multi-cellular spores is recorded with a maximum of 5-15% of single cell spores only occurring in Slide 51C. These counts are not considered high enough to be of any real significance and, therefore, little

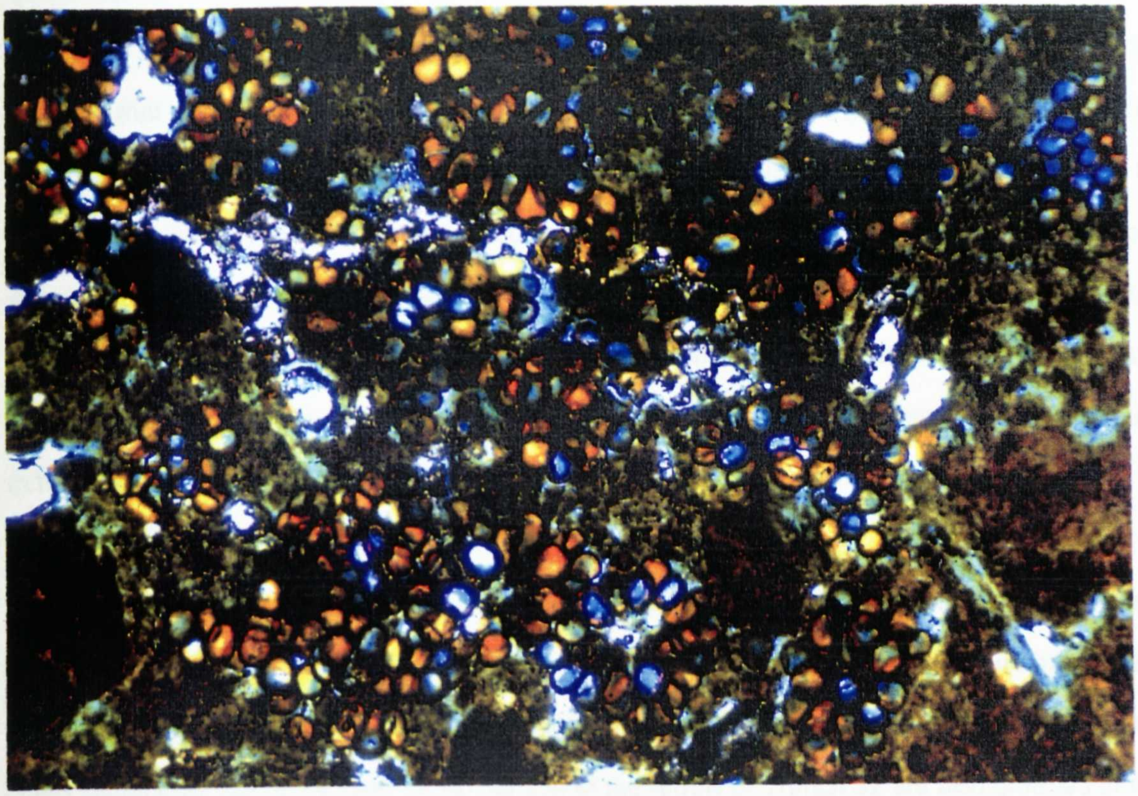

Figure 5.4 - Cluster of single-cell fungal spores, Slide 36/5C, Badentarbat. (Magnification x4, PPL)

time was spent in gaining the knowledge and expertise necessary to identify their source. However, several things are worth noting. Many of the spores occurred in clusters (Figure 5.4) and all were visible at x100 magnification. The size of these spores would suggest that many are not produced by microflora present in the soil, although some large sclerotia of the fungus *Cenoccocum geophilum* were identified (Fitzpatrick, 1993). Swift *et al* (1979, p.81) state that "fungi are largely restricted to aerobic environments". Bacteria, such as *Clostridium*, do persist in anaerobic conditions and are known to produce dormant spores under unfavourable conditions. However, it is highly unlikely that these spores would be large enough to be seen at x100 magnification under a petrological light microscope. It is, therefore, considered most likely that these spores originate from local macroflora. The most obvious source from this site is *Pteridium aquilinum* (bracken) which produces spores of 33 x 28μm (Grime *et al*, 1990) but this cannot account for the variety of spore types found in these slides. It is, however, interesting to note that spore counts are frequently higher in the slides sampled in December rather than August, 1995. At face value, this would appear to correlate with the maximum spore production of *Pteridium* prior to dieback in the autumn. However, relatively high counts of large, multi-cellular spores were recorded to a depth of 80cm in Trench 51 and the shallowest depth recorded of 2cm is still too deep to be associated with the current year's production of fungal spores. It must also be noted that none of these trenches were located in areas of bracken growth. It is possible that these spores are associated with the faeces of grazing animals, such as cattle and sheep, during the history of the site which may account for their inclusion at such a range of depths but this cannot be confirmed without identification of their original source. No clear interpretations can therefore be made about the relatively high frequency of fungal spores in these slides without considerable further investigation of their source. This is a significant project beyond the limits of this research but may be worth pursuing in the future.

The slides grouped in Cluster 2 have a moderate organic content, contain low amounts of amorphous black material and have moderate frequencies of amorphous and cryptocrystalline nodules and coatings. The majority of these slides come from horizons which have a loam or loamy texture. The three slides from the peaty sand Of/Ap horizon of the furrow of Trench 32 are also grouped in this cluster. Soil texture again appears to be a clearly distinguishing feature of this group of slides.

The type of organic material found in these slides also seems to be a function of the soil texture. For example, up to 15% of parenchymatic tissue is recorded in the slides from the peaty sand and loamy peat horizons of Trenches 32 and 46 whilst only a maximum of 1% is found in those from the loamy sand and sandy clay loam horizons of Trenches 53 and 54. In contrast, the slides from Trench 54 contain the highest amounts of amorphous black material with up to 30% recorded in Slide 54B. Amorphous yellow orange material and cell residue content are both highest in the peaty/peat soils of Trenches 32 and 46. All of the slides grouped in this cluster have low amounts of lignified tissue and organ residue. The micromorphological features of all organic material are "considered as cause and effect of ecological processes" (Bullock *et al*, 1985, p.74). The high levels of parenchymatic tissue in the peats and peaty soils of this group is most probably due to the mainly anaerobic conditions of these waterlogged soils reducing the number of microarthropods in the soil. This results in a marked decrease in the decomposition of soil organic matter (Swift *et al*, 1979).

Although low amounts of amorphous black organic material is the overall trend for this cluster, the slides from the sandy clay loams in Trench 54 contain slightly higher amounts than the other slides, especially deeper in the profile. The soil profile in this trench was originally interpreted in the field as containing a possible deepened A horizon or plaggen soil (Conry, 1974). This interpretation was based on the 43cm depth of the mineral A horizon with no overlying peat layer, coupled with the location of the soil in a small enclosure immediately downslope from a settlement structure. Kaleyards with intensely manured soils are common on many crofts in Shetland (Carter & Davidson, in press). Ash and charcoal remains from hearths is a common manure applied to these small enclosures and the amorphous black material may be the only remaining evidence of larger charcoal fragments included in this soil to maintain fertility.

However, comparison with other trenches which have similar sandy clay loam mineral soils with little or no overlying peat shows that these profiles also contain similar amounts of amorphous black organic material. The polygons in which these trenches are situated are considerably further away from the settlement structures of the site and are much bigger, unenclosed areas. It seems unlikely that these areas would have received similar amounts of hearth waste as the small enclosure. In addition, the raised land surface of the enclosure (Polygon 45 - see Figure 2.4) was found to consist mainly of shallow bedrock. Bedrock was struck immediately below the surface on a number of occasions before the profile described and sampled was discovered. The presence of bedrock over such a substantial area of this enclosure makes it an unlikely candidate for any intensive use for crop-growing. The interpretation that the amorphous black organic material is small fragments of charcoal is therefore dismissed.

An alternative interpretation is based on the fact that mineral soils promote faster and greater decomposition of organic matter than organic soils. This decomposition includes catabolism of the plant remains which results in the transformation of the complex organic compounds into simpler organic and inorganic products (Swift *et al*, 1979). It may be that these fragments are discoloured by tannin oxidation products called phlobaphenes (Fitzpatrick, 1993).

The relatively high amounts of amorphous yellow orange fine organic material in the slides from the furrow of Trench 32 may be due to different conditions in the peaty sands compared to the other soil textures represented in this cluster. The fact that these slides come from a furrow which served as a drainage channel suggests that more anaerobic conditions would have prevailed in this horizon despite the sandy nature of the soil. As discussed earlier, anaerobic conditions are unfavourable to many types of soil fauna and decreased rates of organic matter decomposition result. This reduction in decomposition rate is illustrated by the relatively high amounts of parenchymatic tissue and cell residue present in these slides.

This cluster can also be generally described as containing moderate frequencies of amorphous and cryptocrystalline pedofeatures. However, no more than 5% of amorphous and cryptocrystalline nodules or coatings is recorded in any slide and it is, therefore, questionable whether this is an important characteristic used to group these slides together in Cluster 2. Again, subtle differences between the slides can be seen. However, it is more difficult to attribute these differences to different soil textures. Similarly high frequencies of amorphous and cryptocrystalline coatings are recorded in soils with peaty sand, sandy clay loam and loamy sand textures. Before any interpretation based on soil texture can be put forward, it must also be noted that only one of the 5 slides in this group with a sandy clay loam soil texture contains the maximum of 1-5% of these pedofeatures. It is, therefore, questionable to attribute the presence of these features to drainage properties of certain soil textures. Nor can this phenomenon be attributed to depth in the profile as slides at similar or greater depths in the profile contain few amorphous and cryptocrystalline coatings. Similar observations can be made about the frequency of amorphous and cryptocrystalline nodules in the slides from this group. No clear interpretation can, therefore, be proposed for these subtle differences between the slides. It may be that such small differences (no more than 5%) are merely due to natural spatial variability and cannot be categorically attributed to any particular soil characteristic.

It is obvious, therefore, that although these slides have been grouped together because of a combination of similar micromorphological characteristics, there are still subtle differences within the group which can often be attributed to different soil textures and contexts.

Cluster 3 has only one member - the lower section of Slide 32(F)B which is sampled from the Ap horizon of the furrow in Trench 32. The soil texture of this horizon was described as pure sand during the field work and the micromorphological description appears to confirm this. This section of slide 32(F)B contains very high quantities of quartz and feldspar and virtually no organic material. The coarse mineral fraction has a banded basic distribution and 1-5% of amorphous and cryptocrystalline nodules and 5-15% of amorphous and cryptocrystalline coatings are recorded. Although the surface of the furrow is now vegetated, it still plays a significant role as a drainage channel into the *Allt an Fhealing* burn which runs along the bottom of this polygon (Polygon 7 - see Figure 2.4). This sand horizon was probably exposed during the formation of the adjacent rig and was kept weed-free to aid the run-off of water. The rapid movement of water through this sand may well lead to a degree of sorting of the mineral grains which is displayed micromorphologically as a banded basic distribution. This exposed horizon, whilst not suffering poor drainage due to high clay content, may have been waterlogged for substantial periods of time due to its functional nature as a drainage channel. This may well have resulted in anaerobic conditions which led to the segregation of iron and manganese oxides/hydroxides to give the amorphous and cryptocrystalline nodules and coatings visible in the section (Bullock *et al*, 1985).

Cluster 4 groups 14 slides together. These slides are characterised as containing relatively high amounts of sandstone and excrement. All of these slides have an intergrain microaggregate microstructure and a speckled b-fabric. They are sampled from the A horizons of 5 different trenches, ranging in depth from 5-40cm. All of these horizons are described as having a sandy clay loam soil texture except for the upper section of Slide 46D which comes from a loamy sand lens in the middle of a loamy peat profile in Trench 46 in the south east of the site. In contrast, all the other slides come from trenches on the lower slopes to the west of the stream.

Although this group of slides can be generally described as containing relatively high amounts of sandstone, only a maximum of 15-30% is recorded in Slide 44C. It is predominantly the slides from Trenches 42 and 44 which show this trend. These two trenches are situated on two of the patches of "improved", cropped grass with wide, shallow rig and narrow furrows. Virtually no peat has accumulated in these areas and the soil horizons are highly mineral in comparison to the surrounding peats and loamy peats. The mineral nature of these soils provides aerobic conditions which are conducive to the survival of soil fauna and microflora such as *Oribatid* mites and earthworms (Petersen and Luxton, 1982). This leads to greater decomposition of the organic matter input from the surface vegetation. The close cropped grass sward of these areas demonstrates that these are favourite grazing spots. This is likely to increase organic input to the soil via sheep faeces and urine. These organic inputs, coupled with the favourable aerobic conditions of the mineral soil, lead to increased faunal activity and a subsequent increase in the amounts of excrement present in the soil. This, however, does not provide conclusive micromorphological evidence of past anthropogenic activity. Other evidence must also be found to demonstrate the past agricultural practices carried out on these areas.

Some possible evidence is presented in the form of a few clay coatings. These pedofeatures are not present in sufficient numbers to be statistically significant but it can be noted that virtually all clay coatings occur in the slides grouped in Cluster 4. These are predominantly ferruginous and dusty clay in nature, although a few limpid clay coatings are also found in Slides 42A & B. Whether these pedofeatures can be interpreted any more conclusively as evidence of past anthropogenic activity than the increased faunal activity is questionable. The fact that these samples come from soils forming rigs lends credence to interpreting these micromorphological characteristics as evidence of past agricultural activity but it must also be remembered that many of the peat samples also come from soils built up to form rig and furrow. Evidence from the archaeological excavation work provides more conclusive evidence that the soils have been modified in the past by humans by both mechanical disturbance and the input of organic and inorganic waste. Fragments of coal, burnt bone, slate and 19th century glazed pottery were found in Trenches 42 and 44. It is, therefore, on the basis of this artefact evidence that it can be tentatively proposed that the micromorphological features described in these slides may indicate past anthropogenic activity as well as natural variations associated with soil type.

The comminution and mineralisation of the organic material by the micro- and meso-fauna and the mixing of the mineral and organic matter by mega-fauna such as earthworms is instrumental in creating the intergrain microaggregate microstructure evident in all of the slides in this cluster. This mixing of the organic and mineral components of the soil may also be responsible for the speckled b-fabric in these slides.

Cluster 5, again, has only one member. This is Slide 51D from the deep Op horizon in polygon 22 in the south of the site close to the gravel bar. The main distinguishing characteristic of this slide is its pure organic nature. Only up to 1% of quartz is recorded in this slide with no other types of mineral present. Particularly high amounts of parenchymatic tissue and amorphous black and yellow orange fine organic material are present. Surprisingly, this slide is recorded as containing greater amounts of excremental pedofeatures than any other slide from the same profile. This slide comes from a depth of 46-54cm and was not recorded in the field as a distinctly different horizon to the peat above and below this depth. The rig in this area of the site has a particularly high amplitude, probably to aid drainage. The close proximity of the seashore to this trench leads to a tentative interpretation that seaweed may have been applied to these soils as organic fertiliser. This practise was common in many coastal and island regions of western Scotland (Baldwin, 1994;Old Statistical Account, 1794). However, without $\delta^{13}C$ analysis of the peat sampled for section 51D, it is impossible to conclude with any certainty that this highly organic material is from a marine source.

The excremental pedofeatures present in this slide suggest that aerobic conditions prevailed at least long enough for significant faunal activity to occur. These aerobic conditions may have been created by the disturbance and breaking up of the peat horizon during cultivation. It is considered unlikely that faunal activity continued as this layer of peat was subsequently buried since conditions would have become increasingly more anaerobic, hence limiting faunal activity (Seastedt, 1984; Swift *et al*, 1979). It may be that this evidence of faunal activity is relict and relates to a period when this layer of peat was at the surface.

There is one striking feature of the classification of the Level 1 description for Badentarbat. In the majority of cases, all the slides from one profile have been grouped in the same cluster. Cluster 2 contains most of the exceptions to this rule. Nine of the sixteen members of Cluster 2 are actually parts of slides (upper or lower sections, for example), rather than descriptions of entire slides. However, this cluster does also include all the slides sampled from Trench 54. This trench is unique in that it is the only profile sampled from within a small enclosure not displaying rig and furrow morphology. It would be interesting to collect further samples from similar areas on site and see if the HCA process would also group these slides in this cluster.

The various types of soil found throughout the Badentarbat site and their associated micromorphological characteristics have played a significant part in the classification procedure. The natural soil variability would appear to be much more significant than any micromorphological variability that may be caused by different agricultural practices. The Badentarbat samples come from a range of different forms of rig and furrow but the clustering does not demonstrate any significant characteristics which can be attributed to a certain type of cultivation practice such as lazybedding or ploughing with a fixed mouldboard plough and a large team of draught animals.

5.6 Comparison of Boyken and Badentarbat

Twelve parameters appear to have been used in both classifications to differentiate the slides in each cluster from the others: quartz, feldspar, sandstone, lignified tissue, parenchymatic tissue, amorphous black material, cell residue, amorphous and cryptocrystalline coatings, mamillate and spheroidal excrement, microstructure and related distribution. Surprisingly, the analysis of the results of both classifications have identified 19 differentiating parameters for each site. It would therefore appear that only 5 of the total of 33 parameters described during the Level 1 description work have not been used during either classification procedure. These parameters are bone, phytolith, calcium carbonate, diatom and single-cell fungal spore content.

The classifications of the raw Level 1 data for Boyken and Badentarbat both proved difficult to analyse statistically due to the existence of clusters with small memberships. However, it was fairly obvious from studying the raw data why the slides in these small groups had been separated from the others. The single slide from Boyken in Cluster 2 has very similar relative amounts of quartz, feldspar, lignified tissue, parenchymatic tissue, cell residue, amorphous & cryptocrystalline coatings and spheroidal excrement to the single slide from Badentarbat in Cluster 3. However, the other small clusters in each classification (Boyken Cluster 1 and Badentarbat Cluster 5) have very little in common, with only similar relative amounts of feldspar, amorphous black material, cell residue and spheroidal excrement content. This is not surprising, given that the single slide grouped in Badentarbat Cluster 5 is almost purely organic peat and no such soil horizon occurs in Boyken.

Mineral content appears to be a significant characteristic used in both classifications and high mineral content often appears to be associated with high frequencies of amorphous and cryptocrystalline features in both classifications. Amorphous and cryptocrystalline pedofeatures are much more dominant in the classification of the Badentarbat data than that of Boyken. This may be due to the more waterlogged nature of the Badentarbat site but is more probably attributed to the different mineral and peat horizons occurring in this site. Amorphous and cryptocrystalline pedofeatures are much more common in mineral soils and therefore are a useful indicator of the extreme differences in mineral content found in the soils of the Badentarbat site. The more constant mineral nature of the soils across the Boyken site makes it less likely that significant differences in drainage, and hence amorphous and cryptocrystalline pedofeatures, will occur.

A complete lack of depletion pedofeatures in the samples from Badentarbat is surprising, given the high and fluctuating water table at this site. However, it may be that the highly organic nature of many of the soil samples made it difficult to identify these. The problems with producing thin sections from the peaty soils of Badentarbat has also made the task of identifying such features particularly difficult, if not impossible, due to the uneven thickness of several of the slides and thus an apparent lack of these features should not be regarded as conclusive.

Organic material is significant in both sites but for different reasons. The differences in organic material content in the Boyken slides can be related much more directly to anthropogenic activity because of the lack of variability in the soils of the site. In contrast, the differences in organic content of the Badentarbat slides are much more obviously related to the variety of mineral and peat soils occurring across this site. Differences in the decomposition of organic matter in these two types of soil is demonstrated not only by the relative differences in coarse and fine organic material but also, to some extent, by the colour of the amorphous fine organic material. The soil samples which show a higher organic content at Boyken also appear to demonstrate increased frequencies of spheroidal and mamillate excrement. This is also the case at Badentarbat but it is more difficult at this site to confidently interpret the increased occurrence of faunal excrement as evidence of past anthropogenic activity (Courty *et al*, 1989). This, again, is because of the different soil types present in this site.

It is known that soil texture affects faunal activity (Dawood & Fitzpatrick, 1993; Hassink *et al*, 1993; Seastedt, 1984) and other evidence also has to be found in order to interpret increased faunal activity in the mineral soils at Badentarbat as anything other than natural variations in faunal communities and the decomposition rate of organic matter according to environmental conditions. This is provided by artefacts such as coal, bone and pottery fragments found during the archaeological excavation. Artefacts found during the excavations at Boyken also help to support the interpretation of increased faunal activity as evidence of past agricultural practises.

Very few textural features, which are considered in some of the micromorphological literature to be indicative of possible cultivation (Bullock *et al*, 1985; Fitzpatrick, 1993; Jongerius, 1970), have been identified in the slides of both sites. The few coatings identified and described for the slides of both sites consist predominantly of silty and dusty clay and have thus been tentatively interpreted as indicative of mechanical disturbance rather than illuviation, based on past studies. However, these pedofeatures are too rare to be regarded as conclusive evidence on their own and have to be considered in combination with other evidence in order to confidently propose that there is sufficient evidence to indicate certain historical agriculture activities.

No features considered to be of possible anthropogenic origin, such as bone or charcoal, are used as cluster differentiators for the Badentarbat data. The presence of charcoal does, however, appear to be useful in differentiating the samples from Boyken into their respective clusters. This does not indicate that there was little or no charcoal present in the soils at Badentarbat. On the contrary, charcoal fragments were much more common in the Badentarbat slides than in those from Boyken. Small amounts (approximately 1%) of charcoal fragments were common in almost 50% of the Badentarbat slides. In contrast, only approximately 25% of the Boyken slides contained charcoal fragments but several of these slides contained more than 1% of these features. This probably explains why charcoal content was used as a significant parameter during the HCA of the Boyken data and not for Badentarbat.

Microstructure, although not found to be significantly different in statistical terms between clusters at either site, has been shown to demonstrate trends associated with the clustering patterns at both. Whether the different types of this micromorphological feature relate to any particular forms of past agricultural use of the soils, as proposed by Gebhardt (1992), is hard to determine from this evidence alone. Certainly, the samples from neither site have been grouped during the HCA according to their sampling context. For example, the largest cluster for each site contains slides from trenches outwith polygons, sampled from rig and furrow and from polygons with no evidence of rig and furrow. A range of different types of rig and furrow were sampled at Badentarbat but these slides have not produced any distinct differences which can be easily attributed to the implements used to create them. The Level 1 raw data is grouped according to the field class from which each sample comes in Chapter 7 in order to test for any characteristics which may be indicative of past agricultural use.

The Boyken slides appear to be grouped, to some degree, by their depth in the soil profile although only a statistically significant difference was found between Clusters 4 and 5 for this site. No such evidence was found for the Badentarbat site, however. The differences in median depth for each cluster in the Badentarbat classification were too small to produce similar results to that of Boyken. Once again, this difference is attributed to the difference in the soils found at each site. The homogeneous nature of the soils at Boyken creates a sort of control which rules out interpreting any observed differences as merely the characteristic properties of different soil types. However, any observed differences between the samples have to be significantly large in order to also rule out the effects of natural spatial variability, both horizontally and vertically. This is rarely the case at Boyken and only tentative interpretations of anthropogenic influences can be made from the micromorphological evidence alone. There are large differences in certain parameters in the Badentarbat slides. However, these are most confidently and easily explained as the characteristic properties of the different soil types found throughout the site. As for Boyken, no conclusive interpretations of past agricultural practices can be made solely from the micromorphological features described. For both sites, the most convincing interpretation is that the clustering of the slides during the HCA of the Level 1 data reflects the natural differences in soil types (organic and mineral soils) and pedological processes (mainly podzolisation, humification of organic matter and cheluviation).

Although some anthropogenic influences can be suggested for some of this evidence, the clustering process has clearly not grouped these slides according to their "cultural" context.

6. Level 2 Soil Micromorphological Description: Results and Analysis

6.1 Introduction

The Level 2 micromorphological description was undertaken for 2 reasons (Figure 1.3). The first was to test whether a more detailed description of the slides for certain parameters would provide greater evidence of micromorphological differences between the samples from the different field classes. The second reason was to check that the apparent differences between soils from the different field classes, identified during the Level 1 work, were actually more important than possible within-slide variability. It had been noted during the Level 1 work that a single slide may contain more than one type or frequency of a certain parameter and the decision had been made to record the predominant type of the feature or a general estimate of overall frequency at this level of description. The Level 2 method of description was devised in an attempt to quantify the degree of heterogeneity within each slide to check the validity of the Level 1 descriptions.

6.2 Results - Boyken and Badentarbat

The data collected from the Level 2 soil thin section description work were transferred from the recording sheet into an SPSS spreadsheet for analysis. The results from the Boyken and Badentarbat Level 2 descriptive work are presented in Appendix 6. The percentage content of quartz, sandstone, cell residue, mamillate and spheroidal excrement are estimated to the nearest 5% and the descriptions associated with the codes used for the nominal variables are also provided. Each row represents the full description of one 1cm^2 grid square and the depth of each gridsquare from the surface of the soil profile is also recorded. As discussed in Section 4.4.1, only a selection of slides which represented the range of field clusters from each site were described at this level.

6.3 Analysis - Boyken

This very large data set was run through the Gower's coefficient of similarity macro in Minitab and then through the Hierarchical Cluster Analysis (HCA) process in SPSS. The top six coefficient jumps in the agglomeration schedule corresponded to stages 1-5 and 9 in the clustering process. The largest coefficient jump was associated with stage 1 with all the cases grouped together as one large group. Stage 2 had the second highest coefficient jump which split this large single group into two with 33 and 387 members, respectively. The third highest coefficient jump corresponded to stage 4 with 4 clusters of 33, 46, 57 and 284 members. Stage 5 was associated with the fourth highest coefficient jump and resulted in 5 clusters of 22, 11, 46, 57 and 284 members. The fifth highest coefficient jump was at stage 3 where the data were split into 3 clusters of 33, 103 and 284. The sixth highest jump corresponded to stage 9 when 9 clusters were created, each containing 16, 6, 11, 17, 29, ,48, 9, 152 and 132 members, respectively.

The 1 and 2 cluster solutions were ignored as these are almost invariably the most significant jumps but provide little in the way of evidence of classification. The 3 and 9 cluster solutions were disregarded as they were placed 5th and 6th, respectively, in the coefficient rankings below the 4 and 5 cluster solutions. It was decided that, of the remaining two cluster solutions, the 5 cluster solution would be the best to use as this corresponded to the number of field classes from which the slides to be used during the Level 2 work had been selected.

The slides included in each of the 5 clusters are summarised in Table 6.1. It is apparent that, like the Level 1 hierarchical cluster analysis results, the Level 2 results have not been grouped during the HCA process according to the field class to which they belong. It is therefore necessary to establish which distinctive properties have led to these hierarchical cluster analysis results. It must also be noted that several of the slides feature in more than one Level 2 cluster. This is because each case considered during the HCA process corresponds to an individual gridsquare rather than a complete slide and not all of the gridsquares for each slide have been grouped in the same cluster.

Table 6.2 provides a better indication of how well or otherwise the gridsquares from one particular slide, or sub-section of a slide, are grouped together during the Level 2 Hierarchical Cluster Analysis procedure. The clustering of a large proportion of the gridsquares from a particular slide in one cluster is highlighted in bold text. From this, it can be seen that 22 of the 25 slides, or sub-sections of slides, have the majority of the gridsquares for that slide/sub-section grouped in one cluster. The five gridsquares described from the lower left section of slide 1/56A, however, are spread across 4 clusters

Level 2 Clusters	Slides containing gridsquares included in each cluster	Field Class from which each soil sample was obtained
1	13/22A&B	Field Class 1
	1/56A-E	Field Class 2
	11/36A-C	Field Class 3
	26/30A&B	Field Class 5
	22A-C, 30(1)A&B	Field Class 7
2	13/22A Upper, 13/22B	Field Class 1
	1/56A Upper, 1/56C Lower, 1/56D&E	Field Class 2
	11/36A&B, 5/52A-D	Field Class 3
	26/30A	Field Class 5
	22A, 30(1)A&B	Field Class 7
3	1/56A Lower left, 1/56B	Field Class 2
	11/36B&C	Field Class 3
	26/30A	Field Class 5
	22B, 30(1)B	Field Class 7
4	1/56A&B, 1/56C Lower, 1/56D	Field Class 2
	11/36B&C, 5/52A,B&D	Field Class 3
	26/30A&B	Field Class 5
	22B&C, 30(1)B	Field Class 7
5	1/56A&B	Field Class 2
	30(1)B	Field Class 7

Table 6.1- Membership of clusters obtained from HCA of Level 2 micromorphological descriptions - Boyken Level 2. See Figure 2.5 for trench locations.

and Slide 30(1)B shows a similar pattern. The 21 gridsquares described from Slide 1/56E are almost evenly split between Clusters 1 and 2. Observations from this table would seem to suggest that between-slide variation is greater than within-slide variation. This is discussed in full in Section 6.8.

The results of the HCA process were analysed using the Kruskal-Wallis one-way analysis of variance by ranks test and cross-tabulation. Only the cross-tabulation of the basic distribution of mamillate excrement data proved to be statistically significant with $p<0.001$, a minimum expected frequency of 2.567 and 13.3% of the cells having an expected frequency of <5. None of the other nominal variables met this criteria to be considered statistically valid but, as for the Level 1 analysis, trends were observed and cross-checked with the raw data. Manual cross-tabulation of the ordinal data was also carried out to reveal distribution trends which could not be ascertained from the cluster median data alone. A summary of the variables which characterise each of the Level 2 clusters from at least two others is given in Table 6.3 and the cluster medians for the interval and ordinal data are provided in Table 6.4 for reference.

	Level 2 Cluster (No. Gridsquares per cluster)				
Thin Section	**1**	**2**	**3**	**4**	**5**
1/56A Upper	**12**	1	0	3	4
1/56A Lower left	1	0	1	2	1
1/56B	1	0	3	3	**16**
1/56C Upper	**11**	0	0	0	0
1/56C Lower	**6**	1	0	2	0
1/56D Upper	**6**	2	0	2	0
1/56D Lower	**8**	1	0	1	0
1/56E	10	11	0	0	0
5/52A	**14**	1	0	3	0
5/52B	**14**	2	0	2	0
5/52C	**22**	2	0	0	0
5/52D	**19**	1	0	1	0
11/36A	**16**	5	0	0	0
11/36B	**15**	4	2	1	0
11/36C	2	0	1	**16**	0
13/22A Upper	**11**	4	0	0	0
13/22A Lower	**7**	0	0	0	0
13/22B	**18**	2	0	0	0
22A	7	**10**	0	0	0
22B	**15**	0	1	2	0
22C	**17**	0	0	1	0
26/30A	**15**	3	1	1	0
26/30B	**14**	0	0	1	0
30(1)A	**15**	3	0	0	0
30(1)B	8	4	2	5	1

Table 6.2 - Results of Level 2 micromorphological description illustrated by the number of gridsquares grouped in each Level 2 cluster and sorted by thin section - Boyken Level 2.

Level 2 Clusters	Ordinal data	Nominal data
Cluster 1	Quartz content Sandstone content Cell residue content Mamillate excrement content	Basic distribution of mamillate excrement Microstructure
Cluster 2	Quartz content Sandstone content Cell residue content Mamillate excrement content Spheroidal excrement content	Basic distribution of spheroidal excrement
Cluster 3	Quartz content Sandstone content Cell residue content Mamillate excrement content	Basic distribution of quartz Referred distribution of quartz Shape of quartz grains Basic distribution of mamillate excrement Microstructure
Cluster 4	Quartz content Sandstone content Cell residue content Mamillate excrement content	Microstructure
Cluster 5	Quartz content Sandstone content Cell residue content	Related distribution Microstructure

Table 6.3 - Level 2 micromorphological characteristics which differentiate each cluster from the others - Boyken Level 2

	Medians of interval/ordinal data for each Level 2 Cluster				
Micromorphological parameters	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
% Quartz content	30	35	0	22.5	15
% Sandstone content	10	10	100	27.5	57.5
% Cell residue content	5	5	0	0	0
% Mamillate excrement content	5	10	0	0	5
% Spheroidal excrement content	0	5	0	0	0
Depth (cm)	17	13	24	27.5	43

Table 6.4 - Cluster medians for interval/ordinal data from Level 2 descriptions - Boyken Level 2

Cluster 1

Many of the significant clusterings of gridsquares per slide in Table 6.2 occur in Cluster 1, which is the largest with 284 members. The quartz and sandstone content of the gridsquares in Cluster 1 differs significantly from Clusters 3, 4 and 5. The quartz and sandstone content of Clusters 1 and 2 are too alike to be statistically different which is evident from the median data (Table 6.4) as Clusters 1 and 2 have median quartz contents of 30% and 35%, respectively and both have median sandstone contents of 10%. The cross-tabulation data in Table 6.5 demonstrates the similarity between Clusters 1 and 2 with regard to quartz content, with both clusters having a very high proportion of their gridsquares containing >10% quartz grains compared with 0%, 83% and 59% for Clusters 3-5, respectively.

	Percentage of quartz grains (No. of gridsquares)									
Level 2 Clusters	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**% gridsquares per cluster with >10% quartz**
Cluster 1	0	0	5	14	60	29	46	105	25	98
Cluster 2	0	0	1	2	9	9	7	21	8	98
Cluster 3	10	0	1	0	0	0	0	0	0	0
Cluster 4	0	7	1	5	10	5	5	11	2	83
Cluster 5	2	5	2	3	4	1	4	1	0	59

Table 6.5 - Cross-tabulation of quartz grain content - Boyken Level 2.

Table 6.6 also shows the similarity between the results for Clusters 1 and 2. Only 8% and 2% of the gridsquares in Clusters 1 and 2, respectively, contain >50% sandstone fragments. This compares with 91%, 33% and 54% of the gridsquares in Clusters 3-5, respectively. This indicates that the cases in Clusters 1 and 2 contain the highest content of quartz grains and, conversely, the lowest content of sandstone fragments.

Level 2 Clusters	Percentage of sandstone fragment content (No. of gridsquares)																					% gridsquares per cluster with >50% sandstone
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	
Cluster 1	21	99	40	14	11	13	19	12	15	9	9	5	9	3	1	4	0	0	0	0	0	8
Cluster 2	4	21	12	2	4	0	3	4	2	2	2	0	1	0	0	0	0	0	0	0	0	2
Cluster 3	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	1	6	91
Cluster 4	1	9	4	2	3	4	1	2	3	1	1	1	3	1	2	1	3	1	2	1	0	33
Cluster 5	0	1	1	0	0	1	0	1	0	1	5	1	2	1	2	1	2	3	0	0	0	54

Table 6.6 - Cross-tabulation of sandstone content data - Boyken Level 2

The gridsquares clustered in this group generally contain the highest amounts of cell residue and are significantly different to those contained in Clusters 3, 4 and 5. The median data in Table 6.4 supports the Kruskal-Wallis results and simple cross-tabulation of the raw data further illustrates the distribution of the cell residue data per cluster across the range of percentage content values found in the Boyken slides (Table 6.5). This is the only cluster where all of the gridsquares contain at least 5% cell residue. Analysis of the number of gridsquares containing 10% or more cell residue content shows that 14% of the gridsquares in Cluster 1 meet this criteria compared to only 10% in Cluster 2 and 0% for Clusters 3, 4 and 5.

	Percentage of cell residue (No. of gridsquares)					
Level 2 Clusters	**0**	**5**	**10**	**15**	**20**	**% of gridsquares per cluster with >5% cell residue**
Cluster 1	0	243	30	9	2	14
Cluster 2	1	50	5	1	0	10
Cluster 3	11	0	0	0	0	0
Cluster 4	30	16	0	0	0	0
Cluster 5	21	1	0	0	0	0

Table 6.7 - Cross-tabulation of cell residue data - Boyken Level 2

Mamillate excrement content differs significantly from all other clusters except Cluster 5, according to the Kruskal-Wallis test data. The cluster medians given for this parameter in Table 6.4 show that the median for Clusters 1 and 5 is the same at 5% content. This appears to support the Kruskal-Wallis test results. Further analysis of the raw data using cross-tabulation produced the results given in Table. 6.8. This shows that 38% of the gridsquares in Cluster 1 contain more than 5% of mamillate excrement compared to 54% in Cluster 2, 0% in Cluster 3, 23% in Cluster 4 and 27% in Cluster 5. This suggests that the cases grouped in Cluster 1 contain the second highest amounts of mamillate excrement but cannot be statistically differentiated from the mamillate excrement content of the cases in Cluster 5.

One hundred and forty-two gridsquares in Cluster 1 also demonstrate a clustered basic distribution of mamillate excrement. This represents 72% of the total number of gridsquares from the Boyken site samples with this characteristic. Similarly, 162 of the 284 gridsquares in this cluster have a subangular blocky microstructure which represents 79% of the site total for this type of microstructure.

Level 2 Clusters	Percentage of mamillate excrement (No. of gridsquares)							% gridsquares per cluster with >5% mamillate excrement
	0	5	10	15	20	25	45	
Cluster 1	75	102	70	25	6	5	1	38
Cluster 2	6	20	18	6	4	3	0	54
Cluster 3	9	2	0	0	0	0	0	0
Cluster 4	26	14	4	1	1	0	0	23
Cluster 5	9	7	4	1	0	1	0	27

Table 6.8 - Cross-tabulation of mamillate excrement data - Boyken Level 2

Cluster 2

Only 2 slides provide 21 of the 57 cases grouped in Cluster 2 (Table 6.2). Slide 1/56E contributes 11 cases and slide 22A, 10 cases to this cluster. Although the quartz and sandstone content of the cases in this cluster differ significantly from Clusters 3, 4 and 5, they are found to be very similar to those grouped in Cluster 1. The cluster median data in Table 6.4 show that there is only 5% difference in the median quartz content of Clusters 1 and 2, whilst the median sandstone content for these clusters is 10% in both cases. The cross-tabulation data for quartz content in Table 6.6 also shows that Clusters 1 and 2 have exactly the same proportion of gridsquares with a quartz content >10%. This is much higher than any of the three other clusters. Although there is a slight difference in the percentage of gridsquares in Clusters 1 (8%) and 2 (2%) which contain >50% sandstone (Table 6.5), these values are also substantially different to those for Clusters 3-5. Quartz and sandstone content, therefore, cannot be regarded as a characteristic unique to this cluster but may well be considered in combination with other parameters to make the gridsquares grouped in this cluster more alike to each other than to those in any other cluster.

The cell residue content of the gridsquares in Cluster 2 significantly differs from those in Clusters 3, 4 and 5. The cluster median data (Table 6.4) also indicates that Clusters 1 and 2 have similar cell residue contents which are different to Clusters 3-5. The cross-tabulation of the cell residue data further supports the findings of the Kruskal-Wallis test results (Table 6.7). Cluster 2 contains the second highest amounts of cell residue with 10% of the cases containing more than 5% of this parameter. This result is too similar to the figure for Cluster 1 to be statistically significant but the 10%

difference between Cluster 2 and Clusters 3, 4 and 5 does produce a statistically significant result at the 95% confidence level.

A comparison of the gridsquares from Slides 1/56E and 22A, clustered in Cluster 2 rather than Cluster 1 (Table 6.2), shows that those in Cluster 2 contain more excrement than those grouped in Cluster 1. Greater abundances of spheroidal and mamillate excrement are statistically differentiating factors for Cluster 2 from all other clusters. These results are supported by the cluster median data and the cross-tabulation calculations (Tables 6.8 and 6.9). Fifty-four percent and 23% of the gridsquares in Cluster 2 contain more than 5% content of mamillate and spheroidal excrement, respectively. In comparison, only 38%, 0%, 23% and 27% of the gridsquares in Clusters 1, 3, 4 and 5, respectively, contain similar amounts of mamillate excrement. The spheroidal excrement figure compares with only 4% of the cases in Cluster 5 which contain similar amounts of this pedofeature whilst Clusters 1, 3 and 4 contain no spheroidal excrement at all.

	Percentage of spheroidal excrement (No. of gridsquares)					
Level 2 Clusters	**0**	**5**	**10**	**15**	**20**	**% gridsquares per cluster with >5% spheroidal excrement**
Cluster 1	274	10	0	0	0	0
Cluster 2	0	44	9	1	3	23
Cluster 3	11	0	0	0	0	0
Cluster 4	46	0	0	0	0	0
Cluster 5	16	5	1	0	0	4

Table 6.9 - Cross-tabulation of spheroidal excrement data - Boyken Level 2.

A high proportion of the gridsquares (52 of the 57) grouped in Cluster 2 have a clustered basic distribution of the spheroidal excrement. This corresponds to 76% of the total number of gridsquares from the Boyken samples with this type of basic distribution of spheroidal excrement.

Cluster 3

Cluster 3 is the smallest group with only 11 members which are gridsquares from 7 different slides or sub-sections. However, it is still large enough to produce statistically significant results. Ten of the 11 gridsquares in this cluster are characterised by containing no quartz grains (Table 6.6). These are the only gridsquares from the Boyken samples to display this characteristic. Conversely, 10 of the 11 gridsquares grouped in this cluster contain 55% or more of sandstone with 6 of the 11 containing 100%

(Table 6.5). One gridsquare contains no features at all as it covers an area devoid of soil. It appears that this cluster is merely a grouping of the anomalous gridsquares which happen to occur over large fragments of sandstone or in areas devoid of soil.

The cell residue content of the cases in Cluster 3 is only found to differ significantly from Clusters 1 and 2. The cluster medians and the cross-tabulation data support these findings and it can be seen from Table 6.7 that Cluster 3 is the only cluster with 100% of the cases containing no cell residue. Again, this is due to the anomalous nature of the gridsquares grouped in Cluster 3.

Cluster 3 also significantly differs from Cluster 1 and 2 in terms of mamillate excrement content. Again, this is the only cluster where 100% of the gridsquares contain ≤5% mamillate excrement and 9 of the 11 cases actually contain none at all. Although 77% and 73% of the gridsquares in Clusters 4 and 5, respectively, also contain ≤5% mamillate excrement, this is not found to be statistically significant. The cross-tabulation data (Table 6.8) does, however, illustrate a slight difference between Cluster 3 and Clusters 4 and 5 which cannot be appreciated from the cluster median data in Table 6.4 alone.

Although five types of nominal data can also be shown to differentiate this cluster from the others, this is merely because of the high sandstone cover in many of these gridsquares. Ten of the eleven cases in this cluster are recorded as having no basic or referred distribution of quartz, no quartz grain shape and no microstructure whilst 9 of the 11 have no basic distribution of mamillate excrement.

Cluster 4

Cluster 4 has 46 members which display no characteristics amongst the ordinal data which can be attributed exclusively to this cluster alone. The quartz content of the cases in this cluster are, however, significantly different to those in Clusters 1, 2 and 3. The median quartz content for Cluster 4 of 22.5% and Cluster 5 of 15% appears to be too similar to be statistically significant (Table 6.4) but the cross-tabulation data in Table 6.6 does not provide conclusive evidence to support the Kruskal-Wallis results. Eighty-three percent of the gridsquares in Cluster 4 contain >10% quartz grains. However, the figure of 59% for Cluster 5 gives a difference of 24% between the values for these 2 clusters. In comparison, 98% of the gridsquares in Clusters 1 and 2 contain the same level of quartz grains, which is only a 15% difference to the value for Cluster 4. However, if the proportion of gridsquares containing >25% quartz grain content is calculated (Table 6.10), the difference between the values for Clusters 4 and 5 is only 16% compared to 23% and 22% for a similar comparison with Clusters 1 and 2, respectively. Clusters 4 and 5 therefore contain the second lowest amounts of quartz.

Percentage of gridsquares containing >25% quartz grains				
Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
62	63	0	39	23

Table 6.10 - Difference in quartz grain content - Boyken Level 2.

The sandstone content of the gridsquares in Cluster 4 differs significantly from Clusters 1 and 2 but not from Clusters 3 and 5. This is surprising when the median data is examined as there is a greater difference between the medians of Clusters 3, 4 and 5 than those of Clusters 1, 2 and 4. The findings from the Kruskal-Wallis tests are also not supported by the calculations of the percentage of gridsquares in each cluster which contain >50% sandstone (Table 6.5). However, if the percentage of gridsquares which contain >10% sandstone is calculated for each cluster (Table 6.11), it can be shown that there is a greater difference between the percentage of gridsquares in Clusters 1, 2 and 4 containing >10% sandstone content than between Clusters 3, 4 and 5 (Table 6.5).

% of gridsquares in each cluster containing >10% sandstone content				
Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
44	35	91	70	91

Table 6.11 - Difference in sandstone content between Level 2 clusters - Boyken Level 2

The cell residue content of the cases in Cluster 4, again, only differs significantly from Clusters 1 and 2 which appears to correspond with the cluster median results (Table 6.4). Only 16 of the 46 gridsquares grouped in Cluster 4 have a cell residue content of 5% whilst all others in this cluster contain none at all (Table 6.7). Clusters 3 and 5 also display similar characteristics but none of the eleven cases in Cluster 3 contain cell residue and only 1 of the 22 in Cluster 5 contains 5% of this parameter. Therefore, when the percentage of gridsquares which contain >0% cell residue is calculated for each cluster, it can be shown that Cluster 4 actually contains the third highest amounts of cell residue (Table 6.12).

Percentage of gridsquares containing >0% cell residue				
Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
100	98	0	35	4

Table 6.12 - Difference in cell residue content - Boyken Level 2

Similarly, the mamillate excrement content of Clusters 3, 4 and 5 are too alike to be significantly different in statistical terms. The cluster median data for this parameter, however, appears to suggest that there should also not be a statistically significant difference between Clusters 1 and 4, given that Clusters 1 and 5 have the same cluster median of 5% (Table 6.4). However, analysis of the raw data using simple cross-tabulation shows that 77% of the gridsquares in Cluster 4 contain no mamillate excrement which is exceeded only by Cluster 3 where 100% of the gridsquares are also devoid of this pedofeature (Table 6.8).

The gridsquares in this cluster only display a slight trend in one type of nominal variable, with 50% having a spongy microstructure. However, this type of microstructure is by no means exclusive to this cluster as the cases in Cluster 4 merely represent 29% of the total number of cases for the Boyken site.

Cluster 5

Cluster 5 groups 22 cases together, with 16 of these coming from Slide 1/56B. This cluster also displays little in the way of particular characteristics which are unique to it alone. As discussed in previous paragraphs, the quartz and sandstone contents of the gridsquares in this cluster are only significantly different to Clusters 1 and 2. Clusters 3, 4 and 5 are too similar to be statistically distinguishable from each other in terms of quartz and sandstone content (Tables 6.4 - 6.6) . It can merely be said that both Clusters 3 and 5 are characterised by a low quartz content and a high sandstone content.

Similarly, the cell residue content of the cases grouped in Cluster 5 is only significantly different to those in Clusters 1 and 2 which corresponds with the cluster median data (Table 6.4). However, the results in Table 6.12 show that Cluster 5 is, in fact, most like Cluster 3 in terms of cell residue content.

The mamillate excrement content of Cluster 5 does not differ significantly from any other cluster whilst the spheroidal excrement content of Cluster 5 only differs in statistical terms (95% C.I.) from Cluster 2.

However, further analysis of the raw data shows that Cluster 5 has the second highest content of spheroidal excrement, with 27% of the gridsquares in this cluster containing 0% or more of this pedofeature. This compares with 100% for Cluster 1, 4% for Cluster 1 and 0% for both Clusters 3 and 4 (Table 6.13).

Percentage of gridsquares containing >0% spheroidal excrement				
Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
4	100	0	0	27

Table 6.13 - Difference in spheroidal excrement content (>0%) - Boyken Level 2.

Seventy-five percent of the total gridsquares from Boyken which have a gefuric related distribution are grouped in Cluster 5. However, only 11 of the 22 gridsquares grouped in this cluster actually have this type of related distribution. A slightly higher number of cases (13 out of 22) have an intergrain microaggregate microstructure which represents 68% of the total gridsquares from the Boyken samples described as having this type of microstructure.

Depth in soil profile

A possible relationship between the existence of certain parameters and the depth in the soil profile from which the sample comes had been identified during the Level 1 work and it was considered important to test for this possible relationship again during the Level 2 work. Although the depth of each gridsquare from the surface of the soil profile was recorded during the Level 2 work, it was not entered as a variable during the HCA procedure. However, this data was also analysed using the Kruskal-Wallis one-way analysis of variance by ranks test to see if there were any significant differences in depth between the cases grouped in the clusters. The median for each cluster was also calculated and is given in Table 6.4. The depth of the gridsquares in Cluster 1 were found to be too similar to both Clusters 2 and 3 to be statistically significant. However, a significant difference was found between Clusters 1 & 4 and 1 & 5. These findings are supported by the median data in Table 6.4 and cross-tabulation of the raw data provides further evidence to support the Kruskal-Wallis test results (Table 6.14). Only 31% of gridsquares in Cluster 1 are located at a depth of >20cm. A very similar proportion of the gridsquares in Cluster 2 are also within this depth range whilst Cluster 3 has the third lowest figure for this parameter. In comparison, Clusters 4 and 5 have much higher proportions of their cases at this depth.

	Depth from surface of soil profile in cm (No. of gridsquares)					
Level 2 Clusters	**2.5-10.5**	**11.0-20.0**	**20.5-29.5**	**30.0-39.0**	**39.5-47.0**	**% gridsquares at >20cm depth**
Cluster 1	82	114	63	24	1	31
Cluster 2	26	14	16	1	0	30
Cluster 3	1	3	3	1	3	64
Cluster 4	1	10	16	16	3	76
Cluster 5	0	0	1	5	16	100

Table 6.14 - Cross-tabulation of depth data - Boyken Level 2.

Cluster 2 differs significantly from Clusters 3, 4 and 5 but not from Cluster 1. Again, this is supported by the median and cross-tabulation calculations. The cases in Cluster 3 only differ statistically from Cluster 2. This result is not supported by the cluster median data as there is actually a larger difference between the medians for Clusters 3 and 5 than for Clusters 3 and 2. Similarly, the cross-tabulation calculations in Table 6.14 show a 2% greater difference between Clusters 3 and 5 than between Clusters 3 and 2. However, if the percentage of gridsquares which occur at a depth of >10.5cm is calculated (Table 6.15), it can be shown that there is a 37% difference in the figures for Clusters 3 and 2 but only 9% between Clusters 3 and 5.

Percentage of gridsquares per cluster at >10.5cm depth from surface of soil profile				
Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
71	54	91	98	100

Table 6.15 - Difference in depth in profile for Level 2 clusters (>10.5cm) - Boyken

Cluster 4 is found to have a statistical difference, at the 95% confidence level, to Clusters 1, 2 and 5. This is supported by the cluster median results (Table 6.4) and the percentage of gridsquares per cluster at >20.0cm depth given in Table 6.14. There is only a 16% difference between Clusters 3 and 4 compared to a 45%, 46% and 24% difference with Clusters 1, 2 and 5, respectively.

Cluster 5 therefore shows a significant difference from Clusters 1, 2 and 4 which is supported by the cluster median results. However, neither the results from Tables 6.14 nor 6.15 show Cluster 3 to have the figure closest in value to that of Cluster 5 in order to support the non-significant result for this comparison. In both cases, Clusters 4 and 5 are found to be the closest results. The results of the Kruskal-Wallis tests comparing Cluster 5 with other clusters appear to be influenced by the proportion of the gridsquares in each cluster which are at a depth of >39.0cm (Table 6.16). From this calculation, it can be shown that Clusters 3 and 5 have the highest and second highest percentages of gridsquares at this depth.

Percentage of gridsquares in each cluster at >39.0cm depth in the soil profile				
Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
0	0	27	6	73

Table 6.16 - Difference in depth in profile for Level 2 clusters (>39.0cm)- Boyken.

From this analysis, it would appear that the depth of the gridsquares from the soil surface, although not directly used in the HCA process, may indicate a reason for the differences in certain micromorphological characteristics identified between the clusters created during the HCA process.

In summary, Cluster 1 and 2 both have similarly high quartz content, low sandstone content and high cell residue content. Cluster 1, however, contains only moderate amounts of mamillate excrement, virtually no spheroidal excrement and the majority of the gridsquares in this cluster display a subangular blocky microstructure. In contrast, the gridsquares grouped in Cluster 2 contain the highest amounts of mamillate and spheroidal excrement. Cluster 3 groups all the gridsquares which are located over large sandstone fragments or voids. Cluster 4 has a moderately low quartz and high sandstone and cell residue content. These gridsquares also contain low amounts of mamillate and spheroidal excrement and 50% have a spongy microstructure. The gridsquares in Cluster 5 have a similarly low quartz and high sandstone content as those in Cluster 4 but, in contrast, they have a low cell residue content and contain moderate amounts of mamillate and spheroidal excrement. The majority of the gridsquares also demonstrate a gefuric related distribution and an intergrain microaggregate microstructure.

Table 6.17 summarises the characteristics of each cluster by comparing the ordinal data in relative terms from the highest to the lowest contents across the clusters. The most significant types of nominal parameters per cluster are also presented and the results of the analysis by depth are provided for information.

	Differentiating characteristics per Level 2 Cluster - Boyken				
Micromorphological Parameters	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
Quartz content	Highest (=2)	Highest (=1)	Lowest	3rd lowest	2nd lowest
Basic distribution of quartz	-	-	None present	-	-
Referred distribution of quartz	-	-	None present	-	-
Quartz grain shape	-	-	None present	-	-
Sandstone content	2nd lowest	Lowest	Highest	3rd highest	2nd highest
Basic distribution of sandstone	-	-	-	-	-
Referred distribution of sandstone	-	-	-	-	-
Cell residue content	Highest	2nd highest	Lowest (none)	3rd highest	2nd lowest
Basic distribution of cell residue	-	-	-	-	-
Mamillate excrement content	2nd highest	Highest	Lowest	2nd lowest	3rd highest
Basic distribution of mamillate excrement	Clustered	-	None present	-	-
Spheroidal excrement content	3rd highest	Highest	Lowest (=4)	Lowest (=3)	2nd highest
Basic distribution of spheroidal excrement	-	Clustered	-	-	-
Microstructure	Subangular blocky	-	-	Spongy	Intergrain microaggregate
Related distribution	-	-	-	-	Gefuric
Depth	2nd shallowest (≅2)	Shallowest (≅1)	3rd deepest	2nd deepest	Deepest

Table 6.17 - Summary of differentiating characteristics of each Level 2 cluster. Note: The ordinal data is presented for each cluster relative to the others. Only the nominal characteristics which show a large grouping either per cluster and/or in terms of the site total for that characteristic are shown. Some parameters have similar values in 2 clusters. The cluster with the similar value for that parameter is indicated in brackets.

6.4 Interpretation - Boyken

The Level 2 results for Boyken show far more statistically significant differences between the clusters for all parameters measured as ordinal data than the Level 1 results and it is therefore difficult to associate one particular micromorphological characteristic with one cluster. The exception is the small Cluster 3. As with the Level 1 results, it is much easier to identify and interpret the diagnostic features of the smaller clusters. For example, Cluster 3 contains only 11 cases which are all gridsquares located entirely over large sandstone fragments or soil voids which gives extreme or unusual recordings for all parameters. Similarly, sixteen of the 22 cases grouped in Cluster 5 are from one slide, 1/56B, which makes this cluster and its particular characteristics fairly easy to interpret. The grouping of cases into the larger clusters is much harder to interpret and explain in terms of one particular characteristic. These clusters appear to have been created by using a combination of different parameters and the differences between clusters can generally only be described in terms of the amount of each parameter relative to the other clusters.

The basic and referred distributions of minerals, cell residue or excrement rarely produce sufficient variation to be a significant distinguishing characteristic. As discussed in Chapter 4, it was considered useful to describe these characteristics in order to test for any possible trends or particular characteristics which could be interpreted as indicative of past anthropogenic activity such as localised manure input or disturbance from cultivation. No significant differences in the distribution of sandstone fragments with reference to the soil surface were recorded in any great numbers. This does not, therefore, appear to be a useful micromorphological parameter for identifying past cultivation in these soils. Similarly, the lack of variation in both the basic and referred distribution of cell residue suggests that these are not useful parameters for identifying possible evidence of manuring practices in the past in these soils.

Slight differences in the basic distribution of excrement do appear to occur between certain clusters but these are not statistically significant results. The clustered basic distribution of both mamillate and spheroidal excrement is more common than a random distribution. This may be because of the grid recording method but it is also common that excremental pedofeatures occur *in situ*. For example, the faecal evidence of *Oribatid* mites is often found inside the remaining cell walls of roots (Fitzpatrick, 1993). Whether the clustered distribution of excrement reflects anything more than the *in situ* comminution of organic material such as bracken roots is doubtful. Few identifiable organic tissues remained in order to establish whether the organic material had been introduced to the soil as an organic manure from another source. The clustered basic distribution is therefore considered to be a natural phenomenon rather than indicating any past localised application of organic manures.

The contents of quartz, sandstone, cell residue and excrement all produce statistically significant differences between at least 2 clusters. This suggests that these parameters have been used during the HCA process to group the 420 cases into their respective clusters. However, it is difficult to establish one particular property which is unique to each cluster. From Table 6.3, it can be seen that a combination of a number of these different micromorphological characteristics have been used to distinguish the clusters from each other. These differences have been shown in section 6.3 and are often fairly subtle, requiring detailed examination of the data to confirm the statistical results.

The large data set produced during the Level 2 description means that the statistical tests can identify even very subtle differences and prove them to be statistically significant. It is much harder to appreciate these subtle differences by scanning the data with the naked eye. For example, studying the range of results for each parameter which were recorded for the gridsquares of each slide grouped in each cluster, it is almost impossible to identify trends and differences, either between the slides grouped in the same cluster or between clusters (Appendix 6). This makes it very difficult to make interpretations on why the cases have been grouped together as they have. Certainly, these descriptions have not been grouped together according to the context from which they were sampled such as rig and furrow, small enclosures or outwith the bounded field system. Cluster 1, for example contains gridsquares from slides from all of these contexts as well as from polygon 22. This is a large polygon with several parallel dividing earth banks which have been interpreted during the archaeological work as being of early origin, probably predating the field layout in the east of the site. Apart from the earth banks there is no evidence of ploughing in this polygon. This grouping together of cases from such a wide range of contexts suggests that the micromorphological evidence described during Level 2 cannot be directly associated with past anthropogenic activities.

It is also very difficult to identify any differences between the slides from different contexts grouped in each cluster. The cell residue content of the vast majority of gridsquares (86%) grouped in Cluster 1 is 5%. Similarly, spheroidal excrement content is consistently 0% with only 10 of the 284 gridsquares containing 5%. The 41 gridsquares which do contain more than 5% cell residue content mainly occur in samples from between 2-15cm in the profile. This is also true for the few gridsquares in Cluster 2 which contain more than 5% cell residue. This is not surprising since the majority of organic inputs and decomposition of organic matter occurs in the upper few centimetres of the soil.

It is much harder to find any trends in the mineral content of the slides. The quartz and sandstone content of the gridsquares from each slide shows the most variation. For example, the quartz content of the 15 gridsquares from slide 26/30A which are grouped in Cluster 1 ranges from 0-40% and the sandstone content ranges from 0-60% (Appendix 6). There is some evidence of a converse relationship between quartz and sandstone content. The majority of the gridsquares from slides 5/52A-D and 30(1)A and B in Cluster 1 have quartz contents of 30-35%. In comparison, most of these gridsquares contain only 0-10% of sandstone. This appears to be the case for all clusters. This is not unexpected as the mineral content of these soils is consistently high across the site. Sandstone and quartz are the two main minerals found in these soils and, therefore, any reduction in the presence of one of these requires an increase in the presence of the other in order to maintain the consistent mineral content. However, this is merely an observation and does not explain the clusters produced by the HCA of the Level 2 results.

Most of the slides have the majority of their gridsquares grouped in one cluster. Also, many of the trenches are predominantly represented in one cluster. For example, the majority of gridsquares from each of the slides from Trench 5/52 are grouped in Cluster 1. A few gridsquares from these slides are also grouped in Clusters 2 and 4. However, these "anomalous" gridsquares also seem to have a consistency down the profile as all four slides are represented in Cluster 2 and three are represented in Cluster 4. This grouping together of cases from entire trench profiles reflects the homogeneous nature of the Boyken soils vertically down through the profile. The grouping together of so many slides from different contexts within the field system also reflects the homogeneous nature of the soil horizontally across the site.

Slides 1/56A & B and 30(1)B demonstrate particular diversity in comparison to the other slides. Both of the slides from Trench 1/56 have their gridsquare descriptions spread across four of the clusters whilst slide 30(1)B is represented in all 5 clusters. These slides appear to have the greatest within-slide variability for a variety of parameters but it is hard to distinguish the important feature responsible for the presence of certain gridsquares in different clusters. For example, it is difficult to establish why one gridsquare from the upper section of slide 1/56A has been grouped in Cluster 2 rather than Cluster 1. The mineral, cell residue and mamillate excrement content of this gridsquare all fall within the range of the gridsquares from 1/56A grouped in Cluster 1. The only obvious difference is that this gridsquare contains 10% spheroidal excrement whilst those in Cluster 1 contain none. The 3 gridsquares grouped in Cluster 4 merely differ in cell residue content and the 4 grouped in Cluster 5 have a slightly higher sandstone content as well as containing some spheroidal excrement. All of these differences are extremely subtle and demonstrate the sensitivity of the HCA process to such a large data set.

It can be noted that the soil profile in trench 1/56 is the only one described at Level 2 which clearly has past anthropogenic activity demonstrated by the rig and furrow morphology of the land surface. A tentative interpretation that the variability within the top 2 slides from this profile is due to human disturbance is tempting but it is not supported by the fact that slide 30(1)B shows even more variability and comes from a trench dug outwith the field system. The most sensible interpretation is therefore that natural spatial variability is responsible for this separation of the gridsquares in each of these slides into several different clusters.

The Level 2 clusters show marked differences in depth in the profile, although this parameter was not included during the HCA process. It, therefore, appears, that the micromorphological characteristics found to distinguish each cluster from the others are closely associated with the depth of the samples in the profile. This is similar to the Level 1 results and it would again appear that the differentiating characteristics of these soils are due to natural pedological differences associated with depth in the profile rather than any possible anthropogenic influences. Indeed, it is very hard to identify any characteristics from this clustering of the Level 2 data which may be interpreted as indicative of past agricultural practices. The Level 2 data is regrouped according to field class and discussed in Chapter 7 in order to establish whether any such interpretations can be made by using the data in this manner.

6.5 Analysis - Badentarbat

The 421 cases of Level 2 raw data for Badentarbat were run through the Gower's coefficient of similarity and Hierarchical Cluster Analysis in the same way as the Level 2 raw data from Boyken. Again, the top six coefficient jumps were ranked and examined to determine which cluster solution would be used in this classification. Stage 1 in the process again produced the largest coefficient jump and was disregarded. Stage 4 produced the second largest coefficient jump and resulted in the data being split into 4 clusters with 38, 38, 12 and 333 members. The third largest coefficient jump occurred during Stage 2 when the data set was split into 2 groups with 76 and 345 members, respectively. Stage 5 created 5 clusters with 38, 38, 12, 160 and 173 members and corresponded to the 4th highest coefficient jump. The fifth highest coefficient jump occurred when the data was split into 7 groups of 38, 38, 3, 9, 160, 29 and 144 members and the sixth highest corresponded with Stage 6 when the data were split into 6 groups of 38, 38, 12, 160, 29, and 144 members.

Although the 4 cluster solution appeared to be the most significant because it was ranked higher than the Stage 2 solution, it was decided to follow the same policy as had been adopted for analysing the Boyken Level 2 data. The slides selected for description in Level 2 represented samples from 5 different field classes. The 5 cluster solution was therefore selected.

Table 6.18 summarises the soil thin sections from which the gridsquares clustered in each Level 2 cluster belong. As for the Boyken data, several slides are represented in more than one cluster which would appear to suggest that the Level 2 descriptive work demonstrates that within-slide variability is perhaps greater than between-slide variability.

Level 2 Clusters	Slides containing gridsquares grouped in each cluster
Cluster 1	36C-E, 42C, 44C, 46A&B,C Upper,D Lower & E, 49A,B&C Upper, 54A-D
Cluster 2	36A-E, 46A&D Lower, 49A&B Lower, 54A&B
Cluster 3	42A-C, 44A-C, 46A&B,C Lower,D & E Top Left, 49B Upper & C, 54B-D
Cluster 4	36A, 42B, 44C, 46C Lower, 49C Lower
Cluster 5	36A-D

Table 6.18 - Summary of gridsquares grouped in each Level 2 cluster according to slide/sub-section in which they are located - Badentarbat Level 2

	Level 2 Cluster (No. of gridsquares per cluster)				
Thin Section	1	2	3	4	5
36A	0	1	0	0	**17**
36B	0	3	0	1	**14**
36C	1	**11**	0	0	6
36D	**12**	5	0	0	1
36E	**13**	5	0	0	0
42A	0	0	**18**	0	0
42B	0	0	**17**	1	0
42C	2	0	**16**	0	0
44A	0	0	**18**	0	0
44B	0	0	**18**	0	0
44C	9	0	8	1	0
46A	**16**	1	1	0	0
46B	**15**	0	3	0	0
46C Upper	**11**	0	0	0	0
46C Lower	0	0	**8**	1	0
46D Upper	0	0	**11**	0	0
46D Lower	**4**	0	3	0	0
46E Top left	2	0	2	0	0
46E Lower	**11**	6	0	0	0
49A	**16**	2	0	0	0
49B Upper	**7**	0	2	0	0
49B Lower	**7**	2	0	0	0
49C Upper	**4**	0	3	0	0
49C Lower	1	0	4	**8**	0
54A	**17**	1	0	0	0
54B	**14**	1	3	0	0
54C	3	0	**15**	0	0
54D	8	0	10	0	0

Table 6.19 - Results of Level 2 micromorphological description illustrated by the number of gridsquares grouped in each Level 2 cluster and sorted by thin section - Badentarbat Level 2

However, this can only be assessed by examining the number of gridsquares from each slide grouped in each cluster. This information is provided in Table 6.19. The information in Table 6.19 shows that the vast majority of the slides have a high proportion of their gridsquare descriptions grouped in one cluster. These clusterings are highlighted in bold. Only five slides do not demonstrate this uniformity.

Thin sections 44C, 46E Top left, 49C Upper and 54D all appear to have approximately 50% of their respective gridsquares each in Clusters 1 and 3 whilst the lower sub-section of slide 46D has its total of 13 described gridsquares spread across Clusters 1, 2 and 3. From this evidence, it does, therefore, appear that between-slide variation is greater than within-slide variation. This shall be discussed more fully in Section 6.8.

Analysis of the Level 2 raw data using the Kruskal-Wallis one-way analysis of variance by ranks, cluster medians and examination of the raw data using basic manual cross-tabulation showed that a number of micromorphological parameters had been used during the HCA procedure to produce the 5 cluster solution. The differentiating characteristics of the gridsquares in each cluster are summarised in Table 6.20. The information in Table 6.20 was derived from the range of analytical methods given above. Table 6.21 provides the cluster medians for the ordinal and interval data for reference.

Level 2 Clusters	Ordinal data	Nominal data
Cluster 1	Quartz content Sandstone content Cell residue content Mamillate excrement content Spheroidal excrement content	Basic distribution of mamillate excrement Microstructure Related distribution
Cluster 2	Quartz content Cell residue Mamillate excrement	Related distribution
Cluster 3	Quartz content Sandstone content Cell residue content Mamillate excrement Spheroidal excrement	Basic distribution of mamillate excrement Microstructure Related distribution
Cluster 4	Quartz content Cell residue content	Basic distribution of quartz Referred distribution of quartz Shape of quartz grains Basic distribution of cell residue Microstructure Related distribution
Cluster 5	Quartz content Cell residue content Mamillate excrement content Spheroidal excrement content	Basic distribution of mamillate excrement Basic distribution of spheroidal excrement Microstructure Related distribution

Table 6.20 - Level 2 micromorphological characteristics which differentiate each cluster from the others - Badentarbat Level 2

	Medians of interval/ordinal data for each Level 2 Cluster				
Micromorphological parameters	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
% Quartz content	25	5	35	85	10
% Sandstone content	5	0	5	0	0
% Cell residue content	5	10	5	0	10
% Mamillate excrement content	0	5	0	5	15
% Spheroidal excrement content	0	0	0	0	5
Depth (cm)	19.5	33	22.5	23	22

Table 6.21 - Cluster medians for interval/ordinal data from Level 2 description - Badentarbat Level 2

Cluster 1

Cluster 1 has 173 members and 11 of the 28 slides or sub-sections described during the Level 2 work have a high proportion of their respective gridsquares grouped in this cluster (Table 6.19). Four of the five types of ordinal data indicate that Cluster 1 is significantly different (95% C.I.) to at least two other clusters. The quartz content of the gridsquares in this cluster is found to be significantly different to all the other clusters. From the medians provided in Table 6.21, the cases in Cluster 1 appear to contain the third lowest or, alternatively, the third highest, amounts of quartz. A simple cross-tabulation of the raw data confirms this. Table 6.22 shows that 68% of the gridsquares in Cluster 1 contain >15% quartz grains compared to 18%, 94%, 75% and 0% for Clusters 2, 3, 4 and 5, respectively.

The sandstone content of the Cluster 1 members differs statistically from Clusters 2, 3 and 5. This does not appear to be true if only the median data is examined as Clusters 1 and 3 share the same median of 5% sandstone content whilst Clusters 2, 4 and 5 contain a median of 0% for this parameter. However, cross-tabulation of the raw data shows that only 7% of the gridsquares in Cluster 1 contain >15% sandstone fragments (Table 6.23). Cluster 4 produces a very similar result with only 8% of the gridsquares containing the same amount of sandstone. In comparison, Clusters 2, 3 and 5 have 3%, 18% and 0% of their gridsquares, respectively, with >15% sandstone fragments. A similar situation occurs with the cell residue content data.

Level 2 Clusters	Percentage content of quartz grains (No. of gridsquares)																					% of gridsquares per cluster with >15% quartz
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	
Cluster 1	0	38	5	13	15	17	33	26	9	2	4	4	0	1	2	0	3	1	0	0	0	68
Cluster 2	0	25	6	0	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18
Cluster 3	0	1	2	7	5	11	32	48	29	7	4	3	1	0	1	0	3	2	2	0	0	94
Cluster 4	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	5	2	0	0	75
Cluster 5	0	11	26	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 6.22 - Cross-tabulation of quartz grain content data - Badentarbat Level 2

Level 2 Clusters	Percentage content of sandstone fragments (No. of gridsquares)																					% of gridsquares per cluster with >15% sandstone
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	
Cluster 1	67	84	9	3	4	1	2	0	2	1	2	0	0	0	0	0	0	0	0	0	0	7
Cluster 2	35	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3
Cluster 3	6	77	32	19	6	7	4	3	3	2	2	0	0	0	0	0	0	1	0	0	0	18
Cluster 4	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8
Cluster 5	34	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 6.23 - Cross-tabulation of sandstone content data - Badentarbat Level 2

Level 2 Clusters	Percentage of cell residue (No. of gridsquares) 0	5	10	15	20	25	30	% of gridsquares per cluster with >5% cell residue
Cluster 1	9	124	32	1	7	0	3	25
Cluster 2	0	5	25	1	3	0	4	87
Cluster 3	12	145	3	0	0	0	0	2
Cluster 4	8	4	0	0	0	0	0	0
Cluster 5	0	1	21	13	3	0	0	97

Table 6.24 - Cross-tabulation of cell residue data - Badentarbat Level 2

Cluster 1 is found to significantly differ from all other clusters in terms of cell residue content. However, the median data again shows that Clusters 1 and 3 have similar medians, as do Clusters 2 and 5 (Table 6.21). Again, a further breakdown of the raw data using basic manual cross-tabulation (Table 6.24) shows that 25% of the Cluster 1 gridsquares contain >5% cell residue compared to 87%, 2%, 0% and 97% for Clusters 2, 3, 4 and 5, respectively.

The results for mamillate excrement content showed that Cluster 1 only differed from Clusters 2 and 5 for this parameter. The cluster medians given in Table 6.21 for this parameter again suggest that there may be problems with these results. However, cross-tabulation of the raw data appears to demonstrate that the Kruskal-Wallis test results are valid (Table 6.25). The percentage of gridsquares in Clusters 1, 3 and 4 are too similar to produce statistically significant differences between these clusters but the figures for Clusters 2 and 5 are sufficiently different to give the results from the Kruskal-Wallis one-way analysis of variance by ranks test.

Level 2 Clusters	Percentage of mamillate excrement (No. of gridsquares) 0	5	10	15	20	25	% of gridsquares per cluster with >5% excrement
Cluster 1	152	16	4	1	0	0	3
Cluster 2	6	24	5	1	1	1	21
Cluster 3	149	10	1	0	0	0	1
Cluster 4	15	7	0	0	0	0	0
Cluster 5	0	6	7	9	14	2	84

Table 6.25 - Cross-tabulation of mamillate excrement data - Badentarbat Level 2

The evidence for differences in the spheroidal excrement content of the slides in each cluster also illustrates a similar trend. The spheroidal excrement content of the gridsquares in Cluster 1 are found to be significantly different at the 95% confidence level from Clusters 4 and 5 but, again, the median data suggests that there is no difference between Clusters 1-4 for this parameter (Table 6.21). Simple cross-tabulation of the Level 2 raw data, however, may suggest that the findings from the Kruskal-Wallis one-way analysis of variance by ranks tests can be accepted. Table 6.26 shows the distribution of the spheroidal excrement content data and the proportion of gridsquares from each cluster which contain this feature. This simple breakdown of the raw data demonstrates that Clusters 1 and 3 are probably too similar to produce a statistically significant difference between these clusters whilst Clusters 2, 4 and 5 may be sufficiently different from Cluster 1 to give the results found with the Kruskal-Wallis tests.

	Percentage of spheroidal excrement (No. of gridsquares)			
Level 2 Clusters	**0%**	**5%**	**10%**	**% of gridsquares per cluster with >0% excrement**
Cluster 1	173	0	0	0
Cluster 2	36	2	0	5
Cluster 3	159	1	0	1
Cluster 4	11	1	0	9
Cluster 5	3	32	3	92

Table 6.26 - Cross-tabulation of spheroidal excrement content data - Badentarbat Level 2

The lack of any mamillate excrement from 152 of the 173 gridsquares grouped in Cluster 1 also results in the same number of cases having no basic distribution of mamillate excrement. However, it has already been shown that this low level of mamillate excrement is not exclusive to this cluster and both Clusters 1 and 3 show very similar trends for this pedofeature. A range of microstructures are demonstrated by the gridsquares in Cluster 1 but 67% of the total number of gridsquares from the Badentarbat site which demonstrate a spongy microstructure are grouped in Cluster 1. One hundred percent of the occurrences of crack and massive microstructure from the Badentarbat samples are also grouped in this cluster although these total only 4 gridsquares. However 21 of the 23 gridsquares from this site which have been described as having a crumb microstructure are also grouped in Cluster 1 as well as 19 of the 24 with vughy microstructure. All 82 of the gridsquares from the Badentarbat site with a close porphyric related distribution are also in Cluster 1. Ninety of the remaining ninety-one gridsquares in Cluster 1 have an open porphyric related distribution which represents 54% of the site total.

Cluster 2

Cluster 2 contains 38 gridsquares, 11 of these coming from thin section 36C (Table 6.19). Again, quartz content is a significant differentiating factor between this cluster and all others apart from Cluster 5. The cluster medians given in Table 6.21 appear to support this finding with Cluster 2 having a median of 5% quartz content whilst Cluster 5 has a median of 10%. Cluster 2 also differs from Clusters 1, 3 and 4 in terms of cell residue content and, again, this appears to correspond with the median data in Table 6.21. The mamillate excrement content of the gridsquares in Cluster 2 only shows a significant difference from those in Clusters 1 and 3. The median data in Table 6.21 would appear to suggest that there should also be a significant difference between Clusters 2 and 5. The cross-tabulation of the mamillate excrement data across the five clusters is given in Table 6.25 along with the percentage of cases which contain >5% content of this pedofeature. From these results, it would still seem that there is a larger difference between Clusters 2 and 5 than between Clusters 1 and 2, which have been found to be statistically different at the 95% confidence level. However, if the data is further analysed and the percentage of cases which contain >0% mamillate excrement is calculated for each cluster, then Clusters 2 and 5 are found to produce much more similar results (Table 6.27).

Percentage of gridsquares containing >0% mamillate excrement per Level 2 cluster				
Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
12	84	7	58	100

Table 6.27 - Proportion of gridsquares per cluster which contain some mamillate excrement Badentarbat Level 2

All the gridsquares grouped in Cluster 2 have an open porphyric related distribution. This represents only 23% of the total number of gridsquares from the Badentarbat samples but related distribution may be one of the group of parameters which are used to distinguish this cluster from the others.

Cluster 3

The one hundred and sixty gridsquares grouped in Cluster 3 show a significant difference in quartz content from Clusters 1, 2 and 5 but not from Cluster 4. This is surprising given that the difference between cluster median for this parameter between Clusters 3 and 4 is bigger than those between Clusters 1& 3 and 2 & 3 (Table 6.21). Again, cross-tabulation of the raw data provides some evidence to support the findings from the analysis of variance tests. Table 6.22 shows the results of this simple analysis and the percentage of gridsquares in each group which contain >15% of quartz grains. The proportion of gridsquares in Clusters 3 and 4 with a quartz grain content of >15% is much more similar at 94% and 75%, respectively, than the median values of 35% for Cluster 3 and 85% for Cluster 4. There is a much greater difference, however, between the percentage of gridsquares in Cluster 3 with >15% quartz grain content and that of Clusters 1, 2 and 5. The sandstone content results also show similar problems with the cluster median data.

Cluster 3 is found to differ significantly from all other clusters in terms of sandstone fragment content. However, the cluster medians for this parameter given in Table 6.21 show little variation, with Clusters 1 and 3 both having a median of 5% sandstone content. Cross-tabulation of the raw data once again provides some better information to support the analysis of variance results (Table 6.23). Eighteen percent of the cases grouped in Cluster 3 contain more than 15% sandstone fragments whilst all other clusters merely contain 0-8% content of this parameter.

The mamillate excrement content of Cluster 3 is only found to significantly differ from Clusters 2 and 5 from the results of the Kruskal-Wallis test. Whilst the cluster median data would appear to support this finding, it can also be assumed from the median data that Cluster 3 should also significantly differ to Cluster 4 given that Cluster 4 has the same median as Cluster 2 (Table 6.21). Recourse to cross-tabulation of the raw data provides the necessary level of detailed information to allow the Kruskal-Wallis results to be accepted. The results in Table 6.25 show that there is very little difference in the percentage of gridsquares in Clusters 1, 3 and 4 which contain >5% mamillate excrement. Only 1% of the gridsquares in Cluster 3 contain this level of mamillate excrement whilst Clusters 1 and 4 contain 3% and 0%, respectively. This is not a large enough difference to prove statistically significant. Clusters 2 and 5, however, clearly contain much more of this pedofeature with values of 21% and 84%, respectively.

The results of the Kruskal-Wallis tests show that Cluster 3 significantly differs in spheroidal excrement content from Clusters 2, 4 and 5 but not from Cluster 1. The cluster median data do not appear to support this finding (Table 6.21) but from the cross-tabulation data in Table 6.26, it can be seen that the percentage of gridsquares in Clusters 1 and 3 containing some spheroidal excrement are very similar at 0% and 1%, respectively. Clusters 2, 4 and 5, however, show a greater difference with percentage values of 5%, 9% and 92%, respectively.

The lack of mamillate excrement in a large proportion of the gridsquares in Cluster 3 also results in a significant number of the gridsquares having no basic distribution of this pedofeature. However, this only represents 47% of the total number of gridsquares from the Badentarbat site which also display this characteristic. In fact, 98% of the site total is almost evenly split between Clusters 1 and 3. However, microstructure and related distribution seem to be important features used to differentiate Cluster 3 from the others. All 160 of the gridsquares in this cluster have an intergrain microaggregate microstructure and a gefuric related distribution which represents 95% of the site total for each of these parameters.

Cluster 4

Cluster 4 is the smallest cluster with only 12 members. Of these 12 cases, 8 are located in the lower section of Slide 49C. This cluster significantly differs (95% C.I.) from Clusters 1, 2 and 5 in quartz grain content. This appears to correspond with the cluster median data but the difference between the medians for Clusters 3 and 4 also appear to be sufficiently different to create a statistically significant result. However, as discussed under Cluster 3, examination of the cross-tabulation data in Table 6.22 shows that the proportion of gridsquares containing >15% quartz grains in Clusters 3 and 4 are most similar at 94% and 75%, respectively. It can also be seen from this table that, whilst a large proportion of the gridsquares in this cluster contain a high percentage of quartz grains, 3 out of the 12 cases actually contain no quartz at all. Examination of the Level 2 raw data shows that 2 of these 3 gridsquares contain no features at all and merely represent a hole or void in the soil sample. The third gridsquare is found to have a 100% sandstone content which indicates that this gridsquare is situated over a large fragment of sandstone.

The cell residue content of Cluster 4 is also significantly different to that in Clusters 1, 2 and 5. Again, the cluster median data suggests that Cluster 3 should also be significant as it has the same median as Cluster 1 (Table 6.21). However, the results from the cross-tabulation of the cell residue data given in Table 6.24 show that the percentage of gridsquares in Clusters 3 and 4 which contain >5% of this micromorphological feature is very similar at 2% and 0%, respectively. In comparison, Clusters 1, 2 and 5 have much higher proportions containing this level of cell residue.

The 3 gridsquares in this cluster which cover either a void or a large fragment of sandstone give rise to the only descriptions of no basic or referred distribution of quartz and no quartz shape. Similarly, the only 3 related distribution descriptions of "no matrix" relate to these 3 anomalous gridsquares clustered in Cluster 4. The other 9 gridsquares have a gefuric related distribution which represents the remaining 5% of the site total for this type of related distribution . Cluster 3 contains the other 95%.

Cluster 5

The quartz content of the 38 gridsquares grouped in Cluster 5 is found to significantly differ from Clusters 1, 3 and 4. From the cluster medians in Table 6.21, Cluster 5 appears to have the second lowest quartz grain content but there is only 5% difference in the median for this cluster and Cluster 2. This suggests that the quartz content of these 2 clusters is too similar to be statistically different. The percentage of gridsquares in Clusters 2 and 5 which have a quartz content of >15% (Table 6.22), however, is 18% and 0%, respectively. Although these are the two lowest figures for this level of quartz content, there is still a difference of 18% between these figures whilst Clusters 1 and 4 are found to be statistically significant with only a 7% difference. However, if we look at the percentage of gridsquares in each cluster which have >45% quartz content (Table 6.28), we see that Clusters 1 and 2 have the same figure of 0%.

Percentage of gridsquares in each cluster containing >45% quartz content				
Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
9	0	8	75	0

Table 6.28 - Difference in quartz content between Level 2 clusters - Badentarbat Level 2

The cell residue content of the gridsquares in Cluster 5 significantly differs from that of Clusters 1, 3 and 4. The cluster median data (Table 6.21) appear to support this as Clusters 2 and 5 both have a median of 10% cell residue content. The percentage of cases containing >5% of cell residue in Clusters 2 and 5 is also relatively similar at 87% and 97%, respectively (Table 6.24).

Mamillate excrement is found to be a significant differentiating factor between Cluster 5 and Clusters 1, 3 and 4. This time the cluster median data does not appear to support this result as Cluster 2 has the same median value (5%) as Cluster 4 (Table 6.21). The data in Table 6.25, detailing the percentage of gridsquares in each cluster which have a mamillate excrement content >5%, also does not appear to provide convincing evidence to support the Kruskal-Wallis findings. Although the values for Clusters 2 and 5 are the highest at 21% and 84%, respectively, there is still a substantial difference between these figures. However, if the percentage of gridsquares which contain >0% mamillate excrement are calculated (Table 6.27), then it can be seen that the values for Clusters 2 and 5 are still the highest but are now much more similar.

Cluster 5 only significantly differs from Clusters 1 and 3 in terms of spheroidal excrement content. Again, the cluster median data (Table 6.21) cast doubt on this result as Clusters 1-4 all have a median of 0%. The information provided in Table 6.27 also does not show conclusively that there is only a substantial difference between the percentage of gridsquares containing >0% mamillate excrement in Clusters 1&5 and 3&5. These figures merely indicate that there is a greater difference between these cluster pairings than there is between Clusters 2&5 and 4&5.

A high proportion of the gridsquares in Cluster 5 have the same type of basic distribution of mamillate and spheroidal excrement. Thirty-seven of the 38 cases in this cluster have a random basic distribution of mamillate excrement. This represents 63% of the site total for this parameter, with the other 37% being located in Cluster 2. Similarly, 31 of the 38 cases have a random basic distribution of spheroidal excrement which represents 94% of the site total. Again, the other 6% are located in Cluster 2.

All thirty-eight of the gridsquares in Cluster 5 have a spongy microstructure, although this represents only 22% of the total number of cases from the Badentarbat site with this type of microstructure. Similarly, all the Cluster 5 cases have an open porphyric related distribution, representing only 23% of the site total for this micromorphological parameter.

Depth in soil profile

Although the depth of each gridsquare from the surface of the soil profile was recorded during the Level 2 descriptive work, it was not included in the HCA process as a micromorphological feature. It was, however, analysed to assess whether there were any statistically significant differences in the depth of the gridsquares grouped in each cluster. The Kruskal-Wallis one-way analysis of variance by ranks test results showed that the depth of the gridsquares in Cluster 2 were significantly different to those in Clusters 1, 3 and 5. The median data in Table 6.21 also supports this finding as Cluster 2 has a median depth of 33cm whilst Clusters 1, 3, 4 and 5 have very similar medians of 19.5cm, 22.5cm, 23cm and 22cm, respectively. However, it would seem that 22.5cm is the closest depth value to 33cm that is statistically significant at the 95% confidence level, as Cluster 4 is not found to differ significantly from Cluster 2, despite the median depth for Cluster 4 being only 0.5cm deeper than Cluster 3, which is. Again, simple cross-tabulation of the results reveals that there is a greater similarity between the depths of the gridsquares grouped in Clusters 2 and 4 than can be shown by cluster medians alone (Table 6.29).

	Depth from surface of soil profile in cm (No. of gridsquares)					
Level 2 Clusters	**2.5-16.5**	**12.0-21.0**	**21.5-30.5**	**31.0-40.0**	**40.5-50.0**	**% of gridsquares per cluster at >21.0cm depth**
Cluster 1	46	47	23	24	33	46
Cluster 2	4	4	6	12	12	79
Cluster 3	31	38	59	30	2	57
Cluster 4	0	3	8	1	0	75
Cluster 5	0	18	15	5	0	53

Table 6.29 - Cross-tabulation of depth data - Badentarbat Level 2

From Table 6.29, it can be seen that Clusters 2 and 4 have similar percentages of their gridsquares at a depth of more than 21.0cm from the surface of the soil profile, whereas Clusters 1, 3 and 5 have much lower percentages at this depth. The depth of the gridsquares in Clusters 1, 3 and 5 is too similar to give statistically significant results using the Kruskal-Wallis test.

In summary, the gridsquares in Cluster 1 contain moderate amounts of quartz, sandstone, cell residue and mamillate excrement content. They contain no spheroidal excrement at all and demonstrate a range of different types of microstructure. Approximately half the gridsquares are described as having an open porphyric related distribution whilst the remainder demonstrate a close porphyric related distribution. Cluster 2 is characterised as having a low mineral content but a high cell residue and mamillate excrement content. Spheroidal excrement content, however, is low but this is not unique to this cluster and the open porphyric related distribution of the gridsquares in this cluster is also not an exclusive feature of this cluster. In contrast, Cluster 3 has a high mineral content - especially sandstone - and, conversely, a low cell residue, mamillate and spheroidal excrement content. All the gridsquares in this cluster demonstrate an intergrain microaggregate microstructure and a gefuric related distribution. Cluster 4 is also characterised by a high quartz content but only a moderate sandstone content. It has the lowest cell residue and mamillate excrement content and a generally low spheroidal excrement content. The majority of the gridsquares also have a gefuric related distribution. The gridsquares in Cluster 5 have the lowest mineral content and, conversely, the highest cell residue, mamillate and spheroidal excrement content. They demonstrate a spongy microstructure and an open porphyric related distribution.

The differentiating characteristics of each Level 2 Cluster created using the Badentarbat data are summarised in Table 6.30. The percentage content of each of the measured parameters is shown in a ranking format across the clusters. The descriptive parameters which differentiate a cluster from the others is given when either the majority of the cases grouped in that cluster display the same characteristic or when the majority of the cases found with the same characteristic from all the Badentarbat slides are located in one cluster. The relative depth of the gridsquares in each cluster is given relative to the others and is deduced from the cross-tabulation of the raw data. As discussed above, not all cluster comparisons give significantly different differences in statistical terms but this table provides a means of examining the data in simple terms in order to identify any possible relationships between the parameters described during the Level 2 description. It is also possible to compare the results from Boyken and Badentarbat using Tables 6.17 and 6.30, respectively. This will be discussed in Section 6.7.

6.6 Interpretation - Badentarbat

The Kruskal-Wallis one-way analysis of variance by ranks test is highly sensitive when dealing with the large number of cases which constitute the Level 2 data. Even small differences between clusters

Micromorphological Parameters	Differentiating characteristics per Level 2 Cluster - Badentarbat				
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Quartz content	3rd highest	2nd lowest	Highest	2nd highest	Lowest
Basic distribution of quartz	-	-	-	-	-
Referred distribution of quartz	-	-	-	-	-
Quartz grain shape	-	-	-	-	-
Sandstone content	2nd highest	2nd lowest	Highest	3rd highest	Lowest
Basic distribution of sandstone	-	-	-	-	-
Referred distribution of sandstone	-	-	-	-	-
Cell residue content	3rd highest	2nd highest	2nd lowest	Lowest	Highest
Basic distribution of cell residue	-	-	-	-	-
Mamillate excrement content	2nd lowest	2nd highest	Lowest	3rd highest	Highest
Basic distribution of mamillate excrement	None present (≅3)	-	None present (≅1)	-	Random
Spheroidal excrement content	Lowest (≅3)	3rd highest	2nd lowest (≅1)	2nd highest	Highest
Basic distribution of spheroidal excrement	-	-	-	-	Random
Microstructure	Mainly spongy	-	Intergrain microaggregate	-	Spongy
Related distribution	Open & close porphyric	Open porphyric	Gefuric	Mainly gefuric	Open porphyric
Depth	Shallowest	Deepest	3rd shallowest	2nd deepest	2nd shallowest

Table 6.30 - Summary of differentiating characteristics of each Badentarbat Level 2 cluster. Note: The ordinal data is presented for each cluster relative t others. Only the nominal characteristics which show a large grouping either per cluster and/or in terms of the site total for that characteristic are shown. Some parameters have similar values in 2 clusters. The cluster with the similar value for that parameter is indicated in round brackets.

become statistically significant because of the volume of data being analysed. This results in many of the recorded parameters being shown to differ between more than 2 clusters and subsequently no single distinguishing characteristic can be identified for each cluster. Rather, a combination of different characteristics can be associated with each cluster. As with the Boyken data, these characteristics can often only be described in terms of content relative to the other clusters.

In Cluster 1, eleven slides have 50% or more of their gridsquare descriptions grouped in this cluster (Table 6.19). Although the overall observation of the cluster is that these gridsquares are characterised by containing moderate amounts of quartz and sandstone, this is not true for all the cases grouped in this cluster. This further suggests that other parameters, other than mineral content, have been instrumental in creating this clustering pattern. For example, all the gridsquares from slides 36C, D and E, which are grouped in Cluster 1, contain only 5% quartz and no sandstone which is well below the moderate mineral content identified for this group as a whole (Appendix 6). In contrast, several of the gridsquares from slides in Trench 49 contain 50% or more of quartz and slide 44C has six of its nine gridsquares in this cluster described as having ≥20% sandstone content. The most common sandstone content for this cluster is 5%. However, all of these gridsquares are consistently described as containing no mamillate excrement. It could be argued that this indicates that mamillate excrement content is the key distinguishing feature of this cluster. However, the gridsquares in Cluster 3 also have similar recordings for mamillate excrement. If only excrement content were used to create Cluster 1, it seems reasonable to expect the gridsquares from other clusters, also having no mamillate excrement content, to be grouped in this cluster. It must, therefore, be a combination of the range of parameters recorded which is used to distinguish the clusters from each other.

The Level 2 results have not been grouped during the HCA process according to the field class from which they were sampled, despite the fact that these slides were specifically chosen to represent the main field types identified at Badentarbat. Some trends in the clustering process according to soil texture can be identified although these are less clear than for the Level 1 results. For example, the gridsquares grouped in Cluster 1 come from a range of different trenches and also from a range of soil textures. The majority are from peats and loamy or sandy peats but 3 slides from sandy clay loam horizons also have a substantial number of gridsquares grouped in this cluster. It is, therefore, difficult to state that this grouping of slides is related directly to the soil textures assigned in the field. All other clusters, apart from Cluster 5, also contain gridsquares from horizons with a range of different soil textures. However, a dominant soil texture can be identified for each of these clusters and often the occurrences of other soil textures relates only to a small number of gridsquares from each slide. For example, Cluster 3 consists mainly of gridsquares sampled from sandy clay loam and loamy sand horizons. Some peat and peaty horizons are also represented in this cluster but these never constitute more than 3 gridsquares from one particular slide. Only 14 gridsquares out of the total of 160 grouped in this cluster come from horizons described as pure peats or loamy or sandy peats. All the other gridsquares predominantly come from sandy clay loams but also from loamy sands. Similarly loamy peats and pure peats are the main soil textures found in Cluster 2 and only loamy peats from Trench 36 are grouped in Cluster 5. This suggests that soil texture may, again, have some significant influence on the Level 2 HCA process. However, the Cluster 1 cases do not support this simple interpretation and other influences must also be playing a part in the HCA process.

Within-slide variability is demonstrated to some degree by the range of values recorded for each parameter in the gridsquares from each slide (Table 6.19). However, the majority of gridsquares from many slides have been grouped together in one cluster which suggests that within-slide variability is only really significant in a small proportion of gridsquares per slide. Indeed, examination of the ordinal Level 2 data grouped by Level 2 cluster and illustrating the range of results per slide in each cluster, shows that many of the slides produce fairly consistent results over the majority of gridsquares for each parameter (Appendix 6). For example, of the 15 gridsquares from slide 46B which are grouped in Cluster 1, fourteen contain between 25-40% of quartz with the remaining gridsquares containing only 15% of this parameter. The results for sandstone, cell residue and excrement content are even more consistent. Sandstone content ranges only from 0-10%, whilst all 15 gridsquares have a recorded cell residue content of 5%. Thirteen of the gridsquares contain no mamillate excrement whilst 2 only contain 5% and no spheroidal excrement is recorded in any of these gridsquares. This grouping together of the majority of gridsquares in each slide is clearly important and it is considered useful to pay particular attention to the slides in each cluster represented by a significant number of gridsquares in order to try to explain the grouping pattern produced by the HCA process.

Even when only the slides with significant numbers of their described gridsquares grouped in Cluster 1 are considered, it is difficult to find obvious similarities between all of the slides. For example, slide 46A has 16 gridsquares grouped in this cluster which contain 5-35% of quartz. Slide 49A also has 16 gridsquares grouped in this cluster but the quartz content of these gridsquares ranges from 25-70%. Several of these slides have gridsquares with quartz content between 20-35% but this is not consistently the case. Slides 36D and E, for example, have 12 and 13 gridsquares respectively represented in this cluster but all of these gridsquares contain only 5% quartz. The cases grouped in Cluster 1 have clearly not been grouped together merely because of similar quartz contents. A similar situation occurs for all other ordinal parameters.

The majority of gridsquares contain no more than 5% sandstone fragments but slides 44C and 54A both have several gridsquares which contain ≥15%. Most gridsquares contain only 5% of cell residue but slide 49A has 16 of its gridsquares grouped in this cluster and 13 of these contain 10-30% of this parameter. Similarly, most gridsquares contain no mamillate excrement but several gridsquares in slide 46A contain 5-15%. It is, therefore, very difficult to provide any convincing reasons why these gridsquares have been grouped together in one cluster. Differences between slides from different trenches in Cluster 1 can be identified and generally attributed to differences in soil texture and depth in the profile but this does not explain why these soils from quite different contexts have been grouped together.

The highest recordings of sandstone content in Cluster 1 are from the sampled sandy clay loam horizons in Trenches 44 and 54. High sandstone content is also a feature of the gridsquares from slides 44A-C which are grouped in Cluster 3 but the sandstone content of those from Slides 54B-D grouped in this cluster is no more than 15%. This does not suggest that the gridsquares from the sandy clay loams have been separated into different clusters according to sandstone content. In fact, the gridsquares from slide 44C which have been grouped in Cluster 1 have very similar results for all ordinal parameters to those from slide 44C which are grouped in Cluster 3. These two groups of gridsquares from the same slide are distinguished by having different microstructures and related distributions of the coarse and fine mineral fractions. Those grouped in Cluster 1 have a crumb microstructure and a close porphyric related distribution whilst those grouped in Cluster 3 have an intergrain microaggregate microstructure and a gefuric related distribution. However, it is difficult to attribute the grouping of cases in Cluster 1 to one particular type of microstructure as a number of different types are represented in this cluster. Microstructure does not, therefore, appear to be a key distinguishing feature for Cluster 1.

The 3 slides from the top of the profile in Trench 46 are some of the few which contain gridsquares containing mamillate excrement in Cluster 1. This mamillate excrement content is greatest in the top slide, 46A, with up to 15% in one gridsquare. A gradual decrease is seen down through the profile until no mamillate excrement is found below 40cm. This suggests that earthworm activity is greatest in the upper few centimetres of the profile and that they do not inhabit soils deeper than 40cm. This corresponds to the findings of European earthworm activity when introduced to soils under grassland in New Zealand. Bomb Carbon-14 was used to trace the movement of organic matter down through the profile by European earthworms. Carbon-14 was detected at 18cm depth in the soils with earthworms and at only 10cm in those without. In addition, soils with earthworms were found to contain 30% more carbon in the upper 40cm of the profile than soils without, indicating that earthworms actively transport organic matter from the soil surface to a depth of 40cm (Stout, 1983). The results for Trench 54 also indicate that earthworm activity is detectable at 40cm depth but the opposite distribution trend of mamillate excrement is demonstrated down through the profile. No mamillate excrement is found in the top slide from this profile but up to 10% is found in slides 54B and C and 3 gridsquares in slide 54D, sampled from a depth of 32-40cm, contain 5% of this pedofeature. Trench 54, as discussed in Section 5.5, is located in a small enclosure and the soils are described as having a sandy clay loam texture. It may be that the higher mineral content of these soils enables greater earthworm activity at depth. No samples were taken below 40cm in order to be able to establish if 40cm was also the limit of earthworm activity in this trench.

The gridsquares grouped in Cluster 2 commonly contain 5% of mamillate excrement but, again, decreasing earthworm activity down through the profile is indicated by the results from Trench 36. A maximum of 25% mamillate excrement is found in Slide 36A. This steadily decreases down through slides 36B-D until virtually no mamillate excrement is found in slide 36E at a depth of 44-52cm. Again, this shows remarkable agreement with the results from the New Zealand study (Stout, 1983). This is also true for the gridsquares from this trench which are grouped in Cluster 5.

The separation of the gridsquares from the Trench 36 slides into Clusters 2 and 5 appears to be based on spheroidal excrement content. Quartz, sandstone, cell residue and mamillate excrement content is similar for all of these gridsquares but those grouped in Cluster 2 contain no spheroidal excrement whilst those in Cluster 5 contain up to 10%. In contrast, the gridsquares from Trenches 46, 49 and 54 also grouped in Cluster 2 appear to be separated from the other gridsquares from these trenches because of their lower mineral content. For example, none of the gridsquares from Trench 46 grouped in Cluster 3 contain spheroidal excrement. This is also true for those grouped in Cluster 2. However, up to 60% quartz and 35% sandstone content is recorded for those in Cluster 3 compared to a maximum of only 25% quartz content for those grouped in Cluster 2. None of the gridsquares in Cluster 2 contain any sandstone fragments.

The relatively high quartz and sandstone content identified during the statistical analysis as characteristic of Cluster 3 is not clearly demonstrated by all of the cases grouped in this cluster. The slides from one or two particular trenches do, however, show this trend and can be interpreted as influencing the results obtained from the statistical analysis. The high quartz content associated with Cluster 3 can mainly be attributed to the influence of gridsquares from the slides of Trenches 46 and 49. The high sandstone content is influenced by Slides 44A-C. However, it is hard to identify patterns in the quartz and sandstone content in this cluster which are clearly distinct from the other clusters. The mineral content of the gridsquares grouped in this cluster must not, therefore, be the only characteristic used by the HCA process to create this cluster. All of these gridsquares have two characteristics in common; all display an intergrain microaggregate microstructure and all have a gefuric related distribution. Since these are the only characteristics which are consistent for all gridsquares in the cluster, it seems reasonable to assume that these have played an important part in the grouping together of these slides to create Cluster 3.

Cluster 4 groups together all the gridsquares which are located in areas of very high quartz grain concentration with little or no fine material, over large sandstone fragments or over large voids in the soil sample. Eight gridsquares from the lower section of slide 49C make up the majority of this cluster. This horizon was described as loamy sand during the field description but the evidence from the thin section description suggests that this horizon is almost a pure sand. Only 3 of the gridsquares contained any cell residue but 7 were described as containing 5% mamillate excrement which would suggest that some organic material has been present in this soil at some point in its history.

Cluster 5 contains only gridsquares from Trench 36, with the majority coming from slides 36A and B. This cluster groups almost all the occurrences of spheroidal excrement found in the Badentarbat samples and this is probably the single most important distinguishing characteristic for this cluster. Mamillate excrement and cell residue content are also high but the mineral content of these gridsquares is consistently low with no more that 15% quartz and only a maximum of 5% sandstone fragments. All of these slides were sampled from loamy peat horizons and it would appear that the lack of mineral content did not greatly limit soil faunal activity in this profile. The excremental evidence correlates very closely with the cell residue content down through the profile and the reduction in both cell residue and excrement content with depth probably reflects the age of these features as well as the effects of faunal bioturbation.

The hierarchical cluster analysis process carried out on the Level 2 data appears to have used a number of different parameters to create the 5 clusters. No conclusive interpretations can be made to explain the gridsquares grouped together in Cluster 1. This cluster, more than any of the others, appears to use a combination of the different parameters in order to distinguish it from the others. Differences in soil texture can be more confidently proposed as an explanation for the creation of Clusters 2 and 3. Cluster 4 groups together the cases with extreme recordings for quartz content and Cluster 5 groups together most of the gridsquares which contain spheroidal excrement which also contain slightly higher amounts of cell residue than the gridsquares in other clusters. This clustering pattern bears no relation to the field classes from which the thin sections originate and, therefore, no interpretation of past agricultural use can be inferred by the examination of the data in this format. The Level 2 data will be examined according to field class membership in Chapter 7 in order to explore any possible micromorphological characteristics which may be associated with these different areas of the field system.

6.7 Comparison of Boyken and Badentarbat sites

The results of the Level 2 micromorphological description work are much harder to interpret than the Level 1 results for both sites. However, the variation in soil textures and types found across the Badentarbat site provides some evidence on which to base a tentative interpretation. Differences in mineral content are fairly obvious between the peaty soils and the sandy clay loams. However, there is nothing to suggest that the clustering pattern created by the HCA process has any association with the field classes represented by the samples described in Level 2. This is true for both sites and the data needs to be further explored in order to establish whether any micromorphological differences can be found between the samples from the different contexts within the field systems.

The difference in the sampling depth of the slides in each cluster provides the best evidence on which to base an interpretation of the Boyken results. The differences in mineral, cell residue and mamillate content between the clusters is particularly subtle. This is probably due to the homogeneous nature of the soils. This homogeneity is further demonstrated by the lack of variability in microstructure and types of related distribution of the fine and coarse mineral fractions of these soils. Similarly, the basic and related distribution of quartz, sandstone, cell residue and excremental pedofeatures did not show any significant variation for either site. The number of cases which did demonstrate a slight difference in basic or related distribution of a particular parameter was too small to propose a convincing interpretation.

Only a very tentative interpretation of the Level 2 HCA results could be put forward for either site. Some observations could be made and explanations given for the separating of gridsquares from the same slide into more than one cluster but large clusters are particularly difficult to interpret. These large clusters often produce a wide range of results which makes it hard to identify one single distinguishing characteristic for the cluster in question. Often the only conclusion that can be drawn is that a combination of the different parameters has been used in order to group the cases together. Although these sites produced quite different results, they were both equally hard to interpret, despite the large number of statistically significant differences found between clusters using the Kruskal-Wallis one-way analysis of variance by ranks test. However, this large number of significant results is symptomatic of the large data set produced during the Level 2 description.

6.8 Comparison of Level 1 and Level 2 results

Several similarities can be identified between the Level 1 and Level 2 description work and the subsequent hierarchical cluster analysis results for both sites. The Level 1 clusters for each site can be shown to share similar characteristics with at least one cluster from the Level 2 work. For example, the Level 1 Cluster 1 (L1C1) for Boyken is most similar to the Level 2 Cluster 1 (L2C1). Both these clusters contain cases with high amounts of quartz and moderate amounts of spheroidal excrement. From Table 6.31, it can be seen that 3 of the Level 1 clusters for Boyken are most like Level 2 Cluster 1. It might be argued that this evidence indicates that the 3 cluster solution should have been chosen for the Level 1 results. However, the cases grouped in Level 1 Clusters 1, 3 and 4, which are most similar to Level 2 Cluster 1, are never grouped together during the HCA process. The 3 cluster solution is therefore not the explanation. The large Cluster 1 created during the HCA of the Level 2 data appears to indicate that the slides selected for description during the Level 2 work are a more homogeneous group than the entire group of slides from the Boyken site described during the Level 1 work.

Level 1 Cluster	*most like* Similar Parameters	Level 2 Cluster
Cluster 1	High quartz content Moderate spheroidal excrement content	Cluster 1
Cluster 2	Low cell residue content Gefuric related distribution	Cluster 5
Cluster 3	Low sandstone content High mamillate excrement content Subangular blocky microstructure	Cluster 1
Cluster 4	High cell residue content	Cluster 1
Cluster 5	Spongy microstructure	Cluster 4

Table 6.31 - Similarities between Level 1 and Level 2 clusters for Boyken. Note: Level 2 Cluster 3 merely contains gridsquares which overlay large sandstone fragments and voids. Level 2 Cluster 2 is only similar to Level 1 Cluster 4 in terms of depth in the profile which was not a parameter used during the hierarchical cluster analysis procedure.

Further analysis of the Level 1 data is required in order to establish the reasons for this apparent reduction in heterogeneity in the cases described during Level 2. Seven parameters were described at both Levels 1 and 2; quartz, sandstone, cell residue, mamillate and spheroidal excrement content, microstructure and related distribution. The analysis of the Level 1 data in Chapter 5 considered all of the slides from the Boyken site. Only a selection of these slides were used during the Level 2 work. The slides selected for the Level 2 work were chosen for their sampling context within the field system.

Thus, slides from trenches in each of the 4 main field classes created during the HCA of the field classification data were selected as well as some from profiles outwith the field system (Field Class 7). The slides were not, therefore, selected to represent the different Level 1 clusters. These selected slides must be re-analysed in order to establish if they display the same characteristics as those identified for the Level 1 clusters created from considering all of the Boyken samples. Cell residue content, mamillate excrement and spheroidal excrement content, microstructure and related distribution were all found to differentiate between at least 2 clusters during the Level 1 analysis of all the Boyken data. When only the Level 1 results for the slides selected for use in Level 2 are considered, no significant differences are found between the Level 1 clusters for the ordinal data. However, microstructure and related distribution can be shown to demonstrate some differences between the selected slides in each Level 1 cluster, although this is not statistically significant. From this evidence, it can be argued that the selected slides for the Level 2 work are not representative of the Level 1 clusters and their associated characteristics. Indeed, analysis of the significant difference in parameters only described during the Level 1 description shows that the results for the selected slides only correlate with those for all of the slides with regard to amorphous black organic material content (Table 6.32). This suggests that the characteristics which have been identified for the Level 1 clusters using all of the data cannot be applied to sub-groups of this data.

RESULTS FOR ALL SLIDES	**RESULT FOR SLIDES SELECTED FOR LEVEL 2 DESCRIPTION ONLY**
Variables used in both Level 1 and Level 2 descriptions showing a significant difference between Level 1 clusters or identifiable trends (nominal data)	
Cell residue content Mamillate excrement content Spheroidal excrement content ***Microstructure*** ***Related distribution***	***Microstructure*** ***Related Distribution***
Variables used only in Level 1 description showing a significant difference between Level 1 clusters	
Organic residue content ***Amorphous black organic material content*** Lignified tissue content Parenchymatic tissue content Amorphous red brown organic material	***Amorphous black organic material content***

Table 6.32 - Distinguishing features between Level 1 clusters for all slides described at Level 1 compared to those selected for Level 2 description - Boyken. (Features found to be significant for both groups are highlighted in bold italics).

However, there is a much greater correlation between the results for all of the slides and the selected slides when the data is considered according to field class membership rather than Level 1 cluster membership (Table 6.33). Very few significant differences in micromorphological features were found between the different field classes represented by the slides described at Level 1 for Boyken (see Chapter 7 for full discussion). Nevertheless, cell residue and mamillate excrement content were found to be significant distinguishing features when all of the slides were considered as well as only those selected for Level 2 description. Similarly, the siltstone content (which was only used during the Level 1 description) was also found to differ significantly between the field classes for both the selected slides and the entire Boyken set of slides. The slides used for the Level 2 description work are therefore much more representative of the different types of field class from which they were sampled than the Level 1 cluster in which they were grouped during the Level 1 HCA process.

<table>
<tr><th>RESULTS FOR ALL SLIDES</th><th>RESULT FOR SLIDES SELECTED FOR LEVEL 2 DESCRIPTION ONLY</th></tr>
<tr><td colspan="2">Variables used in both Level 1 and Level 2 descriptions showing a significant difference between Field Classes</td></tr>
<tr><td><i>Cell residue content</i>
<i>Mamillate excrement content</i></td><td><i>Cell residue content</i>
<i>Mamillate excrement content</i></td></tr>
<tr><td colspan="2">Variables used only in Level 1 description showing a significant difference between Field Classes</td></tr>
<tr><td><i>Siltstone content</i></td><td><i>Siltstone content</i>
Amorphous black organic material content</td></tr>
</table>

Table 6.33 - Distinguishing features between Field Classes for all slides described at Level 1 compared to those selected for Level 2 description - Badentarbat. (Features found to be significant for both groups are highlighted in bold italics).

The Badentarbat data also show similarities between the Level 1 and Level 2 clusters (Table 6.34). Only slides from three of the five Level 1 clusters were used for the Level 2 work. The Badentarbat descriptions show a slightly different trend to that of Boyken. The large Level 1 Cluster 1 is most similar to Level 2 Clusters 1, 2 and 5. This suggests that the 7 cluster solution may have been more appropriate for the Level 1 data. However, this large cluster is not split into 3 in order to create the 7 cluster solution. The 57 cases in Cluster 1 are split into 2 groups of 37 and 20 cases in the 7 cluster solution. The seventh cluster is created by splitting Cluster 2 into one group of 11 cases and one group of 7 cases. Again, an alternative cluster solution does not provide an easy rectification of this apparent overlap between clusters from the two levels. The three Level 2 clusters which are most like L1C1 have certain characteristics in common such as spongy microstructure and porphyric related distribution but these are combined with other parameters to produce a different combination for each Level 2 cluster. The more detailed level of description at Level 2 has clearly identified some further subtle differences between the cases grouped in L1C1.

Compared to the Boyken results, more statistically significant differences were found between the Level 1 clusters for Badentarbat. Quartz, sandstone, mamillate and spheroidal excrement content as well as microstructure and related distribution were all found to play a part in the separating of the Level 1 data into the five clusters. The Badentarbat slides used for the Level 2 work were also chosen to represent the 4 main field classes from the field classification as well as areas outwith the field system (Field Class 0). The slide selection was not based on the slides displaying the differentiating characteristics between field classes which had been identified during the statistical analysis. Rather, the slides were chosen for their representation of the field context and the soil types found in each and the quality of the soil thin section. As discussed earlier, several of the peaty thin sections had been particularly problematic to produce and, subsequently, several had a considerable variation in thickness across the slide, making identification of certain features difficult. These slides were therefore avoided for the Level 2 work.

Level 1 Cluster	***most like*** **Similar Parameters**	**Level 2 Cluster**
Cluster 1	Low mamillate excrement content Spongy microstructure Porphyric related distribution	Cluster 1
	High quartz content High spheroidal excrement content Porphyric related distribution	Cluster 2
	High cell residue content Spongy microstructure Porphyric related distribution	Cluster 5
Cluster 2	High mamillate excrement content	Cluster 4
Cluster 3	-	Not described
Cluster 4	High sandstone content Intergrain microaggregrate microstructure Gefuric related distribution	Cluster 3
Cluster 5	-	Not described

Table 6.34 - Similarities between the Level 1 and Level 2 clusters for Badentarbat.

The differentiating characteristics between field classes for the selected slides have to be compared with those found between the different field classes for all the Badentarbat slides during the Level 1 work in order to establish whether these are truly representative in micromorphological terms or not (Table 6.35). Again, these differentiating characteristics can be split into 2 groups. The first group consists of all the parameters which were described at both Level 1 and Level 2. For all the slides described at Level 1, only mamillate and spheroidal excrement content were shown to be significantly different between the different field classes. However, when only the data for the selected slides were analysed, the single differentiating characteristic was found to be cell residue content. The second group of variables to be considered are those that were only used during the Level 1 description. Differences in feldspar, fungal spore, amorphous yellow orange organic material and amorphous and cryptocrystalline coatings content were found between the different field classes when all the Badentarbat slides were considered. In contrast, only amorphous red brown organic material and amorphous and cryptocrystalline coatings were found to differentiate between the slides from the different field classes selected for the Level 2 work. This suggests that the slides selected for the Level 2 work do not reflect the differentiating micromorphological characteristics between field classes which were identified for the entire Badentarbat data set for Level 1. The distinguishing features between the Level 1 clusters for the entire Badentarbat data set and the small group of slides selected for the Level 2 work must be examined in order to establish whether these two groups show greater similarities to one another.

RESULTS FOR ALL SLIDES	RESULT FOR SLIDES SELECTED FOR LEVEL 2 DESCRIPTION ONLY
Variables used in both Level 1 and Level 2 descriptions showing a significant difference between Field Classes	
Mamillate excrement content Spheroidal excrement content	Cell residue content
Variables used only in Level 1 description showing a significant difference between Field Classes	
Feldspar content Multi-cell fungal spore content Amorphous yellow orange organic material content ***Amorphous & cryptocrystalline coating content***	Amorphous red brown organic material content ***Amorphous & cryptocrystalline coating content***

Table 6.35 - Distinguishing features between field classes for all slides described at Level 1 compared to those selected for Level 2 description - Badentarbat (Features found to be significant for both groups are highlighted in bold italics)

Table 6.36 presents the results of the analysis of the Badentarbat data when grouped by Level 1 cluster. From this, it can be seen that the slides selected for the Level 2 description work show significant differences between the Level 1 clusters for quartz and sandstone content, microstructure and related distribution. These are also found to be distinguishing features between the Level 1 clusters when all the Badentarbat data is considered. Equally, these two groups both show significant differences in 6 parameters which were not described during the Level 2 work. This suggests that the slides selected for the Level 2 work are actually much more representative of the Level 1 clusters that they were grouped in rather than the field class context from which they were sampled. This explains the statistically significant result of the cross-tabulation of the Level 1 and Level 2 clusters for Badentarbat, despite only three of the five Level 1 clusters being represented by the slides selected for Level 2.

RESULTS FOR ALL SLIDES	RESULT FOR SLIDES SELECTED FOR LEVEL 2 DESCRIPTION ONLY
Variables used in both Level 1 and Level 2 descriptions showing a significant difference between Level 1 Clusters or identifiable trends (nominal data)	
Quartz content ***Sandstone content*** Mamillate excrement content Spheroidal excrement content ***Microstructure*** ***Related distribution***	***Quartz content*** ***Sandstone content*** Cell residue content ***Microstructure*** ***Related Distribution***
Variables used only in Level 1 description showing a significant difference between Level 1 Clusters	
Feldspar content Multi-cell fungal spore content ***Lignified tissue content*** ***Parenchymatic tissue content*** Amorphous black organic material content ***Amorphous & cryptocrystalline nodule content*** ***Amorphous & cryptocrystalline coating content*** ***B-fabric***	***Feldspar content*** Phytolith content ***Lignified tissue content*** ***Parenchymatic tissue content*** Organic residue content ***Amorphous & cryptocrystalline nodule content*** ***Amorphous & cryptocrystalline coating content*** ***B-fabric*** Mineral colour

Table 6.36 - Distinguishing features between Level 1 clusters for all slides described at Level 1 compared to those selected for Level 2 description - Badentarbat. (Features found to be significant for both groups are highlighted in bold italics).

Although the Level 2 data gave more statistically significant results between the Level 2 clusters than were found for the Level 1 data and the Level 1 clusters, neither of these clustering patterns shows any correlation with the field contexts from which the soil thin sections were sampled. Other factors must therefore be found to explain the clustering patterns produced during the HCA of both the Level 1 and Level 2 data. The most convincing interpretation of the Boyken Level 1 clustering pattern was that the micromorphological features which are indicative of natural pedological processes at certain depths in the soil profile have been the most influential in creating the Level 1 clusters. Despite many more statistically significant results between the Level 2 clusters, it was much more difficult to interpret these results. The difference in most parameters between the Level 2 clusters was very subtle and only very tentative interpretations could be proposed. It appeared that a combination of the recorded parameters had been used to a greater degree to create the Level 2 clusters. The large clusters were particularly difficult to explain as they appeared to contain cases with a large range of recordings for mineral content and, to a lesser degree, for other measured parameters. Again, the most convincing interpretation of the Level 2 clusters was that the cases in each cluster were associated with distinctly different depths in the profile.

The Level 1 data and clustering pattern for Badentarbat could be most convincingly explained by differences in soil texture and type. The Level 2 data and clusters for Badentarbat were also much more difficult to explain and interpret than the Level 1 results, despite better statistical results. Again, a combination of parameters have been used by the HCA to produce the Level 2 clusters. However, the differences in parameters between clusters can be identified more easily for the Badentarbat site than for the Boyken site. This is probably due to the greater variability in the soils at Badentarbat. The larger Level 2 clusters were, again, harder to explain than the smaller clusters but trends in the different soil textures represented in each cluster could be illustrated. Different soil textures were again proposed as the most likely explanation of the Level 2 clustering pattern.

The interpretations of the Level 1 and Level 2 results and subsequent clustering patterns are thus very similar for both sites. This might suggest that there is no real advantage in undertaking the more labour-intensive Level 2 description work as the same interpretations can be achieved by using the Level 1 descriptions. However, certain questions must be asked of the Level 2 methodology: Should all of the slides have been described at this level, too? Was the best sub-group picked for the Level 2 work? Were the right micromorphological parameters described at Level 2?

It was logistically impossible to undertake the Level 2 work for all 126 soil thin sections within the timescale of the research project. Had this been undertaken, the data sets produced for Level 2 would have been at least three times the size of those created using the group of selected slides. It has been shown that the HCA process and the statistical tests are very sensitive when approximately 420 cases are considered in each Level 2 data set and this makes explanation and interpretation of the Level 2 results very difficult. It is considered likely that larger data sets would merely increase the sensitivity of the HCA process and statistical tests to differences between cases and clusters which would further complicate the task of determining the meaning of the results. Using soil micromorphology to interpret archaeological landscapes necessitates the collection and description of large numbers of slides. Standard, full descriptions of soil thin sections take even experienced micromorphologists several hours per slide (Murphy *et al*, 1985) and generates a large amount of information for each slide which must then be analysed and interpreted. An attempt was made during this research to develop a description method with a more targeted approach which allowed the salient characteristics of a large number of slides to be described, analysed and interpreted. It was considered possible that the important information could be gathered through two possible routes: by describing a fairly large range of micromorphological parameters for the entire thin section, or by undertaking a number of more detailed descriptions of a smaller number of parameters across each thin section. The selection of the relevant micromorphological parameters was based upon past micromorphological studies and personal knowledge of the sites and their soils. In order to be able to compare the results from the two sites, the same parameters were described for each. Several of the parameters chosen for both the Level 1 and Level 2 work showed little, if any, variation between slides or gridsquares and can therefore be considered not useful for identifying possible differences. It must be accepted that other parameters not used during this research may provide further useful information and should replace the non-useful parameters identified during this first attempt. This can only be tested by further research. It can also be argued that the range of parameters used in this research have not been adequately tested on a large enough range of sites to conclude that the non-variable parameters are, indeed, not useful for studying soils from medieval farm systems in Scotland. However, a first attempt at any new methodology can never hope to achieve all the answers. Pilot studies are commonly used to test new theories, methods and products and the research undertaken for this project is merely considered to be the first step in trying to develop an understanding of Scottish medieval or later field systems using micromorphological techniques and quantitative analysis where possible.

The method of selecting slides for the Level 2 work has been shown, through post-hoc statistical analysis, to be less representative of the field classes of Badentarbat than originally thought at the time of selection. The Boyken samples, however, do seem to more accurately reflect the different field contexts from which they come. Although the selection of the slides for description at Level 2 was based on a combination of the results of the desk-top field classification of each site and logistical and practical considerations, it may also have been prudent to undertake the full statistical analysis of the

Level 1 results prior to starting the Level 2 work. However, it took several months, despite the help of a professional statistician, to explore the Level 1 data and identify statistical tests which could usefully analyse the range of data produced during the micromorphological description. Decisions on the Level 2 work, therefore had to be made before analytical techniques were fully developed. However, the Level 2 results from this research do not conclusively show that the method of selection was inappropriate as the chosen Boyken slides were found to be more representative of the field class from which they came, rather than the Level 1 cluster in which they had been placed. The lack of representativeness of the field classes displayed by the Badentarbat slides described at Level 2 may merely be due to the significant variability of the soils at this site over-riding any slight possible micromorphological evidence of variations in agricultural practice which may exist. The lack of any conclusive micromorphological evidence for any anthropogenic activity, let alone different agricultural practises in the more homogeneous soils of Boyken suggests that the soil evidence for such activities in these historical sites may be limited. Again, this needs to be further tested on other sites across Scotland.

The Level 2 work was also carried out in order to test whether within-slide variability was actually greater than the variability between slides identified during the Level 1 work. Within-slide variability was not found to be significant in the slides from either site. Cell residue content, spheroidal excrement content, microstructure and related distribution results were all found to be highly consistent for the slides from both sites. Mamillate excrement content showed some within-slide variation for some slides but not all. Quartz and sandstone content are the parameters which produced the greatest range of results but often the distribution pattern of the results of the Level 1 and Level 2 work are similar (Figures 6.1 and 6.2).

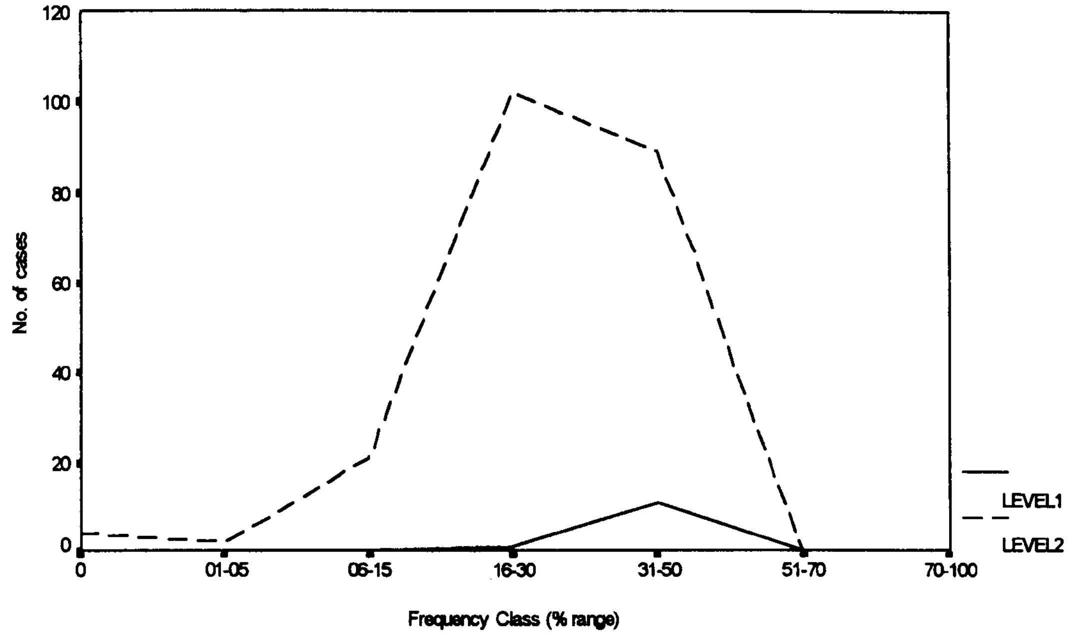

Figure 6.1 - Comparison of Level 1 and Level 2 data grouped by Level 1 Cluster. Quartz content, Cluster 4 - Boyken.

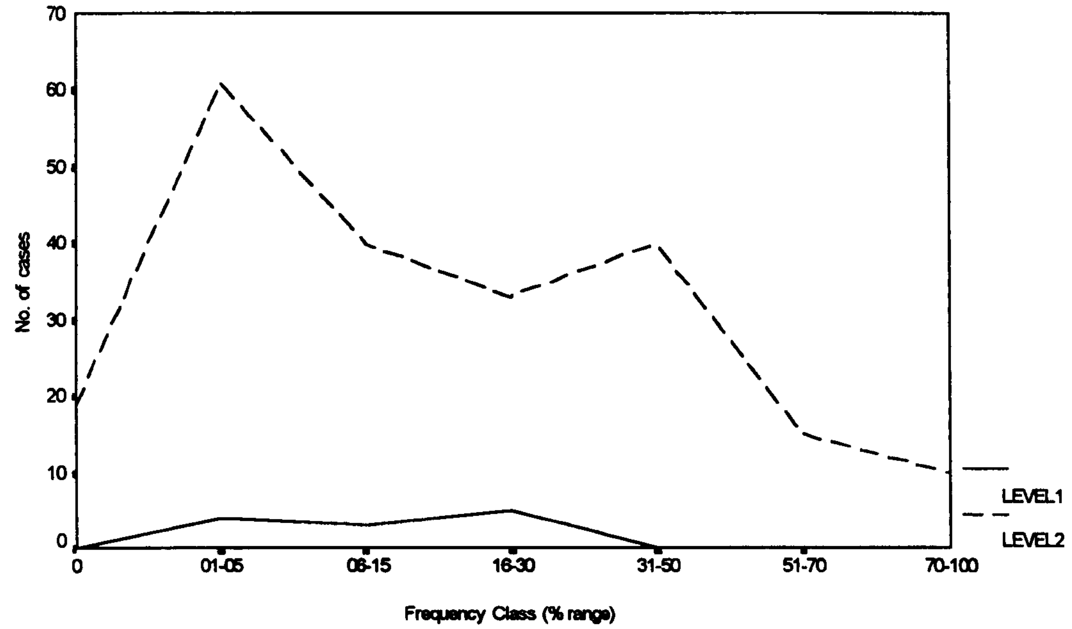

Figure 6.2 - Comparison of Level 1 and Level 2 data grouped by Level 1 Cluster. Sandstone content, Cluster 4 - Boyken.

There appears to be a general tendency to over-estimate the quartz content of slides during the Level 1 description (Figure 6.1). The size, shape and distribution of quartz within these soil thin sections is highly variable. This makes it hard to give an accurate "guesstimate" of the total quartz content of a slide. Guidelines for estimated abundance of features are provided in the Handbook for Soil Thin

Section Description (Bullock *et al.*, 1985, p.24-25) but these are presented as individual diagrams of the abundance of objects of a uniform size. A range of sizes at different abundance rates are depicted but it is up to the individual micromorphologist to estimate the total abundance within a slide when a range of sizes are present. It is much easier to estimate the quartz content of a 1cm^2 gridsquare than to estimate the content for an entire soil thin section. It is for this reason that the Level 2 results are considered more accurate than the Level 1 results. However, as long as the micromorphologist is consistent in his or her estimation of quartz content, then relative differences between slides can still be identified and considered valid.

The distribution pattern of the recordings of sandstone content at Levels 1 and 2 are also fairly similar for both sites but there appears to be some evidence that sandstone content is either under-estimated at Level 1 or over-estimated at Level 2 (Figure 6.2). Much of the sandstone recorded for both sites occurs as large fragments in the soil thin sections. This allows for a much better estimation of abundance using the diagrams in the Handbook of Soil Thin Section Description (Bullock *et al.*, 1985). These sandstone fragments are often several cm in length and diameter and, therefore, entire gridsquares may completely overlay these features. This leads to an extreme recording of 100% abundance. If the distribution of the sandstone fragments coincides with the distribution of the described gridsquares on each slide, then exaggerated recordings may occur for this parameter. The Level 1 results are, therefore, considered more accurate for sandstone fragments. The slight difference in results between the two levels of description is therefore attributed to a tendency to over-estimate sandstone content at Level 2.

The distribution patterns of the mamillate excrement recordings for Levels 1 and 2 do not show the same degree of similarity for all clusters as those for mineral content. However, some observations can be made about the most common abundance of this pedofeature found using the Level 1 and Level 2 data grouped by Level 1 cluster (Figure 6.3). In this, and other, clusters, the most common mamillate excrement content for Level 1 is greater than that for Level 2. This may be due to similar problems as those encountered with estimating quartz content. Mamillate excrement pedofeatures can cover a large range of sizes depending on the species and size of the soil fauna creating it. Excrement can also occur in clusters as well as being randomly distributed and, as discussed in Chapter 4, it is often difficult to determine whether coalesced excremental material should be classed as a pedofeature or should merely be considered as a characteristic of the soil microstructure. There is, therefore, a significant degree of subjectivity involved in the estimation of excrement content. If the mamillate excrement is relatively small and non-coalesced, then it is considered more likely that an accurate estimation of excrement content can be achieved when examining a 1cm^2 gridsquare than an entire soil thin section. However, if the mamillate excrement is coalesced into larger "aggregates" then it is likely that such pedofeatures will be considered as micro-peds within a single 1cm^2 gridsquare. It is, therefore, impossible to state whether the Level 1 or Level 2 method of describing soil thin sections gives the most accurate estimate of abundance.

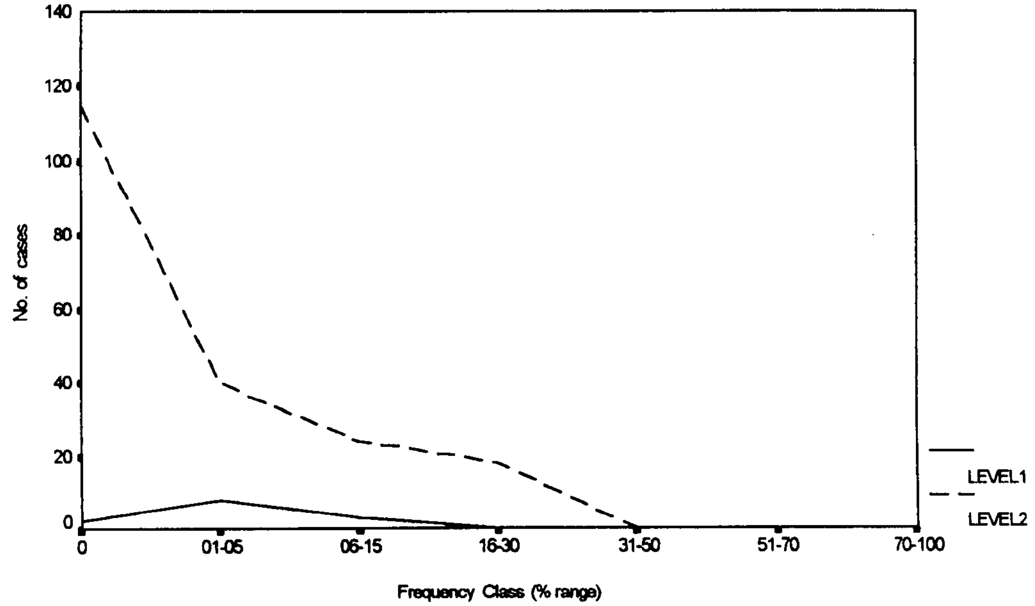

Figure 6.3 - Comparison of Level 1 and Level 2 data grouped by Level 1 cluster. Mamillate excrement content, Cluster 1 - Badentarbat.

In summary, a similar interpretation is proposed for the results of both the Level 1 and Level 2 results for both sites. The Level 2 results, however, are more difficult to interpret, despite their greater statistical significance. It could be argued that the relative difficulty in interpreting the Level 2 results is because not all of the slides described at Level 1 were used for the Level 2 work. However, the sensitivity of the HCA process and the statistical tests to the large data set produced during Level 2 suggests that using an even larger data set would demonstrate an even greater number of subtle differences in micromorphological parameters and clusters which could be even more difficult to interpret. The method is fairly labour-intensive and it must also be remembered that it took approximately 12 hours to process the information through the Gower's Coefficient of Similarity equation written as a macro for Minitab for each Level 2 data set. This suggests that, for the purposes of gaining an understanding of the soils of medieval or later Scottish field systems, the Level 1 method of description provides just as much useful information as the Level 2 method and the data set produced can be more easily handled and interpreted. However, the abundance of certain parameters is more accurately estimated using the grid sampling method of Level 2. This is not considered a great problem if a consistent approach is employed when estimating the content of features during the Level 1 work as relative differences between slides is considered more important than accurate counts. Within-slide variability is greatest for mineral content but the overall within-slide variability is rarely more significant than the between-slide variability identified during the Level 1 work.

7. Testing for Form/Function relationships

7.1 Comparison of Field System and Level 1 Thin Section Classifications

The thesis advanced is that there is a critical relationship between field form and its function and that this relationship can be identified using soil thin section micromorphology together with field classification techniques. Two field systems were selected to test whether these techniques can provide some evidence of a relationship between the form and the function of different field units (polygons) found in medieval or later field systems in Scotland. Figure 1.3 shows the research design. A variety of morphological and topographical characteristics were measured and recorded for these sites using existing survey maps and aerial photographs. This data was input into a hierarchical cluster analysis to determine a classification of the various polygons within each site (Chapter 2). Soil samples were then collected from polygons grouped in each of the main field classes identified from the desk-top field classification study. The micromorphological description techniques employed have been explained in Chapter 4 and the results of the two levels of micromorphological description have been presented and discussed at length in Chapters 5 and 6. Each of these sets of data was also input into a hierarchical cluster analysis to classify the micromorphological information. The clusters produced by the HCA process using the Level 1 data did not correspond to the field classes from which the soil samples originated. The Level 1 data must, therefore, be manually grouped according to field class membership in order to establish whether there are any significant micromorphological differences between the slides from different field classes which were "masked" by the micromorphological evidence of differences in soil type and pedogenic processes. The results of this analysis are presented in Sections 7.1.1 and 7.1.3. The interpretation of the results and analysis for each site are discussed in Sections 7.1.2 and 7.1.4. The results from the two sites using the Level 1 data are compared in Section 7.1.5.

7.1.1 Results - Level 1 data grouped by Field Class, Boyken

Six field classes were identified during the HCA of the field system data for the Boyken site (Chapter 2). When sampling in the field, it was considered important to compare the soils from within the polygons with those found outwith the field system. These latter samples were collectively termed Field Class 7 for simplicity in discussion. Samples were collected from trenches in polygons from 5 of the 7 defined field classes (Table 7.1). Field Classes 4 and 6 were not sampled as both of these classes merely constituted one polygon (see Figure 2.5).

Field Class No.	Field Class Description	Trenches sampled from each Field Class (Trench No./Polygon No.)
1	Truncated with rig and/or lynchets	13/22, 20/22, 21/22
2	Short rig	1/56, 27/38, 6/10, 8/38
3	No rig	11/36, 19/47, 28/47, 5/52, 29/52
4	Lynchets with rig (50:50 ratio)	Not sampled
5	Lynchets only	25/30, 26/30
6	Long rig, large field area, largest total length of lynchets	Not sampled
7	Outwith polygons	22, 23, 30(two monoliths)

Table 7.1 - Trenches representing each Field Class described during the Level 1 micromorphological work, Boyken. See Figure 2.5 for the location of these trenches.

The median of each parameter, which was measured ordinally, is given for each Field Class in Table 7.2. The lack of variability in the samples from the Boyken site is obvious from these figures. Only siltstone, cell residue and mamillate excrement content show any statistically significant differences between field classes using the Kruskal-Wallis one-way analysis of variance by ranks test. Microstructure and related distribution are the only two nominal variables showing some degree of variability across the site. However, the variability in related distribution is very slight, with only one slide showing a gefuric rather than a porphyric related distribution. Slightly more variability is found in terms of microstructure but cross-tabulation of the Level 1 results does not reveal any evidence of one type of microstructure being particularly prevalent in slides from one particular field class. The homogeneous nature of the soils at Boyken have already been discussed and this is clearly reflected in the results discussed here. The uniform parent material of greywackes and shales across the site clearly plays a significant part in creating this homogeneity. The site is also not large enough to experience significant differences in climate which may produce different rates and forms of pedogenesis such as podzolisation and peat formation. Rather than discuss the many apparent similarities between the slides from each field class individually, the three variables which do give significant results shall be discussed in turn.

Siltstone Content

Statistically significant differences in siltstone content occur between Field Classes 1 & 3 and 2 & 3. Certainly, the siltstone medians for Field Classes 1 and 2 (Table 7.2) are higher than for any other field class. However, Field Classes 3 and 7 both have a median of 2 (1-5%). If there is a significant difference between Field Classes 1 and 2 when compared with Field Class 3, then the median values suggest that there should also be a statistically significant difference between these two field classes and Field Class 7. Simple cross-tabulation of the siltstone content values recorded for each field class reveals a subtle difference between Field Classes 3 and 7 that cannot be appreciated by considering the median values (Table 7.3). It would appear that the 3% difference in the percentage of slides containing >5% siltstone between Field Classes 3 and 7 is sufficient to make a comparison between Field Class 3 and Field Classes 1 & 2 statistically significant but not for a similar comparison with Field

	Median of each parameter per field class sampled (frequency class)				
Micromorphological Parameter	Field Class 1	Field Class 2	Field Class 3	Field Class 5	Field Class 7
Quartz content	5	5	5	5	5
Feldspar content	1	1	1	1	1
Sandstone content	4	3	3	3	3
Siltstone content	4	3	2	2.5	2
Phytolith content	1	1	1	1	1
Bone content	0	0	0	0	0
$CaCO_3$ content	1	1	1	1	1
Multi-cell fungal spore content	2	1	1	1	1
Lignified tissue content	1	1	1	0	1
Parenchymatic tissue content	2	2	2	2	2
Organ residue content	1	1	1	0.5	1
Charcoal content	0	1	0	0	0
Single cell fungal spore content	1	1	1	1	1
Amorphous black organic material content	1	2	1	1	1
Amorphous yellow orange organic material content	1	1	1	0.5	1
Amorphous red brown organic material content	1	1	1	1	1
Cell residue content	1	2	1.5	2	2
Silty clay coatings content	0	0	0	0	0
Dusty clay coatings content	0	0	0	0	0
Limpid clay coatings content	0	0	0	0	0
Amorph. & cryptocrystalline nodules content	2	3	2.5	2	2
Amorph. & cryptocrystalline coatings content	0	1	1	1	0
Mamillate excrement content	2	3	3	1.5	3
Spheroidal excrement content	3	3	2	1.5	3
Depletion pedofeature content	0	1	1	1	0

Table 7.2 - Medians for each ordinal parameter described at Level 1 per Field Class - Boyken.

Class 7. Field Classes 1 and 2 both contain relatively high amounts of siltstone in comparison to the other 3 field classes.

	No. of slides per frequency class of siltstone content					
Field Classes	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**4 (15-30%)**	**5 (30-50%)**	**% slides with >5% siltstone**
Field Class 1	0	0	3	4	0	100
Field Class 2	0	3	6	4	2	80
Field Class 3	5	6	6	1	0	39
Field Class 5	0	3	2	1	0	50
Field Class 7	2	5	3	2	0	42

Table 7.3 - Cross-tabulation of Level 1 siltstone content data per Field Class - Boyken.

Cell residue content

Only a comparison of the cell residue content of slides in Field Classes 1 and 7 gave a statistically significant result. Again, the median results do not conclusively support this result. Although Field Class 1 has the lowest median value of 1 (1%), Field Classes 2, 5 and 7 all produce the same median value of 2 (1-5%). There must be differences in the distribution of the cell residue data for the three latter field classes which cannot be recognised through calculating the median value. Table 7.4 presents the cross-tabulation results for cell residue content per field class. This shows that Field Classes 2, 5 and 7 have differing proportions of their slides containing >1% of cell residue content. Field Class 7 has the highest percentage at 80%. In contrast, only 14% of the slides grouped in Field Class 1 contain a similar amount of cell residue. It would, therefore, appear that the 69% difference between Field Classes 1 and 7 is sufficient to produce a statistically significant result whilst the 46% and 53% difference between Field Class 1 and Field Classes 2 & 5, respectively, is not.

	No. of slides per frequency class of cell residue content				
Field Classes	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**% slides with >1% cell residue**
Field Class 1	0	6	1	0	14
Field Class 2	0	6	9	0	60
Field Class 3	1	8	9	0	50
Field Class 5	0	2	4	0	67
Field Class 7	0	2	5	5	83

Table 7.4 - Cross-tabulation of Level 1 cell residue content data per Field Class - Boyken.

Mamillate excrement content

A comparison of the mamillate excrement content of Field Classes 2 & 5 produces the only statistically significant result for this parameter. The median results once again appear to indicate that a similar result should be obtained for a comparison of Field Classes 3 & 5 and 5 & 7, given that Field Classes 2, 3 and 7 all have a median value of 3 (5-15%) for mamillate excrement content. However, examination of the cross-tabulation of the mamillate excrement data reveals differences in the data distribution for these latter field classes (Table 7.5). Eighty percent of the slides from Field Class 2 contain >5% mamillate excrement compared with 61% and 67% for Field Classes 3 and 7, respectively. In contrast, Field Class 5 contains no slides with a mamillate excrement content of >5%. The largest difference is, therefore, between Field Classes 2 and 5, confirming the results of the Kruskal-Wallis one-way analysis of variance by ranks test.

	No. of slides per frequency class of mamillate excrement content					
Field Classes	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**4 (15-30%)**	**5 (30-50%)**	**% slides with >5% mamillate excrement**
Field Class 1	0	4	0	1	2	43
Field Class 2	1	2	8	3	1	80
Field Class 3	3	4	9	2	0	61
Field Class 5	3	3	0	0	0	0
Field Class 7	0	4	7	1	0	67

Table 7.5 - Cross-tabulation of Level 1 mamillate excrement content per Field Class - Boyken.

Summary

Siltstone, cell residue and mamillate excrement content, therefore, highlight the few differences that occur between the slides from the 5 field classes sampled (Table 7.6). No micromorphological characteristic is found which differentiates one field class from all of the others. Often, only a single characteristic differentiates one field class from one other. However, Field Classes 1 and 2 are differentiated from some of the other field classes by a combination of two parameters. The slides in Field Class 1 have both a high siltstone content and a low cell residue content. Field Class 2 is also characterised by a high siltstone content but this is combined with a high mamillate excrement content in order to differentiate it from more than one other field class. The slides in Field Class 3 are characterised by their low siltstone content. The Field Class 5 slides have a low mamillate excrement content whilst Field Class 7 is differentiated by a high cell residue content.

Field Class	Field type	Micromorphological characteristics
Field Class 1	Truncated with rig and/or lynchets	• High siltstone content • Low cell residue content
Field Class 2	Short rig	• High siltstone content • High mamillate excrement content
Field Class 3	No rig	• Low siltstone content
Field Class 5	Lynchets only	• Low mamillate excrement content
Field Class 7	Outwith polygons	• High cell residue content

Table 7.6 - Micromorphological characteristics of field classes - Boyken, Level 1.

7.1.2 Interpretation - Level 1 data grouped by Field Class, Boyken

The small number of parameters which show a statistically significant difference between the field classes was most easily presented in the results section by considering each of these micromorphological features in turn. The interpretation of the results must consider the nature of each field class, as identified during the desk-top field classification. The location of the trenches from which the soil samples within each field class come may have an important influence on the results and, hence, the results from each trench within a particular field class need to be examined. Differences in the results from different trenches in the same field class may indicate that the field classification produced during the desk-top study is inaccurate. The results of the HCA on the Level 1 data discussed in Chapter 5 appears to indicate that the strongest differentiating characteristics of these slides are most closely associated with their depth in the profile and natural pedogenic processes rather than any association with the field context from which they originate. This suggests that any micromorphological evidence of anthropogenic influence on the soil is inconclusive, if it exists at all. Therefore, it may equally be that the field classification is fairly accurate but that the length of time since the agricultural activity, which produced this landscape occurred, is too long to be able to detect any micromorphological evidence of this due to ongoing pedogenetic processes. Each field class represented by the Level 1 data shall, therefore, be discussed and interpreted in turn. Parameters which show subtle differences between trenches in the same field class will also be discussed.

Field Class 1 - Truncated polygons with rig and/or lynchets

The slides in Field Class 1 (truncated polygons with rig and/or lynchets - see Figure 2.5) contain relatively high amounts of siltstone and the least amounts of cell residue of any of the field classes. Three trenches were sampled in this field class, all located in Polygon 22. This polygon contained a number of linear structures aligned downslope which were classified as lynchets by the RCAHMS. Smith (1975) discusses lynchet fields at Otterburn and Appletreewick which both have similar features aligned downslope, perpendicular to the contour lines. However, lynchets are more normally regarded as accumulations of soil downslope of agricultural activity and running along the contours, not perpendicular to them (Davidson, 1982; Limbrey, 1975). Smith (1975) also suggests that the lynchets at these sites are produced by the movement and reaccumulation of soil during ploughing in the Medieval period. However, virtually all of the rig and furrow studied for this research occurs perpendicular to the contours of the slope (see Figures 2.4-2.9) rather than across slope. It also seems reasonable to assume that such ploughing activity would create distinct evidence of rig and furrow across the slope between the lynchet accumulations orientated downslope. This is not the case. The lynchets at Appletreewick create a series of terraces across the slope from east to west. Although the "lynchets" in Polygon 22 at Boyken are also regularly aligned across the slope, they do not produce a terraced effect. They are therefore interpreted, by the archaeological team from AOC (Scotland) Ltd., as possible boundaries to small, discrete strips of land presumably worked under some form of tenurial system. Excavation of one of these linear banks which appears to merge with the enclosure banks for Polygon 22 shows that it actually runs under the existing boundary for this polygon. These linear structures have therefore been interpreted as remnants of an earlier phase of agricultural use, although this is not thought to be of any greater antiquity than other irregular enclosures still found on this site.

The persistence of these slight features in the landscape would suggest that the subsequent use of this area of land was neither intensive nor of long duration. No rigs are present in this polygon although they are features of the other 3 polygons grouped in this field class. The high amount of siltstone identified as a characteristic of this field class may, in fact, be a characteristic of Polygon 22 alone. The lack of rig in this polygon suggests that arable cropping was not the main function of this area and the abundance of siltstone may be due to the lack of mechanical disturbance. However, this interpretation naturally leads to a further expectation that similar amounts of siltstone should also be present in Field Class 3 (polygons containing no rig). This is not the case. Closer inspection of the raw Level 1 data actually shows a much closer similarity between the siltstone abundances in Field Classes 1 and 2 (see Table 7.3).

The Boyken site is situated on an area with some very steep slopes. Perhaps the soil disturbance caused by cultivation, other than by plough, or the creation of the turf banks in Polygon 22 resulted in the downslope movement of the finer soil material, leaving a greater proportion of coarse mineral fragments in the disturbed areas. Trench 20 is situated furthest downslope in Polygon 22 and is described as containing 5-15% siltstone, compared with the 15-30% found in Trenches 13 and 22 further upslope (Appendix 7). It may be that high amounts of siltstone are indicative of a change in the coarse:fine ratio of the mineral content of soils due to downslope movement of the fine fraction of soils disturbed at some time by human activity but this needs to be tested more thoroughly in other polygons before this interpretation can be accepted.

The low amount of cell residue found in samples from this field class is not considered as anything more than slight natural variability of the soils. No sample from Boyken contains any more than 15% cell residue and all samples with these highest values are from thin sections grouped in Field Class 7 (Appendix 7). This means that 4 out of the 5 field classes sampled contain no more than 5% cell residue. It must also be remembered that abundances are described in ranges and a sample described as having a cell residue abundance of 2 (1-5%) may only contain 2% of this feature rather than the maximum of 5%.

Apart from the difference in siltstone content in Trench 13/22, compared to Trenches 20/22 and 21/22, few other micromorphological parameters show any obvious differences between these 3 trenches (Appendix 7). The upper slide of Trench 13/22 contains up to 4% more organ residue than any of the others and both of the slides from this trench contain up to 30% mamillate excrement content compared to only a maximum of 5% for each of the slides from Trenches 20/22 and 21/22. Bracken was common across this polygon and the roots of these plants are recorded as disrupting the A horizon of each of these trenches (Appendix 3). Although the profile descriptions for these three trenches do not indicate that the bracken was especially more abundant in Trench 13/22, it could be that the evidence for this is more obvious at the microscopic level. This subtle difference between the trenches in Polygon 22 is probably no more than natural spatial variability.

There does appear, therefore, to be some slight micromorphological evidence which may be indicative of past anthropogenic activity in this polygon. However, this is far from conclusive and does not necessarily indicate a particular method of cultivation. Because only one polygon of the four grouped in Field Class 1 was sampled for soil thin section description, it is impossible to determine from the micromorphological work whether Field Class 1 is a coherent group or not. This must be determined from the results and analysis of the field classification study alone.

Field Class 2 - Polygons with short rig

Field Class 2 (short rig) also contains high amounts of siltstone as well as mamillate excrement. The theory of movement of the fine soil fraction downslope due to human disturbance proposed for Field Class 1 can be further tested using the samples taken from Trenches 8/38 and 27/38. Trench 27/38 was dug diagonally downslope from Trench 8/38 in a polygon which was mapped as containing some remnants of rig and furrow. However, these rig and furrow could not be identified during this field work. Only one slide was sampled from the shallow profile of Trench 8/38, which contains 15-30% siltstone. In comparison, the two slides from Trench 27/38 further downslope contain only 5-15% and 1-5% of this parameter (Appendix 7). This is similar to the findings from the trenches in Polygon 22 and, whilst not proving the theory conclusively, it does suggest that further research, specifically looking at samples taken on transects downslope, may be warranted.

Mamillate excrement content is relatively high for this field class. However, it must be remembered that a statistically significant difference was only found between this field class and Field Class 5 and, therefore, it cannot be concluded that mamillate excrement content is a particularly good distinguishing feature for Field Class 2.

Field Class 2 groups together all the polygons which contain short rig and furrow. There are 27 polygons in this field class which occur in two main groups in the site. All but two of the Field Class 2 polygons are located to the east of the post-Improvement dyke which bisects this agricultural landscape

(Figure 2.5). The remaining 25 polygons are located either at the top of the steep slope or between the long linear bank along which the settlement clusters are located and the upslope dyke of the post-Improvement fields. The cultivation remains in these 2 clusters of Field Class 2 polygons are, however, very different.

The cultivation remains mapped in the polygons situated towards the top of the hill on the east side of the site (Polygons 33-50) are very difficult, sometimes impossible, to distinguish in the field due to their very slight nature. However, the remains found in the polygons towards the bottom of this slope, close to the regular post-Improvement landscape are much more substantial in form. This suggests that the main area of sustained agricultural activity was downslope of the alignment of the linear bank and settlement clusters and that much of the evidence has been lost under the reorganised landscape. It does seem unlikely that the inhabitants would have chosen to cultivate the steeper, more difficult slopes rather than the more gently contoured land close to the watercourse.

The desk-top field classification used only the information available from the survey map and an aerial photograph of the site and, therefore, these actual differences in rig forms were not recorded. This is reflected in the classification as Field Class 2 contains not only the polygons from the lower slopes containing substantial rig and furrow but also the much more slight remains located in the polygons at the top of the slope. We, would, therefore, expect to see differences in the nature of the samples taken from these different areas if our theory of an infield-outfield type of system is correct (see Chapter 1). Examination of the raw Level 1 data does indicate some differences between the polygons of upper and lower slopes. Three samples in Field Class 2 are taken from Polygon 38 at the top of the site and these can be seen to contain no charcoal, whilst the majority of samples taken from Polygon 56 and 10 on the lower slopes do contain small amounts of charcoal fragments (Appendix 7). These amounts of charcoal are small and it could also be argued that this may be evidence of a natural burn sometime in the past. However, the probability of natural burns in Scotland must be very small and, given the supporting archaeological evidence of anthropogenic activity in these lower areas (in the form of clay pipe bowls, extant rig and furrow and the proximity of settlement structures), the presence of charcoal in Trenches 56 and 10 is considered as evidence of anthropic inclusions to the soil.

The presence of this charcoal may, of course, be a factor of convenience since Polygons 10 and 56 are more closely associated with settlements and considerable energy would be required to transport sufficient quantities of household waste to the upper polygons to ensure better crop yields. However, the position of the settlements also provides a clue to the most important areas of the site and perhaps this is where the Boyken and Badentarbat sites can be most easily compared. All settlement structures on the Badentarbat site are aligned along the head-dyke immediately upslope of the area of cultivation remains. Boyken also possesses a linear alignment of settlements along a bank. Could this linear bank be interpreted as a similar head-dyke to that found at Badentarbat and can this interpretation and comparison thus be extrapolated to suggest that the main area of agricultural activity (the infield) at Boyken would be most probably located on the area immediately downslope from this structure?

Little other micromorphological evidence is found to confirm this theory but only the samples from Polygons 10 and 56 are available as evidence for the "infield" part of the suggested field system as all other samples are taken from locations above or to the west of the linear bank. Soils subjected to continuous cultivation commonly received organic fertilisers to maintain the fertility of the soil over many seasons of cropping (Dodgshon, 1980; Fenton, 1986: Smout, 1969). There appears to be no difference in the content of coarse or fine organic material between Polygon 38 and Polygons 10 and 56 apart from the content of amorphous black fine organic material. The samples from Polygon 56 contain up to 30% of amorphous black fine organic material whilst those from Polygon 38 contain a maximum of 5%. However, Polygon 10 contains no more than 1% of this parameter (Appendix 7).

Polygon 10 is a small area of high amplitude rig. Two possible explanations have been put forward for the nature of the rigs in this small polygon. The rigs are short, straight, of high amplitude and end abruptly on the edge of a break of slope. The first theory is that these rigs are spade-dug thus allowing cultivation up to the edge of the break of slope. The second is that these rigs are created by use of the fixed mouldboard plough and have been substantially truncated by subsequent land reorganisation. Evidence of this land reorganisation is apparent at no great distance immediately downslope from this polygon and the regular nature of the rigs would suggest that the second explanation is the more likely of the two.

If Polygon 10, as we see it today, is merely a fraction of its original extent due to reorganisation of the land, then it is considered unlikely that domestic waste from the household would have been the main fertiliser used in this area. It is considered more likely that these larger areas were fertilised by folding cattle and sheep overnight on them and perhaps by applying the highly soiled winter bedding from the byres. The Testaments of the Dumfries Register dated 1600-1665 have been studied in great detail by Coutts (1986). These provide a useful insight into the farming practices in the Dumfries area at this time. Manuring techniques were considered important enough by some farmers to be written in as part of the conditions of their will. One farmer wanted a horse kept on the farm "for manuring of the ground" (Dumfries Register of Testaments 3/561 cited in Coutts, 1986). During the winding up of another farm, the dung and fuel around the house were valued at 20 merks (Edinburgh Register of Testaments, 25.10.1606 cited in Coutts, 1986). Maintaining the fertility of the land was clearly important and livestock played a major role in this activity. Therefore, so did the availability of pasture and meadow in order to feed sufficient livestock to maintain arable land fertility.

Information contained in the Old Statistical Accounts of 1794 and 1845 for the parish of Westerkirk, in which Boyken is situated, indicates that this area was primarily used for sheep farming with around 18,000 Cheviot sheep recorded in both Accounts. The Statistical Account of 1845 also states that arable and meadow land constituted 1,560 acres of the agricultural land in the parish whilst 25,547 acres were not in tillage but were considered "excellent pasture". A mere 200 acres were recorded as under wood or plantation. This, of course, merely states the agricultural use of the land around the time of the Improvements and radiocarbon dates from this site indicate that the area has been in agricultural use since at least the early medieval period (Chapter 3). The reorganisation of the land during the Improvements and the move to predominantly sheep farming may have resulted in the loss of Polygon 10 to arable cultivation before Polygons 38 and 56 which are located further upslope of the new geometric field layout seen today towards Boyken Burn. Any evidence of former organic inputs in this polygon may, therefore, have been eradicated by natural soil processes since its relatively early abandonment. Roy's map of *c.* 1750 indicates arable cultivation on the upper slopes of the Boyken site where Polygon 38 is located. The slight nature of the cultivation remains in this area suggests that it was only worked for a short period of time and it may be that this was the last-ditch effort by the tenants to work the land prior to abandonment. Boyken is not mentioned in the rentals after 1793.

If the interpretation that Polygon 56 is a garden plot is correct, then we would expect such a small area, closely associated with a settlement structure, to receive large amounts of household waste such as hearth ashes, charcoal and domestic waste. The large amounts of amorphous black fine organic material found in this polygon may originate from the burnt organic material in the hearth ashes. This cannot be the only explanation for the presence of amorphous black fine organic material, however, as we have already discussed the unlikelihood of the transportation of domestic wastes up the hill to where Polygon 38 is located.

Several small lumps of burnt lime were found in the upcast soil of several mole-hills in this area at the top of the site and the present land-user confirmed that he could recall the use of this type of fertiliser on the area on a regular basis up to around 1970. During the excavation of several trenches in this area, evidence of regular breaching of the boundary banks and irregular lower boundaries to the A horizon of trenches located within the polygons was uncovered. This was interpreted as possible evidence of deep ploughing but this was strongly refuted by the land-user who emphatically denied any memory of the area being ploughed during his life-time. The evidence of disturbance, however, does remain and may suggest that more recent land management in this area has led to a slight increase in the amount of amorphous black fine organic material originating from the burnt lime dressing.

The micromorphological evidence for Field Class 2, therefore, suggests that some evidence of past anthropogenic activity still exists in the soils from these functional units. However, this micromorphological evidence cannot be associated with any particular method of cultivation such as mouldboard ploughing or spade cultivation. Differences in the microstructure of soils cultivated with various implements have been found in experimental studies (Gebhardt, 1992). However, these experiments were carried out on calcareous colluviums and loessic-loams which are very different to the brown podzols of Boyken and they were unable to establish the effects of ageing on these features. The microstructure from the polygons with clear rig and furrow morphologies at Boyken did not show any significant differences to those from the polygons with no evidence of cultivation (Field Class 3) or from outwith the polygons (Field Class 7). It may be that any differences in microstructure produced at the time of cultivation have since been eradicated by continuing pedological processes. The micromorphological evidence from the slides from Field Class 2 can only be said to be related to the manuring practises associated with these arable units in the past rather than the physical cultivation method used.

The micromorphological evidence does indicate differences between the two main groups of polygons in this field class which could not be identified during the desk-top field classification. This may mean that a more accurate classification of the fields in this site may be achieved by also incorporating some of the micromorphological data in the field classification exercise but the field classification aimed to use only readily available data.

Field Class 3 - Polygons with no rig

Polygons grouped in Field Class 3 are enclosures containing no rig or other cultivation remains. Three of the twenty-one polygons in this field class are represented by the soil thin sections. The soils in this field class are characterised by low amounts of siltstone. Soil disturbance and subsequent downslope movement of the fine fraction of the disrupted soil has been given as a possible explanation for the high amounts of siltstone found in Polygon 22 (Field Class 1). If this theory is correct, it would therefore follow that areas not subjected to soil disturbance would contain proportionately less siltstone as the fine fraction of the soil remains *in situ*. This result seems to concur with this interpretation. However, it does appear that the result has been slightly biased by the result from Trench 5/52 where all samples contained no more than 1% siltstone (Appendix 7). The samples from this trench also contained the most organic material and 2 samples contained small amounts of charcoal fragments.

A layer of single-species (*Corylus avellana* - hazel) charcoal was discovered at 30-35cm depth in the profile during field work and radiocarbon dating produced a calibrated date of 860 ±50 BP. Although this indicates that the soils in this area have been disturbed at some point in the past, the persistence of such a large amount of charcoal in one location suggests that development of the soil profile continued after these activities with little or no human disturbance. The banks associated with this enclosure were also found to run under some of the enclosure banks at the top of the hill, further indicating their early origin. This group of polygons (Polygons 50-54) is situated on a particularly steep part of the site and has been interpreted by the archaeological team as a set of transient stock enclosures (McCullagh, 1996).

Polygons 36 and 47 were also sampled from this field class. Polygon 36 was a highly truncated fragment of an enclosure upon which Polygon 35 had been superimposed (Figure 2.5). No cultivation remains were evident in the remaining fraction of this enclosure but any such remains may well have been eradicated by the reorganisation of the land. However, the cultivation remains in Polygon 35, mapped by the RCAHMS survey, proved to be very slight structures and a furrow that was mapped as continuing through the western bank of Polygon 38 (superimposed on Polygon 35) was interpreted as a wheel track in association with the other regular breaches of surrounding enclosure banks thought to be created by ploughing activity. This area has clearly undergone several reorganisations and this is one problem that was highlighted during the desk-top study of the survey map and aerial photograph of the site. Can this area truly be classed as a field system or can it merely be described as an evolving landscape containing several non-contemporaneous relict features? The field work evidence suggests that the latter interpretation is the more accurate.

Indeed, Polygon 47, as identified during the desk-top field classification, was interpreted in the field as a vestigial piece of land between enclosures rather than an enclosure in its own right. The samples from Trench 19/47 were actually taken from underneath the bank separating Polygons 43 and 47 which was shown by detailed field survey to be one of the earliest banks in the area. A deep podzol displaying distinct eluvial and illuvial horizons was found to exist underneath this bank. Trench 28 was located within Polygon 47. There is no significant difference in any parameter between these two trenches apart from a higher percentage of mamillate and spheroidal excrement in the upper few centimetres of the top sample from Trench 19 (sampled from the peaty turf mat at 0-8cm depth in the profile) and a few clay coatings in sample 19/47B taken from 10-18cm in the profile (Appendix 7). This would appear to support the theory that Polygon 47 is an area of natural soil not associated with any particular anthropogenic landuse.

There are very few distinguishing micromorphological features for this field class. However, subtle differences in organ residue and amorphous black fine organic material between Polygons 36 and 47 from the upper eastern complex of polygons and Polygon 52 on the steep midslopes indicate that perhaps these three polygons are not as similar as is suggested by the field classification results (Appendix 7). The problems with interpreting the upper complex of polygons during the field classification have already been discussed in Chapter 2 and these results appear to confirm that the recording and classification of these polygons is inaccurate. However, the results from Trench 5/52 do not show any startling differences to those from the slides sampled from outwith polygons (Field Class 7). If Polygon 52 was merely used in the early Medieval period as a stock enclosure, then it is probable that the micromorphological evidence for this, such as increased phytoliths and organic content from animal faeces, has long since been lost. Equally, it may be that the current grazing of cattle and sheep across the entire Boyken site has masked any subtle differences that may have existed between the unrigged polygons and the areas outwith the field complexes.

Field Class 5 - Lynchets only

Field Class 5 contains 2 polygons (28 and 30) containing only lynchets. The samples from this field class were characterised by having the lowest abundances of mamillate excrement. Samples were taken from two trenches located in Polygon 30. The profiles of these trenches were very similar and this is reflected in the micromorphological results (Appendix 7). Trench 25 was located in an area with many tree stumps whilst Trench 26 was in area of open grassland. Neither trench was in an area colonised with bracken which was the case in many other parts of the site. Although not statistically significant, these two trenches do contain very little lignified tissue compared to the samples from other polygons and it may be that the lack of bracken in Polygon 30, coupled with this slight micromorphological evidence indicates that bracken is the main source of lignified tissue in the Boyken soils. The low amounts of mamillate excrement in these trenches may reflect the lack of lignified tissue in these soils to provide an adequate food source for large numbers of soil fauna.

Another interpretation may relate to the apparent antiquity of the remains in Polygons 28 and 30. The "lynchets" in Polygon 28 are very similar to those found in Polygon 22 and discussed earlier. These linear banks are again not considered to be lynchets but banks marking strips of land held under a tenurial system. The lynchets in Polygon 30, however, do appear to conform to the general description of these features. Excavation of one of these structures by the archaeological team nevertheless showed it to be more probably a built embankment rather than an erosional feature. These similarities with Polygon 22 would also suggest an early origin for these polygons and, indeed, a rectangular dwelling with an associated area of substantial lazybeds is superimposed on the eastern extent of Polygon 30 demonstrating its place in the chronology of this site. The relative antiquity of the cultivation remains in this polygon indicates that agricultural activity has been abandoned for some considerable period of time. It is considered likely that natural soil processes have eradicated any possible signatures of anthropogenic activity that may have been present in these soils immediately after abandonment.

From the field excavation work, it would seem more logical to group Polygons 28 and 30 with Polygon 22 (Field Class 1). However, the micromorphological evidence does indicate subtle differences between the slides from Polygons 22 and 30. The slides in Polygon 22 contain more siltstone than those in Polygon 30. This may be because the slopes are less steep in Polygon 30, reducing the amount of downslope movement of the fine soil fraction. Equally, the orientation of the lynchets along the contours in Polygon 30 compared to the perpendicular orientation in Polygon 22 may reduce the extent of soil movement. It is, thus, difficult to reach a firm conclusion about the validity of Field Class 5. The results for many of the micromorphological parameters described at Level 1 are similar to at least one or more of the other field classes and no firm interpretation of the former use of these polygons can be based on the micromorphological evidence alone.

Field Class 7 - Outwith polygons

Field Class 7 has been added to the original classification of Boyken to allow the comparison of soils from areas outwith identified polygons throughout the site. Three trenches were dug and sampled. Two monoliths were taken from different sides of Trenches 23 and 30 to provide some indication of the scale of natural variability within the soils (Appendix 7). From the Level 1 results it appears that variability between the soils from these trenches is very slight and this apparent homogeneity in soil properties is a particular feature of this site which it was hoped would provide some sort of controlled background upon which it may be possible to discover micromorphological indicators of human agricultural activity. Unfortunately, few indicators have been identified which may be conclusively associated with particular past agricultural practises. Field Class 7 is found only to differ significantly to

Field Class 1 (truncated polygons with rig and/or lynchets) in terms of cell residue content. No explanation other than natural variation can be given for this phenomenon based on these results.

The lack of any real distinction between the trenches sampled from outwith the field system and those from units within confirms that evidence for past agricultural activity in these soils is scarce and very slight when it does occur. Natural pedogenesis appears to have masked or eradicated any evidence that may once have existed in these soils. Pastoral farming has been predominant in this area for many centuries and the continued presence of stock on this site makes it particularly unlikely that differences between the field units used as stock enclosures in the past and those used for arable cultivation can be identified using only soil micromorphology techniques.

Summary

It is therefore concluded that few micromorphological indicators have been found which characterise particular agricultural practises in different areas at this site, although it appears that evidence of different manuring practises is more easily identified than differences in rig morphology. The presence of charcoal and amorphous black fine organic material in Trench 1 in Field Class 2 provides evidence of human activity, although these parameters do not produce statistically significant differences (95% C.I.) for comparisons between field classes. Micromorphological examination of the soils from a field system in Papa Stour also identified variations in charcoal and humified peat which were attributed to different manuring practises (Carter & Davidson, in press). This relative lack of evidence for human activity may be due to the antiquity of the site and the length of time since its abandonment for arable cultivation. No mention of Boyken is found in the rentals of the Buccleuch estate after 1793 and natural soil processes in these freely draining shaly podzols since abandonment may have eradicated all such information.

The complex chronology of the site must also play a part in this lack of evidence. Much of the site has been shown to be a palimpsest of reorganised parcels of land and the desk-top field classification carried out using only the information available prior to field work must be considered as inaccurate. This was appreciated prior to the commencement of field work and the results from this subsequent work merely confirms that the many questions raised by this desk-top study were justified and real problems have been faced in attempting to create a valid field classification system from the existing data.

7.1.3 Results - Level 1 data grouped by Field Class, Badentarbat

Five field classes were identified during the field classification of the Badentarbat field system data. Trenches have been dug in at least one polygon from each of these field classes and samples taken for soil thin section description. An additional field class (Field Class 0) was added to allow the consideration and comparison of samples from trenches dug outwith the field system polygons. The trenches sampled from each field class are detailed in Table 7.7, along with the polygon number in which each trench was located. The location of these trenches is given in Figure 2.4.

Field Class No.	Field Class Description	Trenches sampled from each Field Class (Trench No./Polygon No.)
0	Outwith polygons	49, 50, 53
1	Short rig	32/7, 34/3, 36/5, 43/40, 44/35, 47/31
2	No rig	54/45
3	Long rig	46/22, 51/22
4	Reverse-S rig	52/29
5	Rig on steep slope, higher altitude	42/44, 45/36

Table 7.7 - Trenches representing Field Classes described during Level 1 micromorphological work, Badentarbat. See Figure 2.4 for location of trenches.

The medians per field class for the ordinal data described during the Level 1 micromorphological description are given in Table 7.8. These figures are calculated using the frequency class codes. The percentage ranges associated with each frequency code are detailed in Appendix 4. Where two consecutive frequency codes are equally dominant for a certain parameter (for example, 1 and 2), a value mid-way between these two points is given (1.5 in this case).

Several micromorphological parameters are found to significantly differentiate between two or more different field classes at the 95% confidence interval. The amount of feldspar, $CaCO_3$, multi-cell fungal spores, amorphous yellow-orange organic material, amorphous and cryptocrystalline coatings and mamillate and spheroidal excrement were all found to be show differences between at least two field classes. No statistically significant results were obtained for the nominal data and little in the way of trends associated with the field classes could be identified. Often the most obvious differences in the nominal variables was between slides from different trenches grouped in the same field class rather than between the field classes themselves. This shall be discussed more fully in section 7.1.4.

	Median of each parameter per field class sampled (frequency class)					
Micromorphological Parameter	**Field Class 0**	**Field Class 1**	**Field Class 2**	**Field Class 3**	**Field Class 4**	**Field Class 5**
Quartz content	3	5	5	5	3.5	6
Feldspar content	2	3	4	2	2	4
Sandstone content	1	0	1	1	0	1
Siltstone content	1	0	1	0	0	0
Phytolith content	1	1	1	1	1	2
Diatom content	0	0	1	0	0	0
$CaCO_3$ content	0	0	1	1	1	1
Multi-cell fungal spore content	1	1	1	1	0.5	1
Lignified tissue content	1	1	0	0	0	1
Parenchymatic tissue content	3	2	1	3	2	2
Organ residue content	1	1	1	1	0.5	1
Charcoal content	1	0	1	1	0.5	0
Single cell fungal spore content	1	1	1	1	1	1
Amorphous black organic material content	2	3	3	3	2	3
Amorphous yellow-orange organic material content	1	2	1.5	1	1	2
Amorphous red-brown organic material content	1	2	1.5	1	1.5	2
Cell residue content	2	3	1	3	2	2
Silty clay coatings content	0	0	0	0	0	0
Dusty clay coatings content	0	0	0	0	0	0
Limpid clay coatings content	0	0	0	0	0	0
Amorph. & cryptocrystalline nodules content	1	1	1	0	1	2
Amorph. & cryptocrystalline coatings content	0	1	1	0	0	1
Mamillate excrement content	1	1	2	1	0.5	2
Spheroidal excrement content	1	1	1	1	0	2

Table 7.8 - Medians of Level 1 ordinal parameters per field class, Badentarbat.

Field Class 0 - Outwith polygons

The slides in Field Class 0 can be differentiated from at least one other field class in terms of feldspar content, amorphous yellow-orange fine organic material, amorphous and cryptocrystalline coatings and mamillate excrement. Statistically significant differences were found in the feldspar content of Field Class 0 and Field Classes 2 and 5. These results are supported by the median values for feldspar per field class (Table 7.8). Cross-tabulation of the feldspar data and calculation of the percentage of slides in each field class containing >5% feldspar further supports the results of the Kruskal-Wallis test (Table 7.9). Field Classes 0, 1 and 3 are all too similar to produce a statistically significant result when Field Class 0 is compared with the latter two. Field Classes 2 and 5, in comparison, both have similarly high feldspar content which give a large enough difference when compared with Field Class 0 to produce a statistically significant result.

	No. of slides per frequency class of feldspar content					
Field Classes	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**4 (15-30%)**	**% slides with >5% feldspar**
Field Class 0	0	7	2	5	1	40
Field Class 1	0	6	8	13	6	58
Field Class 2	0	0	0	0	4	100
Field Class 3	1	5	4	6	1	41
Field Class 4	0	4	4	2	0	20
Field Class 5	0	0	1	4	7	92

Table 7.9 - Cross-tabulation of feldspar content data per field class - Badentarbat, Level 1.

The amorphous yellow-orange fine organic material content of Field Class 0 differs significantly only to Field Class 1. However, the median results in Table 7.8 suggest that a significant difference should also be found between Field Class 0 and Field Class 5, given that Field Classes 1 and 5 both have a median value of 2 (1-5%). However, cross-tabulation of the amorphous yellow-orange fine organic material data and calculation of the percentage of slides containing >5% of this feature demonstrates that there are differences between Field Classes 1 and 5 which cannot be appreciated by using median values alone (Table 7.10). Field Class 0 contains no slides with >5% of this feature whilst 45% of the slides in Field Class 1 contain 5-50%. These two results represent the two extremes of amorphous yellow-orange fine organic material content and, therefore, the Kruskal-Wallis test results can be accepted as valid.

	No. of slides per frequency class of amorphous yellow-orange organic material content						
Field Classes	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**4 (15-30%)**	**5 (30-50%)**	**% slides with >5% amorph. yellow-orange fine organic material**
Field Class 0	2	9	4	0	0	0	0
Field Class 1	1	5	12	8	4	3	45
Field Class 2	0	2	2	0	0	0	0
Field Class 3	1	9	6	1	0	0	6
Field Class 4	2	6	1	1	0	0	10
Field Class 5	1	0	8	3	0	0	25

Table 7.10 - Cross-tabulation of amorphous yellow-orange fine organic material data per field class - Badentarbat, Level 1.

The content of amorphous and cryptocrystalline coatings differs significantly between Field Class 0 and Field Class 5. However, the median values do not support this result. The number of these features present in the Badentarbat slides is low, with Field Classes 0, 3 and 4 all having a median value of 0 (0%) for this feature whilst the medians for Field Classes 1, 2 and 5 are all 1 (1%) (Table 7.8). From these results, you would expect that if a significant difference is found between Field Class 0 & 5, then a similar result should also be obtained for a comparison of Field Class 0 with Field Classes 1 and 2, given that they have the same median value as Field Class 5. Cross-tabulation of the amorphous and cryptocrystalline coatings data and calculation of the percentage of slides containing >1% of this feature provides sufficient evidence to confirm the Kruskal-Wallis test results (Table 7.11). Differences between Field Classes 1, 2 and 5 can be identified at this level of detail which cannot be appreciated from the median results alone. From this table, it can be seen that a comparison of Field Class 0 with Field Class 5 produces the largest difference and, therefore, the Kruskal-Wallis results can be accepted as accurate.

	No. of slides per frequency class of amorphous & cryptocrystalline coatings content				
Field Classes	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**% slides with >1% amorph. & crypto. coatings**
Field Class 0	9	6	0	0	0
Field Class 1	11	16	4	2	18
Field Class 2	0	4	0	0	0
Field Class 3	9	3	5	0	29
Field Class 4	8	2	0	0	0
Field Class 5	1	6	3	2	42

Table 7.11 - Cross-tabulation of amorphous and cryptocrystalline coatings data per field class - Badentarbat, Level 1.

A comparison of Field Class 0 with Field Class 5 also produces a statistically significant result for mamillate excrement content. Again, the median results do not entirely support this result as both Field Classes 2 and 5 have a median of 2 (1-5%) whilst Field Class 0 has a median of 1 (1%) (Table 7.8). Cross-tabulation and calculation of the percentage of slides containing >1% of this pedofeature provides sufficient detail to enable the Kruskal-Wallis results to be compared and accepted as valid (Table 7.12). From this table, it can be seen that Field Classes 2 and 5 actually differ in the percentage of slides containing >1% mamillate excrement content. Seventy-five percent of the slides in Field Class 2 contain >1% of this pedofeature whilst 92% of those in Field Class 5 contain similar amounts. This means that a greater difference occurs between Field Classes 0 & 5 than between Field Classes 0 & 2. The Kruskal-Wallis results can therefore be accepted.

	No. of slides per frequency class of mamillate excrement content					
Field Classes	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**4 (15-30%)**	**% slides with >1% mamillate excrement**
Field Class 0	6	5	3	1	0	27
Field Class 1	16	5	5	5	2	36
Field Class 2	0	1	3	0	0	75
Field Class 3	6	6	3	2	0	29
Field Class 4	5	4	1	0	0	10
Field Class 5	0	1	7	3	1	92

Table 7.12 - Cross-tabulation of mamillate excrement data per field class - Badentarbat, Level 1.

Field Class 1 - Polygons with short rig

Field Class 1 differs from the other field classes in terms of $CaCO_3$, amorphous yellow-orange fine organic material and mamillate excrement content. The $CaCO_3$ results are treated with some caution as it is not certain that this feature was correctly identified during the micromorphological description. The presence of sand lenses in some of the peat profiles, the sandy nature of the Bw horizons, as well as the loamy nature of some of the peats and the proximity of the sea at this site are all features which might suggest that calcareous sand is present in these soils. This could be through natural deposition or by anthropic inclusions. As previously mentioned, the application of calcareous sand is known to have been a common method of improving peat soils in this area (Baldwin, 1994). However, Bunting (1997) did not find any evidence of $CaCO_3$ in the substantial peat core extracted from the small lochan on this site used for palaeoenvironmental work. The presence of $CaCO_3$ was identified using both the guidelines in the Handbook for Soil Thin Section Description (Bullock *et al*, 1985) and knowledge gained during a micromorphology training course in 1996.

A statistically significant difference was only found between a comparison of Field Class 1 with Field Class 5. This result is not supported by the median results in Table 7.8 which show that Field Classes 2-5 all have a median value of 1 (1%) for this parameter, whilst Field Classes 0 and 1 have a median of 0 (0%). However, simple cross-tabulation of the $CaCO_3$ data and calculation of the percentage of slides containing >0% of this feature does indicate that the greatest difference between field classes occurs between Field Classes 1 and 5 (Table 7.13). The majority of the slides grouped in Field Class 1 contain no $CaCO_3$ at all, whilst 11 of the 12 slides in Field Class 5 contain 1-5% of this feature. Only one slide from the entire Badentarbat site contains greater quantities of this parameter and the vast majority of slides contain a mere 1%. This evidence supports the findings of the Kruskal-Wallis one-way analysis of variance by ranks tests.

	No. of slides per frequency class of $CaCO_3$ content				
Field Classes	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**% slides with >0% $CaCO_3$**
Field Class 0	8	7	0	0	47
Field Class 1	25	8	0	0	24
Field Class 2	1	3	0	0	75
Field Class 3	8	6	3	0	53
Field Class 4	4	4	1	1	60
Field Class 5	1	10	1	0	92

Table 7.13 - Cross-tabulation of the $CaCO_3$ data per field class - Badentarbat, Level 1.

A statistically significant difference in amorphous yellow-orange fine organic material content is found when Field Class 1 is compared with Field Classes 0, 3 and 4. The median results in Table 7.8 appear to support these findings. However, the calculation of the percentage of slides containing >5% of this micromorphological feature given in Table 7.10 does not fully support these results. A large difference is found when the figure for Field Class 1 is compared with that for Field Classes 0, 3 and 4 but a similarly large difference is also found between Field Class 1 and 2. Examination of the cross-tabulation results, however, reveals that there are slight differences in the distribution of the data for Field Classes 0, 2, 3 and 4. If the percentage of slides which contain >1% of amorphous yellow-orange fine organic material is calculated, these differences in distribution become more apparent (Table 7.14). It can now be seen that comparisons of Field Class 1 with Field Classes 0, 3 and 4 produce differences of 55%, 41% and 62%, respectively. A similar comparison of Field Class 1 with Field Class 2 only gives a difference of 32%. The Kruskal-Wallis test results can, therefore, be accepted.

% slides containing >1% amorphous yellow-orange fine organic material					
Field Class 0	**Field Class 1**	**Field Class 2**	**Field Class 3**	**Field Class 4**	**Field Class 5**
27	82	50	41	20	92

Table 7.14 - Percentage of slides per field class containing >1% amorphous yellow-orange fine organic material - Badentarbat, Level 1.

Field Class 1 was also found to differ from Field Class 5 in terms of mamillate excrement content. However, the median results once again suggest that a similar results should occur for a comparison of Field Class 1 with Field Class 2, as both Field Classes 2 and 5 have a median value of 2 (1-5%). However, the cross-tabulation results and the percentage of slides containing >1% of this pedofeature given in Table 7.12 shows a subtle difference between these two clusters. It would appear that the 48% difference between Field Classes 1 and 2 is not sufficient to produce a statistically significant result using the Kruskal-Wallis test whilst the 56% difference between Field Classes 1 & 5 is.

Field Class 2 - Polygons with no rig

Field Class 2 only differs from other field classes in terms of feldspar content. A statistically significant difference is obtained from comparisons of Field Class 2 with Field Classes 0, 3 and 4. These findings are supported by the median results in Table 7.8. Examination of the medians for feldspar indicate a difference of 2 frequency classes for each of these comparisons. In comparison, only a one frequency class difference occurs between Field Classes 1 & 2 and the medians for Field Classes 2 and 5 are both 4 (15-30%). The cross-tabulation data given in Table 7.9 also supports the Kruskal-Wallis test results. Of the five possible comparisons with Field Class 2, those with Field Classes 0, 3 and 4 produce the largest differences in the percentage of slides containing >5% feldspar. This confirms the Kruskal-Wallis test results.

Field Class 3 - Polygons with long rig

The slides in Field Class 3 show significant differences in their feldspar, multi-cell fungal spore and amorphous yellow-orange fine organic material content. Only comparisons of Field Class 3 with Field Classes 2 and 5 give statistically significant differences in feldspar content. This is supported by the median data (Table 7.8). The cross-tabulation data and the calculations of the percentage of slides containing >5% feldspar provide further evidence to support the Kruskal-Wallis test results (Table 7.9). Comparison of Field Class 3 with Field Classes 2 and 5 produce the largest differences at 59% and 51%, respectively. Comparisons with the remaining Field Classes produce a difference of no more than 21%.

The only significant difference in multi-cell fungal spore content occurs when Field Class 3 is compared with Field Class 4 for this parameter. However, very little difference is shown in the multi-cell fungal spore content for each field class when the medians are calculated (Table 7.8). All field classes, except Field Class 4 have a median of 1(1%). In comparison, Field Class 4 has a median of 0.5. This indicates that an equally high number of slides in this Field Class contain either no multi-cell fungal spores or 1% of these features. This can be demonstrated by simple cross-tabulation of the multi-cell fungal spore data (Table 7.15). From this table, it can also be seen that the majority of slides in Field Classes 0, 1, 2 and 5 contain 1% of this parameter. Field Classes 3 and 4 demonstrate similar distributions to each other but Field Class 3 contains slides with 1-5% multi-cell fungal spore content whilst the slides in Field Class 4 do not contain more than 1%. If the percentage of slides containing >1% multi-cell fungal spores is calculated, then it can be shown that Field Class 3 has the greatest proportion at this frequency level. However, Field Classes 2, 4 and 5 have no slides with this level of multi-cell fungal spores and, therefore, a comparison of Field Class 3 with each of these field classes produces the same result. This clearly does not support the Kruskal-Wallis test results. Further calculation of the percentage of slides which contain <1% of this parameter demonstrates that Field Class 4 has the greatest proportion of slides at this level of frequency. However, the greatest differences using this threshold occur when Field Class 4 is compared with Field Class 2 and Field Class 5, not Field Class 3. Again, this does not provide convincing evidence upon which to accept the Kruskal-Wallis results as valid. Nevertheless, if the results from these two calculations are looked at together, it can be shown that Field Classes 3 and 4 produce the most extreme values in either direction and should, therefore, produce the greatest difference during the multiple field comparisons carried out using the Kruskal-Wallis one-way analysis of variance by ranks test. These results may thus be regarded as valid.

	No. of slides per frequency class of multi-cell fungal spore content			**% slides with multi-cell fungal spores**	
Field Classes	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**<1%**	**>1%**
Field Class 0	2	8	5	13	33
Field Class 1	3	26	4	9	12
Field Class 2	0	4	0	0	0
Field Class 3	1	8	8	6	47
Field Class 4	5	5	0	50	0
Field Class 5	0	12	0	0	0

Table 7.15 - Cross-tabulation of multi-cell fungal spore data per field class - Badentarbat, Level 1.

The amorphous yellow-orange fine organic material content of the slides in Field Class 3 only differs significantly from that of Field Class 1. However, the median results suggest that a similar result should also occur for a comparison of Field Class 3 with Field Class 5 as both Field Classes 1 and 5 have a median of 2 (1-5%). Again, the median results prove inadequate for illustrating the true nature of the Level 1 data for this parameter. Table 7.10 shows the differences in distribution of the amorphous yellow-orange fine organic material per field class and the percentage of slides containing >5% of this parameter. From this, it can be demonstrated that a greater difference occurs between a comparison of Field Class 3 with Field Class 1 (39%) than with Field Class 5 (19%).

Field Class 4 - Polygon with reverse-S rig

Field Class 4 shows significant differences between field classes for six different micromorphological parameters: feldspar, multi-cell fungal spore, amorphous yellow-orange fine organic material, amorphous and cryptocrystalline coatings and mamillate and spheroidal excrement content. Most of the comparisons of field classes which produce these results have already been discussed in the context of Field Classes 0-3 and, therefore, they shall merely be mentioned briefly here. Comparisons of this field class with Field Class 5, however, have not been previously discussed and a comparison of these two field classes shows statistically significant differences for four parameters. The feldspar content of Field Class 4 is found to differ significantly to Field Classes 2 and 5. This is supported by the median data in Table 7.8 and the cross-tabulation data in Table 7.9. From the latter table, it can be seen that Field Class 4 has the lowest percentage of slides containing >5% feldspar. In contrast, Field Classes 2 and 5 have the highest percentage of slides with similar amounts of this feature.

The low multi-cell fungal spore content of the slides in Field Class 4 have been discussed under *Field Class 3* above. No other field class comparisons produced a significant result for this parameter. Field Class 4 differs significantly from Field Class 1 with regards to amorphous yellow-orange fine organic material. Whilst the median results do not completely support these findings, the calculations presented in Table 7.10 do confirm that there is a large difference between these two field classes for this parameter. The results from Table 7.14 indicate that the slides in Field Class 4 contain the lowest amounts of amorphous yellow-orange fine organic material.

The content of amorphous and cryptocrystalline coatings in Field Class 4 only differs significantly from that in Field Class 5. These findings are not supported by the median results (Table 7.8). Field Class 4 has a median of 0 (0%) whilst Field Class 5 has a median of 1 (1%). However, Field Classes 1 and 2 also have medians of 1 (1%), suggesting that comparisons of Field Class 4 with these classes should also produce a significant result. The cross-tabulation of the amorphous and cryptocrystalline coatings data does show slight differences in the distribution of the data between field classes but the calculation of the percentage of slides containing >1% of this feature produces the same result (0%) for Field Classes 1, 2 and 4. A simple shifting of the threshold does not produce more convincing evidence. However, if the distribution of the data for this parameter is examined to identify the extremes (as done for multi-cell fungal spore data under *Field Class 3*) then the differences which gave the significant result using the Kruskal-Wallis test can be identified (Table 7.16). The greatest percentage of slides containing <1% of this feature occurs in Field Class 4. In contrast, the greatest percentage of slides containing >1% amorphous and cryptocrystalline coatings occurs in Field Class 5. The most extreme left and right distributions of the data for this parameter therefore occur in Field Classes 4 and 5 and a comparison of these two field classes should therefore show the most significant difference. The Kruskal-Wallis test results can, therefore, be accepted.

	No. of slides per frequency class of amorphous & cryptocrystalline coatings content				**% slides with amorph. & crypto. coatings**	
Field Classes	**0 (0%)**	**1 (1%)**	**2 (1-5%)**	**3 (5-15%)**	**<1%**	**>1%**
Field Class 0	9	6	0	0	60	0
Field Class 1	11	16	4	2	33	18
Field Class 2	0	4	0	0	0	0
Field Class 3	9	3	5	0	53	29
Field Class 4	8	2	0	0	80	0
Field Class 5	1	6	3	2	8	42

Table 7.16 - Cross-tabulation of amorphous & cryptocrystalline coatings data per field class plus calculations of proportion of slides in each field class containing <1% or >1% of this feature - Badentarbat, Level 1.

A statistically significant difference in mamillate excrement was only found for a comparison of Field Class 4 with Field Class 5. This is supported by the median data (Table 7.8) as Field Class 4 has the lowest median value of 0.5 (equal amounts of slides with 0% and 1% content) whilst Field Class 5 has the highest median value at 2 (1-5%). The cross-tabulation data and calculations of the percentage of slides containing >1% of this pedofeature further confirms these results. Field Class 4 has the smallest proportion (10%) of slides with this frequency level of mamillate excrement whilst Field class 5 has the largest at 92%.

Spheroidal excrement content was only found to significantly differ between Field Classes 4 and 5. The median data (Table 7.8) supports these results as Field Class 4 has the lowest median of 0 (0%)

whilst Field Class 5 has the highest median at 2 (1-5%). However, despite the cross-tabulation data in Table 7.17 showing differences in the distribution of the spheroidal excrement data, it takes more than one simple threshold calculation to provide conclusive evidence to support the Kruskal-Wallis test results. Again, extremes in the distribution of the spheroidal excrement data for each field class need to be demonstrated by calculating the percentage of slides containing <1% and >1% of this pedofeature. From these calculations, it can be shown that Field Class 4 has the largest percentage of slides containing <1% of this pedofeature whilst Field Class 5 has the largest percentage of slides containing >1%. A comparison of these two extremes of left and right distribution of the spheroidal excrement content data can be expected to produce the most significant result and the Kruskal-Wallis results can therefore be regarded as valid.

	No. of slides per frequency class of spheroidal excrement content					% slides with spheroidal excrement	
Field Classes	0 (0%)	1 (1%)	2 (1-5%)	3 (5-15%)	4 (15-30%)	<1%	>1%
Field Class 0	7	4	4	0	0	47	27
Field Class 1	9	8	8	6	2	27	48
Field Class 2	0	4	0	0	0	0	0
Field Class 3	6	6	3	2	0	35	29
Field Class 4	6	2	2	0	0	60	20
Field Class 5	0	4	3	5	0	0	67

Table 7.17 - **Cross-tabulation of spheroidal excrement data per field class - Badentarbat, Level 1.**

Field Class 5 - Polygons with rig on steep slope

Field Class 5 shows statistically significant differences between field classes for five parameters: feldspar, $CaCO_3$, amorphous and cryptocrystalline coatings and mamillate and spheroidal excrement content. Each of these differences has already been discussed in the context of the field class compared with Field Class 5 and the emphasis shall, therefore, be on identifying the particular characteristics of Field Class 5 for each parameter. The feldspar content of Field Class 5 differs significantly from that of Field Classes 0, 3 and 4. This is supported by the median data in Table 7.8 and the cross-tabulation results in Table 7.9. From Table 7.8, it can be seen that the slides in Field Class 5 contain similarly high amounts of feldspar as those grouped in Field Class 2.

Field Class 5 is found to significantly differ in $CaCO_3$ content to Field Class 1 (see Table 7.13). From the calculation of the percentage of slides containing >0% of this parameter, it can be shown that Field Class 5 has the highest proportion of slides containing this parameter.

Amorphous and cryptocrystalline coatings are found to be a differentiating characteristic between Field Class 5 and Field Classes 0 and 4 (see Tables 7.10 and 7.15). The evidence from these tables indicates that the slides in Field Class 5 contain the highest amounts of this feature.

Statistically significant differences in mamillate excrement content are found between comparisons of Field Class 5 with Field Classes 0, 1 and 4. The median data also suggests that a statistically significant results should also be obtained for a comparison of Field Class 5 with Field Class 3, as the Field Class 3 has the same median (1 or 1%) as Field Classes 0 and 1 (Table 7.8). The cross-tabulation data and the calculations of the percentage of slides containing >1% mamillate excrement content given in Table 7.12 also shows that a greater difference occurs when Field Class 5 is compared with Field Class 3, which did not give a significant result, than with Field Class 1, which did. However, by calculating the percentage of slides containing >0% mamillate excrement, rather than >1% of this feature, it can be seen that there is only a 35% difference between Field Class 5 and 3. In comparison, the difference between Field Class 5 and Field Classes 0, 1, and 4 is 40%, 48% and 50%, respectively (Table 7.18). The Kruskal-Wallis results can, therefore, be accepted as accurate.

% slides containing >0% mamillate excrement					
Field Class 0	**Field Class 1**	**Field Class 2**	**Field Class 3**	**Field Class 4**	**Field Class 5**
60	52	100	65	50	100

Table 7.18 - Comparison of slides in each field class containing >0% mamillate excrement - Badentarbat, Level 1.

Field Class 5 has been shown to differ significantly only from Field Class 4 in terms of spheroidal excrement content (see *Field Class 4* above). The median data (Table 7.8) indicates that the slides in Field Class 5 contain the greatest amounts of this pedofeature. This is confirmed by the results of the cross-tabulation of the spheroidal excrement data in Table 7.17 where 67% of the Field Class 5 slides have been recorded as containing >1% of this pedofeature.

Summary

Analysis of the Badentarbat Level 1 data shows that 7 of the ordinal parameters recorded show statistically significant differences between two or more field classes (Table 7.19). None of the nominal variables, however, produce any statistically significant results and no obvious trends per field class could be identified. The slides in Field Class 0 represent the soils outwith the polygons and can be distinguished by a combination of different features. They contain low amounts of feldspar fragments, low amounts of amorphous yellow-orange fine organic material and amorphous and cryptocrystalline coatings and moderate amounts of mamillate excrement content. Field Class 1 (short rig) is characterised by low $CaCO_3$ content, high amorphous yellow-orange fine organic material content and moderate amounts of mamillate excrement. Field Class 2 (no rig) has only one differentiating characteristic. The slides in this field class contain high amounts of feldspar. The slides in Field Class 3 (long rig) can be distinguished by a combination of moderate amounts of feldspar fragments, low-moderate amounts of amorphous yellow-orange fine organic material and relatively high amounts of multi-cell fungal spores. Field Class 4 (Reverse-S rig) uses the largest combination of parameters to distinguish it from the others. It is characterised by containing moderate amounts of feldspar fragments, multi-cell fungal spores, amorphous yellow-orange fine organic material, mamillate and spheroidal excrement. The slides representing Field Class 5 (rig on steep slopes) combine 5 different parameters in order to distinguish them from the others. They are characterised by containing moderate-high amounts of feldspar fragments and high amounts of $CaCO_3$, amorphous and cryptocrystalline coatings, mamillate and spheroidal excrement.

7.1.4 Interpretation - Level 1 data grouped by Field Class, Badentarbat

The Badentarbat samples cover a wide range of types of cultivation remains as well as soils. From the comparison of the morphological characteristics of the rig and furrow with previous studies of cultivation remains, the Badentarbat site can be interpreted as containing examples of rig and furrow produced both with the plough and with the *cas-chrom* or delling spade (Dixon, 1994; Fenton, 1976; Jirlow & Whitaker, 1957; Parry, 1976). There are relatively few areas within the head-dyke that delimits this system which do not contain evidence of rig and furrow or lazybedding and such areas as do exist are generally small enclosures. The field classification clearly distinguishes these latter polygons from those with cultivation remains but the differences between the

Field Class	Field type	Micromorphological characteristics
Field Class 0	Outwith polygons	• Low feldspar content • Low amorphous yellow-orange fine organic material • Low amorphous & cryptocrystalline coatings content • Moderate mamillate excrement content
Field Class 1	Short rig	• Low $CaCO_3$ content • High amorphous yellow-orange fine organic material content • Moderate mamillate excrement content
Field Class 2	No rig	• High feldspar content
Field Class 3	Long rig	• Moderate feldspar content • High multi-cell fungal spore content • Low-moderate amorphous yellow-orange fine organic material
Field Class 4	Reverse-S rig	• Moderate feldspar content • Low multi-cell fungal spore content • Low amorphous yellow-orange fine organic material • Low amorphous & cryptocrystalline coatings content • Low mamillate excrement content • Low spheroidal excrement content
Field Class 5	Rig on steep slope	• High feldspar content • High $CaCO_3$ content • High amorphous & cryptocrystalline coatings content • High mamillate excrement content • High spheroidal excrement content

Table 7.19 - Micromorphological characteristics of each field class - Badentarbat, Level 1.

different types of cultivation remains appears to be less distinct. This may be due to the number of "artificially created" polygons on this open field system being kept to a minimum for classification purposes. This resulted in a number of large polygons which may contain more than one type or orientation of cultivation remains. From the Level 1 results and the Hierarchical Cluster Analysis (HCA) of the Level 1 data, it also appears that the differentiating characteristics are more closely associated with soil type than with any anthropogenic influence. However, manual grouping of the samples according to field class membership and testing for significant differences in the measured parameters between the different field classes has revealed a number of micromorphological characteristics which distinguish each field class from at least one other for a certain parameter. Can these distinguishing micromorphological characteristics be interpreted as evidence of different anthropogenic influences or are they merely due to differences in natural pedogenic processes across the site? The evidence for each field class shall be discussed in turn. The section will conclude with a summary of the interpretation of the Level 1 micromorphological evidence for the entire Badentarbat site.

Field Class 0 - Outwith polygons

The low amounts of feldspar found in this field class are thought to be associated with the disruption caused to these areas outwith the head dyke by the stripping of turf. This practise was common throughout Scotland and often led to the movement of substantial amounts of material from one area to another (Cameron, 1995; Davidson & Simpson, 1984; Fenton, 1976). This material was used both for fuel and building materials and the Baron Court books hold several records of anxious lairds forbidding this practise as it was depleting the resources of the land. This physical disruption and depletion of the soil, coupled with the increased exposure to the elements, is likely to cause accelerated weathering which results in the rapid loss of this susceptible mineral. However, feldspar is not an abundant mineral on any part of this site, with no more than 30% abundance in any one slide and this interpretation must be kept in context. Indeed, a fairly large difference can be seen between the three trenches which represent Field Class 0 (Appendix 7). The feldspar content in Trench 49 ranges from only 1% in slides 49A and 49B(L) to 15-30% in slide 49C(L). The slides from Trench 53 contain no more than 5-15% of this parameter. In contrast, four of the five slides from Trench 50 contain only 1% feldspar. This suggests that the low feldspar values for Field Class 0 might actually be biased by the results from Trench 50. Both Trenches 50 and 53 were located outside the head-dyke on the western slopes of the site (Figure 2.4). It could be expected that the results from these two trenches would be quite similar. However, Carter (in McCullagh, 1996) records evidence of a 12-15cm deep A horizon below approximately 30cm of peat in the area of Trench 50 which he interprets as a possible prehistoric agricultural soil, given the close proximity of stone cairns and a small circular structure. This agrees well with the profile description for Trench 50 (Appendix 3), although a strong iron pan was not found between the Ah and Bw horizons. It may, therefore, be that the low feldspar content of Trench 50 is due to an even longer history of disturbance, by perhaps both cultivation and turf-stripping, than any other area on site. Read *et al* (1996) have found trends of increased weathering of feldspar with an assumed increase in age of terraces on the River Thames. Trench 36 in Field Class 1 is the only other trench which displays such consistently low amounts of feldspar in all slides.

Very little difference in amorphous yellow-orange fine organic material content is found between the three trenches in Field Class 0 (Appendix 7). Compared to other trenches at the Badentarbat site the Field Class 0 trenches contain relatively low amounts of this parameter. However, no statistically significant difference in any other type of organic material is found between the Field Class 0 samples and others. Had the amounts of all types of organic material been low for Field Class 0, the obvious interpretation would have been that stripping of the upper organic layers over the history of the site has resulted in a relative lack of organic content in these soils. Such an interpretation is clearly over-simplistic. A relative reduction in only the amorphous yellow-orange fine organic material suggests that chemical weathering has played a role in creating this particular characteristic in these soils. The chemical decomposition of organic matter can follow a number of paths, depending on the environmental conditions and the type of organic matter input into the system (Swift *et al*, 1979). However, Babel (1975) states that, generally, leaf-browning substances in parenchymatic tissues result in a colour change from no colour through yellow to brown during the chemical decomposition process. Phlobaphene-containing tissues also follow a similar process and colour changes. Applying this information to the low amounts of amorphous yellow-orange fine organic material found in the Field Class 0 samples suggests that there is a reduction in the amount of partly decomposed organic material in these soils. The general vegetation survey of the site undertaken by Mills and Holden (McCullagh, 1996) indicates that the area outside the western head-dyke is covered by *Calluna/Erica* heath with *Nardus stricta* whilst the area beyond the eastern head-dyke is *Calluna/Erica* heath only. Few herbaceous plants were found in these areas which would provide an annual input of parenchymatic tissues. This may explain the low amounts of amorphous yellow-orange fine organic material in these areas but this interpretation is far from conclusive.

Although the Field Class 0 slides can generally be described as containing low amounts of amorphous and cryptocrystalline coatings, the differences between Field Classes 1, 2, 3 and 4 are very subtle and cannot be considered as a distinctive characteristic particularly for Field Class 0. However, subtle differences in the presence of this parameter can be shown between Trench 53 and Trenches 49 and 50 in Field Class 0 (Appendix 7). All the slides in Trench 53 contain 1% amorphous and cryptocrystalline coatings whilst only slide 49B(L) gives a similar result. All other slides contain no amorphous and cryptocrystalline coatings at all. It is debatable whether a convincing interpretation can be proposed when such small amounts and differences occur. It may be that this is no more than natural variability. Amorphous and cryptocrystalline coatings and nodules indicate anaerobic conditions in the soil profile (Bullock *et al*, 1985). However, sufficient amounts of mineral material also need to be present in the soils to allow the required redox reactions to take place. The peaty nature of these soils may be the reason for these low recordings but this is not a characteristic of only the slides in Field Class 0. This micromorphological feature is therefore not considered a particularly good indicator for this field class.

Moderate amounts of mamillate excrement content have also been identified as a distinguishing feature of the slides in Field Class 0. However, this is only statistically significant when compared with the results for Field Class 5. It cannot, therefore, be regarded as a unique feature of these slides alone. Once again, subtle differences in the recordings for the three trenches in this field class can be identified for this parameter (Appendix 7). The slides in Trench 49 contain between 1-15% of this pedofeature whilst the majority of slides in Trenches 50 and 53 contain no mamillate excrement at all. The presence of this pedofeature in Trench 49 could be interpreted in two ways: the soils and environmental conditions in this trench are more conducive to earthworms or the mamillate excrement is actually ageing spheroidal excrement produced by smaller soil fauna such as *Oribatid* mites which has coalesced to form larger aggregates. There is little evidence from the field descriptions of these trenches of any radical differences in the soil profiles. All of these trenches were sampled in late November and the water content was high in all soil profiles. It was, however, particularly high in Trench 49 which is situated outwith the eastern head-dyke. Several authors state that mite populations can withstand anaerobic conditions much more than earthworms (Pawluk, 1985; Petersen and Luxton, 1982; Swift et al, 1979). Standing water was common on the land surface in the eastern part of the site, outside the head-dyke, and it is considered unlikely that these conditions would be more conducive to earthworms than the marginally drier conditions on the steeper western slopes above the head-dyke in which Trenches 50 and 53 were situated. The latter interpretation must therefore be accepted as the most plausible but it is still difficult to explain why Trench 49 should produce different results to those for Trenches 50 and 53. Spheroidal excrement content is also slightly higher in some of the Trench 49 slides than from the other two trenches in this field class but no convincing explanation for this can be proposed.

The soils of Field Class 0 (outwith polygons), therefore, show very few differences to the soils sampled from within the field system. The few differences that have been identified are difficult to interpret in terms of pedological processes specific to this area of the site. Slight differences between the trenches can also be identified which suggests that there is some natural variability in the soils surrounding the field system. It may be that this natural variability is as important as the differences identified between field classes from the analysis of the Level 1 data according to field class membership.

Field Class 1 - Polygons with short rig

The Field Class 1 slides (short rig) come from six different trenches and can be distinguished from at least one other field class by three different micromorphological characteristics. These samples display low $CaCO_3$ content, high amounts of amorphous yellow-orange fine organic material and moderate amounts of mamillate excrement. However, examination of the data on a trench by trench basis for each parameter shows that there are also differences in the content of these parameters between trenches in the same field class (Appendix 7).

The low amounts of calcium carbonate are being treated with caution as Bunting (1997) found little or no evidence for carbonates during her analysis of the peat cores from the lochan on this site. However, this project deals with the top soils and evidence for the parish of Lochbroom from the Old Statistical Account of 1794 states that "the manure most used is sea-ware" and that "some of the more substantial of the farmers use a small quantity of shelly sand of which there is a large bank towards the northern extremity of the parish". Evidence given by John Maclean, a crofter and shoemaker in Altandhu, Coigach during the 1884 Highlands and Islands Commission into the condition of crofters and cottars gives an indication that Badentarbat was regarded as one of the better and more substantial farms in Coigach when he states "There were three places - Old Dornie and Risdale and Baden Tarbet which were occupied by tenants long ago, and which were then worth six times the value of the places, I now work, according to my father's story". This seems to suggest that it is likely that marine carbonates were added to the topsoils of Badentarbat. However, the $\delta^{13}C$ information provided with the ^{14}C dates for a range of trenches on the site show little variation in carbon content of marine origin but only two of these trenches were actually located within the fields rather than in or under a boundary structure (Chapter 3). More $\delta^{13}C$ analysis of a wider range of soils from all the field classes is required to address this apparent discrepancy in the results. However, it is interesting to note that all of the slides in Trenches 44 and 47 contain 1% of $CaCO_3$ whilst almost all of the other slides representing this field class contain none (Appendix 7). The soils in Trenches 44 and 47 differ from the others in that they do not have substantial peat horizons. Both of these trenches have sandy clay loam A horizons and it is considered likely that the presence of $CaCO_3$ in these profiles is due to the sandy, mineral nature of these soils in comparison to the peat soils of the other trenches in this field class. However, the presence of calcium carbonate is not exclusive to the mineral soils found in small pockets across the site. Calcium carbonate has also been recorded in peaty loam and loamy peat horizons in other field classes. Nevertheless, none of the Badentarbat trenches contain high amounts of calcium carbonate, even those close to the beach and containing sand lenses, and it is considered unlikely that carbonates would survive for any great length of time in the acidic peat conditions found throughout the site (Tipping & Carter, *personal communications*). Certainly, the presence of $CaCO_3$ in two of the Field Class 1 trenches appears to be due to natural soil conditions rather than anthropogenic inclusions of shelly sand. It must be accepted, however, that significant anthropogenic influence has created these small patches of relatively peat-free mineral soils at Badentarbat, as environmental conditions conducive to the formation of peat occurred across this site.

The high amounts of amorphous yellow-orange fine organic material may possibly be associated with the application of organic manure to these rigged fields, as noted in the Old Statistical Account (1794). However, the majority of this fine organic material is monomorphic and the peat profiles found in Trenches 32, 34, 36 and 43 in this field class contain greater abundances than the mineral soil profiles found in the remaining 2 trenches in this group (44 and 47). It is, therefore, also possible to interpret this result as natural heterogeneity in the soils of the site. This biasing of the results within each field class highlights the need for caution in interpreting these results in terms of discrete groups of different types of agricultural practise, especially where more than one type of soil profile is included in the group.

The moderate amounts of mamillate excrement recorded for Field Class 1 is not considered a particularly distinctive feature of this field class alone for the same reasons given for Field Class 0.

The mamillate excrement results for this field class also only differ significantly from Field Class 5 and it must, therefore, be considered that mamillate excrement content is a particularly important feature of Field Class 5. Subtle differences between the trenches grouped in Field Class 1 can, nevertheless, be identified (Appendix 7). Most of the slides in Trench 32 contain no mamillate excrement at all whilst the slides from Trench 47 contain 5-30% of this pedofeature. Trench 47 actually has the highest recordings of mamillate excrement of any trench from the Badentarbat site whilst Trench 32 has the lowest recordings. The slides from Trench 34 also contain no more than 1% of mamillate excrement. Trench 36 shows a steady decline in the amount of mamillate excrement with depth in the profile from 5-15% to 0%. This large variation in the mamillate excrement results for Field Class 1 clearly casts doubts on this micromorphological parameter being associated with a particular type of agricultural practise for the Field Class 1 polygons. Once again, these variable recordings can be best explained by soil type. The mineral profiles of sandy clay loam contain the greatest amounts of mamillate excrement content whilst the peat profiles contain the least amounts. This is probably due to the more anaerobic conditions in the peat profiles inhibiting the presence and activity of earthworms whilst the better mineral soils provide the more aerobic environment preferred by these animals.

Field Class 1, therefore, is represented by trenches in polygons with differing soil characteristics. Despite a few differences being identified between this field class and others for three parameters, almost as many differences can be found between the different trenches representing Field Class 1. These latter differences have not, however, been statistically tested during this stage of the analysis and these observations are merely based on manual comparisons of the data for each trench. Calcium carbonate is predominantly present in the mineral soils. Similarly, the highest recordings of mamillate excrement content are also from the mineral soils in Trenches 44 and 47. In contrast, the high amounts of amorphous yellow-orange fine organic material are found in the organic soils of Trenches 32, 34 and 36. Interpreting any of these features as distinctive anthropogenic influences particular to this field class is not possible due to the variability of the results.

Field Class 2 - Polygons with no rig

Unfortunately, only one trench was sampled from an area within Field Class 2 (no rig). This trench (54) was located in a small enclosure approximately 15 metres below the head dyke on the west side of the site. Although bedrock was hit at a shallow depth below the surface at several points within this enclosure, a deep soil was also found which was originally considered as "plaggen" in nature. The only differentiating characteristic found for this trench was the high feldspar content. McCullagh (1996), in his report to Historic Scotland, states that this enclosure is a late addition to the landscape and overlies the local rig. This indicates that the "plaggen" type soil found within this enclosure is late in origin and, therefore, may have undergone less mechanical disturbance and exposure to the elements than other areas. The feldspar may also have been added from another source as part of the management process which resulted in this deepened soil profile. However, Carter's soil survey of the site (McCullagh, 1996) places this enclosure in an area of freely and imperfectly draining podzols and cultivated podzols with some peaty surface horizons and the abundance of feldspar may be due to the nature of the soils in this area. The only other trench that may possibly be located on the fringes of this area of podzols is Trench 45 which displays some similar characteristics (Appendix 7). The favoured interpretation is that this is a natural mineral soil profile. Given the amount of shallow bedrock found within the enclosure, it is considered unlikely that this was extensively used as a garden plot or kale yard, for example, which was the original interpretation of this structure.

This trench cannot be seen as typical of the fields containing no rig and it is to the detriment of this project that no further samples were taken from this group. However, the main aim was to attempt to micromorphologically distinguish the differences in agricultural practise and the obvious range of rig types at this site afforded an excellent opportunity for comparison of different cultivation techniques which constituted the main emphasis of this project.

Field Class 3 - Polygons with long rig

Field Class 3 contained areas with long rig, a small average angle of slope and at low altitude. Two trenches were located in this area (46 and 51) and both had deep peat profiles on to loamy sand. These trenches contained moderate amounts of feldspar, high amounts of multi-cell fungal spores and low-moderate amounts of amorphous yellow-orange fine organic material.

The moderate amounts of feldspar are also found in the slides from Field Class 4. This evidence suggests that chemical and physical weathering processes may not have been as severe in these areas as in Field Class 0, for example, where relatively low amounts of feldspar were found. This may be because these areas have not been subjected to as much disturbance by humans. From the field evidence gained through the soil work and the archaeological excavation and survey, it is considered likely that the areas in Field Classes 3 and 4 (only 3 areas in total) constitute those which have been used only infrequently, and probably towards the end of the working life of the site as a farm system. Despite these areas possessing distinctive rig and furrow of high amplitude which, in most areas, appears to have been cultivated by plough, the areas are relatively flat, prone to significant waterlogging and would have been regarded as undesirable for cultivation except for in the most desperate times of need such as the population increase during the late 18th/early 19th centuries. The Old Statistical Account for 1845 shows that the population of the parish of Lochbroom increased from 2211 in 1755 to 3500 in 1794 and stood at 4615 in 1831, a more than 100% rise in population in less 80 years. Herring catches were also failing around this time putting further pressure on land resources.

The water table in the two polygons designated as Field Class 3 (Polygons 22 and 23 - see Figure 2.4) is particularly high due to the low altitude and gentle slopes and the proximity of the lochan and gravel bar. This results in anaerobic conditions in these soils, despite the high amplitude rig morphology. As discussed previously in this chapter and Chapter 6, such conditions are prohibitive to soil fauna. In anaerobic conditions, fungi are the most active decomposers of organic material (Swift *et al*, 1979; Petersen & Luxton, 1982). This may explain the high content of multi-cell fungal spores found in these soils. Bracken does not grow on this part of the site. Although transportation of fungal spores from the bracken plants on the western slopes of this site cannot be completely ruled out, the fact that these fungal spores are found throughout the deep profiles of both of these trenches suggests that this is not the only source of fungal spores in these soils.

The low-moderate amounts of amorphous yellow-orange material may also be due to the anaerobic conditions of these soils which slows down the decomposition of organic matter. Soil fauna play an important role in the comminution of organic matter and their absence is likely to greatly slow down the decomposition process. The area classed as Field Class 3 has also been interpreted as a late inclusion in the agricultural landscape of Badentarbat in times of population pressure. These soils may, therefore, not have been subjected to prolonged and repeated disturbance from cultivation which allows slightly more aerobic conditions to prevail. This may explain why the amorphous yellow-orange fine organic material content is lower in these trenches than in Trench 32 (Field Class 1), for example, where radiocarbon dating has established that these latter soils may have been cultivated over a period of 4000 years (Appendix 7).

The results for Trenches 46 and 51 in Field Class 3 are similar for almost all parameters (Appendix 7). However, the slides in Trench 46 do contain greater quantities of amorphous and cryptocrystalline coatings than those in Trench 51. The soils in Trench 46 are described as sandy or loamy peats in comparison to the pure peats of Trench 51. Whilst this is not a statistically significant parameter for differentiating between this field class and the others, it does further demonstrate that a certain amount of mineral material needs to be present to allow amorphous and cryptocrystalline features to form.

Field Class 3 is therefore interpreted as a late addition to the Badentarbat field system during times of population pressure in the late 18th/early 19th centuries. The micromorphological evidence in the slides taken from this field class indicates that the soil conditions are particularly waterlogged, inhibiting faunal activity and the decomposition of organic matter. The moderate amounts of feldspar in these soils provides a further clue to the temporary nature of these areas of rig and furrow, despite their high relief giving an air of permanence to this part of the landscape.

Field Class 4 - Polygon with reverse-S rig

Field Class 4 contains only one, anomalous, area containing reverse-S rig. The samples from Trench 52 show several distinguishing characteristics, some of which are shared with other field classes. The slides from Trench 52 contain moderate amounts of feldspar and low amounts of multi-cell fungal spores, amorphous yellow-orange fine organic material, amorphous and cryptocrystalline coatings and mamillate and spheroidal excrement.

The moderate feldspar content has already been discussed under *Field Class 3* and is considered to be due to the late and transient use of this area of land for cultivation. The Reverse-S nature of the rig and furrow in this area is unique in the Badentarbat site and it remains a mystery why only this small area displays such a rig morphology. This type of rig is associated with the use of the old Scotch plough prior to 1750 which required a large team of draught animals to pull it (Fenton, 1976). Each draught animal was often owned by different tenants and some were even part-shared between two or more people. It, therefore, seems unlikely that so many people would invest the use of their animals for the working of such a small piece of land. It may be that the peat-cuttings close to Polygon 29 have eradicated other evidence of the use of this type of plough but this cannot be stated with certainty.

Although the use of this type of plough is generally thought to have ceased in Lowland Scotland from the time of the Improvements onwards, use of the lighter version of the old Scotch plough used in the Highlands and Islands and drawn by horses rather than oxen, is known to have persisted in some areas until much later. It is, therefore, difficult to date this rig with any great certainty and no reference to the type of cultivation implements used in this area have been found in the historical documentation. However, we know from the historical documentation that, between 1842-1870, Badentarbat was effectively run as a sheep farm with rentals from this period only referring to shepherds or fishermen (Bangor-Jones, in McCullagh, 1996). It can thus merely be stated that all rig and furrow at Badentarbat are unlikely to date from later than the mid 19th century.

The high multi-cell fungal spore content of the slides in Field Class 3 has been attributed to the anaerobic conditions of the sampled profiles. However, this interpretation is called into question by the results for Field Class 4. Trench 52 was particularly wet. The trench was dug late on the 28th November, 1995. On returning to the trench to carry out the field description on the morning of the 29th November, the trench was found to be half-full of water, despite no rainfall during the night. Anaerobic conditions, therefore, must occur in this extremely wet profile and high amounts of multi-cell fungal spores might be expected if the interpretation given under *Field Class 3* is correct. However, the opposite is found. Five of the ten slides from Trench 52 contain only 1% of this parameter whilst the remaining five contain no multi-cell fungal spores at all (Appendix 7). The possibility that these fungal spores might originate from the bracken found on the western slopes of the site has already been discussed and rejected due to the presence of these spores at depth in the profile. However, it might be argued that the predominant south-westerly winds in this area would transport the bracken fungal spores from the western slopes across the site in an easterly direction. Trench 52 lies upslope and due west of the bracken-covered slopes and would, therefore, only receive fungal spores from these plants during the less frequent easterly winds. A convincing explanation of these fungal spore results and their significance to the soil profiles in which they occur can only be achieved by identifying their source of origin. This remains an area of research for the future and no interpretations can be proposed based on the inadequate evidence provided from this study.

The small amount of amorphous yellow-orange fine organic material is probably due to the anaerobic conditions of the peat inhibiting both the chemical and mechanical decomposition of organic material, as discussed in the context of Field Class 3. These conditions may also account for the very low amounts of faunal activity which are demonstrated by the low content of spheroidal and mamillate excrement found in the soils of Trench 52. The low content of excrement, even compared to the similarly waterlogged peat soils of Field Class 3, suggests that the anaerobic conditions of the soils in Trench 52 are the most extreme of all those sampled at Badentarbat. It may be that the environmental conditions are too severe to allow even bacterial and fungal decomposition of organic material to take place.

The peats in Trench 52 contain similarly low amounts of mineral material to Trench 51 in Field Class 3 (Appendix 7). Both of these trenches also contain low amounts of amorphous and cryptocrystalline coatings. The organic nature of these soils is therefore considered to be the reason for such low recordings of this pedofeature.

Field Class 4, therefore, appears today as an anomalous area of reverse-S rig and furrow but the investment of draught animals and people required to produce this type of rig morphology makes it unlikely that this is the only area of this site that has been cultivated using the old Scotch plough in the past. It can, therefore, only be assumed that the other areas where this type of cultivation took place have been lost by later human activity on this site. Although several micromorphological features can be shown statistically to differ from at least one other field class, none of these can be regarded as unique characteristics of this field class alone. The micromorphological evidence is therefore considered to characterise the type of soil rather than having any associations with past agricultural activities.

Field Class 5 - Polygons with rig on steep slope

The polygons in Field Class 5 are characterised by having greater average slopes and a higher upper altitude. Three trenches were sampled in this field class; Trenches 38, 42 and 45. Five micromorphological parameters distinguish this field class from at least one of the others. This group of slides is characterised by high feldspar and CaCO3 content and high amounts of amorphous and cryptocrystalline coatings and spheroidal and mamillate excrement. Like, Field Class 1, this field class contains samples from trenches with very different soil textures which can be shown to produce variable results for certain parameters. Trench 38 contains loamy peat to a depth of 66cm, whilst Trenches 42 and 45 merely contain a peaty turf mat of a few centimetres above a sandy clay loam A horizon to a maximum of 40cm depth, although the sandy clay loam of Trench 45 has a much higher organic content and corresponds to a Munsell Chart reading of 10YR/2/1 similar to that for Trench 38. Trench 38 contains loamy peat, rather than pure peat, as confirmed by the LOI results (40%) obtained by AOC during their soil analysis. It is therefore likely that, either the mineral soil properties of Trenches 42 and 45, or the organic properties of Trenches 38 and 45 combined, may have influenced these results. This is illustrated by the average depth in the profile which was found to be significantly more shallow than in all other field classes, despite Trench 38 being one of the deepest trenches dug on the site. The more shallow nature of Trenches 42 and 45 appear to have influenced this result.

The high amounts of feldspar signified as a characteristic of this field class are primarily found in the more mineral soils of Trenches 42 and 45 (Appendix 7). However, it must be stressed that high amounts of feldspar in this context is a relative term and all samples from Trenches 42 and 45 merely contain frequent (15-30%) abundances of this mineral. This property is not thought to be attributable to any agricultural practise but is rather a natural property of these mineral soils since the more peaty profile in Trench 38 produced only up to 15% abundance of feldspar in keeping with other peat profiles sampled throughout the site.

The amount of $CaCO_3$ in the Field Class 3 soils is only high in relative terms to the other soils sampled at Badentarbat. Only one slide contains the maximum of 1-5% of this feature whilst all other slides grouped in Field Class 3, except slide 38A, merely contain 1% of $CaCO_3$ (Appendix 7). As noted earlier, Trench 38 has been shown through LOI tests to contain significantly higher amounts of mineral material than was appreciated during the field description work. Trenches 42 and 45 both have sandy clay loam A horizons. The presence of calcium carbonate in these Field Class 5 slides is probably due to the sandy nature of these soil profiles. Further evidence to support this interpretation comes from the similar recordings obtained during description of the sandy clay loams of Trenches 44 and 47 grouped in Field Class 1.

The amorphous and cryptocrystalline coatings content is also only high in relative terms to the other field classes. Only slides 42A and 45C contain the maximum recordings of 5-15% of these pedofeatures for this field class (Appendix 7). In comparison, none of the slides from Trench 38 contain more than 1% of this micromorphological feature. Again, similar values and data distributions can be shown between Trenches 42 (Field Class 5) and 47 (Field Class 1) and Trenches 45 (Field Class 5) and 44 (Field Class 1) for this parameter. It must therefore be considered that the amorphous and cryptocrystalline coatings results for Field Class 5 have been biased by the results for Trenches 42 and 45 and owe more to the soil texture of these soils than to the type of agricultural remains and former function of the Field Class 5 polygons represented by these three trenches.

The high amounts of spheroidal and mamillate excrement are particular features of the samples from the more organic soils of Trenches 38 and 45. Trench 42 contains no more than 5% of mamillate excrement and 1% of spheroidal excrement compared with up to 30% mamillate excrement in thin section 45A and 15% spheroidal excrement in sections 38A, C and D (Appendix 7). The presence of relatively high amounts of both these types of excrement in the Field Class 5 soils suggests that the environmental conditions in these soils are conducive to soil fauna. It has already been discussed that horizons with a greater mineral content result in more aerobic conditions which promote the presence and activity by soil fauna. However, the food source must also be present in order for such activity to occur and, therefore, it is no surprise that the more organic soils contain the greatest amounts of excremental pedofeatures.

The nature of the rig and furrow in these areas is distinctive of that produced by the later fixed mouldboard plough which was lighter and did not require a large team of draught animals to pull it (Fenton, 1976). However, the different soil profiles have produced very different rig. Trenches 42 and

45 have wide, straight rig of low amplitude whilst Trench 38 has long curvi-linear rig of high amplitude. The lack of any deep peat horizon in Trenches 42 and 45 suggests that these areas have either been in constant cultivation, even during the period of abandonment and peat growth in other areas on site, or that the peat was stripped to reveal the better soils for cultivation.

Trench 38 has long, regular, curving rig of very high amplitude in an area that was still wet underfoot during the particularly dry summer of 1995 when the field work took place. It is believed that this area was taken into cultivation late in the history of the site due to population pressure as mentioned earlier and, indeed, the AMS ^{14}C date of cal BP 300±80 obtained from a charcoal sample in Trench 38 appears to confirm this interpretation. It is also considered likely that turf or mineral materials were added to this area to increase the drainage properties of the soil and that the most likely crop grown on this area would have been potatoes (Tipping, *personal communication*).

The micromorphological results for the Field Class 5 slides cannot be shown to have any association with a particular type of cultivation practise in the past. It has been demonstrated that each of the parameters which have been shown to statistically differ from at least one other field class are biased by the results from one or two out of the three trenches in this group. Many of the results for Trenches 42 and 45 can be shown to be very similar to the results from the sandy clay loam profiles of Trenches 44 and 47 in Field Class 1. This suggests that the micromorphological features of these soils are more closely associated with soil texture and type than with any particular function associated with the rig morphology in these polygons.

Summary

The Level 1 micromorphological results, when grouped by field class, have shown differences between field classes for a number of parameters. Whilst these results initially appear promising, closer examination of these results and the Level 1 data shows that these "distinctive" features can only be associated with different soil types rather than particular cultivation practises in each field class. This suggests that the field classification results, based only on rig and polygon morphology and topographic characteristics has not produced a true picture of the Badentarbat field system. However, it may equally be that any evidence of past anthropogenic activity and influence on these soils has been eradicated by subsequent pedological processes since the abandonment of the site for arable cultivation in the mid 19th century. From these results, it would appear that the best evidence of past agricultural activity on this site can be gained through studying the rig morphology and the macroscopic characteristics of the soils as well as the historical documentation for the site.

7.1.5 Comparison of Level 1 results for Boyken and Badentarbat

The slides from the Boyken site showed statistically significant differences between at least two field classes for three micromorphological parameters. In contrast, the Badentarbat slides showed differences for six micromorphological parameters. However, none of the micromorphological properties for either site can be shown to be unique to only one field class. Although it initially appears that the Badentarbat results are much better than the Boyken results, it can be shown that the different soil types in Badentarbat are mainly responsible for the identified micromorphological features rather than the form and function of the polygons from which the samples come. The more consistent soil type found at Boyken, however, does allow some interpretation of possible differences in the function of the various polygons sampled. The micromorphological information is not sufficient in itself to reach a convincing interpretation. The information gained through archaeological excavation, field survey and research of the historical documentation plays an important role in the interpretation process. Soil micromorphology is merely an analytical technique and it was never considered possible that all necessary information for interpreting these landscapes would be acquired through using only this diagnostic tool. Nevertheless, the dearth of micromorphological evidence for past anthropogenic activity in the soils for both sites is disappointing, if not unexpected. It is almost 150-200 years since abandonment of these field systems for anything other than livestock grazing. Natural pedological processes have continued to further modity these soils since their abandonment for arable agriculture. The continued presence of livestock across both of these abandoned sites has possibly masked any differences that used to exist between the soils used primarily for arable crops and those used as pasture during the working lifetime of the field system.

The lack of micromorphological evidence between the different field classes at each site may equally be due to the fact that the field classification results are inaccurate. Problems with interpreting and measuring the rig and polygon morphology at each site using only the existing survey maps and aerial photographs have already been discussed in Chapter 2. The micromorphological results from both sites appear to confirm that the devised field classification procedure requires significant modification and improvement in order for it to accurately reflect not only the morphology of the field remains but also their environmental context. The problems faced in interpreting the field systems at Boyken and Badentarbat are very different. The Boyken site is difficult to interpret due to complicated sequences of different layouts of enclosures whilst the problem at Badentarbat is due to the unenclosed nature of much of this agricultural landscape. Both of these characteristics requires subjective interpretation of the landscape rather than merely objective measurement of the extant features. The apparent lack of micromorphological evidence to explain the function of the various field units at both sites may, therefore, be due to erroneous interpretation and classification of the landscape rather than loss of features in the soil which can be directly attributed to past anthropogenic activity.

7.2 Introduction - Testing form and function using Level 2 data

The Level 2 micromorphological description work was undertaken for two purposes: 1) to test whether a more detailed analysis of the slides for a smaller set of parameters would provide more useful information for identifying any possible relationship between the form and function of different field units within medieval or later field systems in Scotland and, 2) to check that within-slide variability did not outweigh the between-slide variability identified during the Level 1 work. Both of these considerations have been discussed at length in Chapter 6. However, the Level 2 results were, again, not clustered during the HCA process according to their field class context. In order to determine whether there are any micromorphological characteristics which show significant differences between the field classes determined during the desk-top field classification study, the Level 2 data must be manually regrouped according to the field class from which each case was sampled and be reanalysed. The analysis of the Level 2 results grouped by field class for each site are presented in Sections 7.2.1. and 7.2.3. The interpretations of this analysis are discussed in Sections 7.2.2 and 7.2.4. The results from the two sites are then compared in Section 7.2.5.

7.2.1 Results - Level 2 data grouped by Field Class, Boyken

A selection of slides from trenches representing each field class sampled at Boyken were used for the Level 2 micromorphological work (Table 7.20). All the soil thin sections produced from each trench are described at this level and the medians for each micromorphological parameter per field class is given in Table 7.21. Only three of the five parameters measured as ordinal data showed statistically significant differences (95% C.I.) between two or more field classes; sandstone, cell residue and mamillate excrement content. The medians per field class for quartz and spheroidal excrement content clearly demonstrate little or no variability between the field classes for these parameters. None of the nominal variables produced statistically significant results for comparisons between the field classes and no obvious trends were identified from manual examination of the cross-tabulation of these results.

Field Class No.	Field Class Description	Trenches selected from each Field Class (Trench No./Polygon No.)
1	Truncated with rig and/or lynchets	13/22
2	Short rig	1/56
3	No rig	11/36, 5/52
4	Lynchets with rig (50:50 ratio)	Not sampled
5	Lynchets only	26/30
6	Long rig, large field area, largest total length of lynchets	Not sampled
7	Outwith polygons	22, 30(1)

Table 7.20 - Trenches selected to represent each field class for Level 2 work - Boyken. See Figure 2.5 for location of trenches.

	Median of each ordinal parameter per field class sampled (percentage)				
Micromorphological Parameter	**Field Class 1**	**Field Class 2**	**Field Class 3**	**Field Class 5**	**Field Class 7**
Quartz content	30	25	30	35	30
Sandstone content	20	25	5	10	25
Cell residue content	5	5	5	5	5
Mamillate excrement content	10	5	5	0	5
Spheroidal excrement content	0	0	0	0	0

Table 7.21 - Medians of ordinal parameters described during Level 2 - Boyken.

Field Class 1- Truncated polygons with rig and/or lynchets

Trench 13/22 represents Field Class 1 which was characterised during the field classification as truncated polygons containing rig and/or lynchets. The only statistically significant differences (95% C.I.) between Field Class 1 and the other field classes were for sandstone and mamillate excrement content. The sandstone content of Field Class 1 differs significantly from that of Field Class 3. A comparison of these two field classes also reveals a statistically significant difference in mamillate excrement content. Similarly, a comparison of Field Class 1 with Field Class 5 demonstrates a significant difference in mamillate excrement content.

The median results for sandstone content appear to support the findings from the Kruskal-Wallis one-way analysis of variance by ranks test. Field Class 1 has a median value of 20% whilst Field Class 3 has a median of 5%, giving a 15% difference for this comparison. This is the largest difference for any comparison of Field Class 1 with the other sampled field classes. Cross-tabulation of the sandstone content data for each field class and calculation of the percentage of gridsquares per field class which contain >25% of this parameter provides further evidence to support the Kruskal-Wallis test results (Table 7.22). Forty percent of the Field Class 1 gridsquares contain >25% sandstone content, whilst only 20% of the Field Class 3 gridsquares contain similar amounts of this parameter. Again, this comparison with Field Class 1 produces the largest difference. The results for Field Classes 2, 5 and 7 are all too similar to that of Field Class 1 to produce a statistically significant result. The Kruskal-Wallis test results can, therefore, be accepted.

Comparison of Field Class 1 with both Field Classes 3 and 5 produced statistically significant results for mamillate excrement content using the Kruskal-Wallis test. However, the median results suggest that a statistically significant difference should also be obtained for a comparison of Field Class 1 with Field Classes 2 and 7, given that the median of 5% for both these field classes is the same as that for Field Class 3. Cross-tabulation of the mamillate excrement data and calculation of the percentage of gridsquares containing >10% of this parameter demonstrates subtle differences in the distribution of the data which cannot be appreciated from the median results alone (Table 7.23). From these calculations, it can be shown that a comparison of the percentage of gridsquares containing >10% mamillate excrement in Field Class 1 with Field Classes 3 and 5 gives differences of 19% and 24%, respectively. In contrast, similar comparisons of Field Class 1 with Field Classes 2 and 7 show only differences of 3% and 9%, respectively. This suggests that the Kruskal-Wallis test results are valid.

Field Class	Sandstone content (%) per field class (No. of gridsquares)																					Percentage of gridsquares containing >25% sandstone
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	
Field Class 1	0	2	9	6	6	2	3	3	4	1	2	1	2	1	0	0	0	0	0	0	0	40
Field Class 2	0	19	20	7	5	4	5	6	7	3	9	5	5	1	3	2	4	3	0	0	1	50
Field Class 3	18	60	20	8	2	5	7	4	5	2	1	0	1	1	2	1	1	0	0	1	2	20
Field Class 5	1	12	11	1	2	0	0	0	2	1	1	1	2	2	0	2	0	1	0	0	1	37
Field Class 7	8	24	4	2	4	7	8	6	4	7	4	1	5	0	0	2	1	0	2	0	2	46

Table 7.22 - Cross-tabulation of sandstone content data per field class - Boyken, Level 2.

Field Class	Mamillate excrement content (%) per field class (No. of gridsquares)							Percentage of gridsquares containing >10% mamillate excrement
	0	5	10	15	20	25	45	
Field Class 1	2	12	18	6	1	2	1	24
Field Class 2	31	25	30	12	6	5	0	21
Field Class 3	51	59	26	6	1	0	0	5
Field Class 5	18	15	2	0	0	0	0	0
Field Class 7	23	34	20	9	3	2	0	15

Table 7.23 - Cross-tabulation of mamillate excrement data per field class - Boyken, Level 2.

Field Class 2 - Polygons with short rig

The slides from Field Class 2 described at Level 2 showed statistically significant differences for sandstone, cell residue and mamillate excrement content. A comparison of Field Class 2 with Field Class 3 gave statistically significant results for each of these three parameters whilst a comparison of Field Class 2 with Field Class 5 showed differences in cell residue and mamillate excrement content.

The median results for sandstone content suggest that the Kruskal-Wallis test results are valid (Table 7.21). A comparison of the median for Field Classes 2 and 3 produces the largest possible difference of any comparison of these 5 field classes. The cross-tabulation results also suggest that the Kruskal-Wallis test results can be accepted (Table 7.22). The percentage of gridsquares in Field Class 2 with >25% sandstone content is 50%. The value for Field Class 3 is 20%. The 30% difference between these results is also the largest possible for a comparison of Field Class 2 with the other field classes. These results can therefore be accepted as correct.

The cell residue content of the Field Class 2 slides differs significantly from Field Classes 3 and 5. However, the median results (Table 7.21) for this parameter show that the median for all field classes is 5%. This clearly does not agree with the Kruskal-Wallis test results. Cross-tabulation of the cell residue content data also does not provide clear evidence to support these results (Table 7.24). The distribution of the data for each field class is very similar and clearly confirms that the median value for each field class is 5%. However, Field Class 2 does contain the gridsquares with the highest cell residue content of 20%. A simple calculation of the percentage of gridsquares containing more than a certain amount of cell residue content also cannot clarify the situation and confirm the Kruskal-Wallis test results. If the percentage of gridsquares which contain >5% of this parameter is calculated, it can be shown that the greatest difference between field classes occurs for a comparison of Field Class 2 with Field Class 5. A comparison of Field Class 2 with Field Class 3 shows a difference of 7%. However, the same difference is found from a comparison of the results of this calculation for Field Class 2 and Field Class 7. Indeed, no threshold can be found which shows that the difference between Field Classes 2 and 3 is greater than a similar comparison of Field Class 2 with Field Class 7. This is largely because the majority of cell residue results are 5%. When the percentage of cells containing this level of cell residue in each field class is calculated, it can be shown that 72% of the gridsquares in Field Class 3 contain 5% of cell residue whilst 87% of the Field Class 7 gridsquares contain similar amounts. There are, therefore, subtle differences in the data distribution for Field Classes 3 and 7 which may explain the Kruskal-Wallis results.

	Cell residue content (%) per field class (No. of gridsquares)					
Field Class	**0**	**5**	**10**	**15**	**20**	**Percentage of gridsquares containing >5% cell residue**
Field Class 1	0	40	2	0	0	5
Field Class 2	33	67	3	4	2	8
Field Class 3	18	103	21	1	0	15
Field Class 5	1	21	8	5	0	37
Field Class 7	11	79	1	0	0	1

Table 7.24 - Cross-tabulation of cell residue content data per field class - Boyken, Level 2.

The mamillate excrement content of Field Class 2 also differs significantly to that of Field Classes 3 and 5 but, once again, the median values do not support these results (Table 7.22). Field Classes 2 and 3 both have a median value of 5%. The median results do, however, show a difference between Field Class 2 and Field Class 5. The cross-tabulation of the mamillate excrement data per field class given in Table 7.23 shows that Field Class 2 contains gridsquares with 25% mamillate excrement content whilst the gridsquares in Field Class 3 contain no more than 20%. The gridsquares in Field Class 5 contain no more than 10% of this parameter. The calculation of the percentage of gridsquares which contain >10% mamillate excrement therefore shows a 16% difference between the values for Field Classes 2 and 3 and 21% for a similar comparison of Field Classes 2 and 5. These are the largest differences found by comparing Field Class 2 with the other field classes described at Level 2 and the Kruskal-Wallis test results can, therefore, be accepted as correct.

Field Class 3 - Polygons with no rig

The Field Class 3 slides described at Level 2 were also shown to differ in sandstone, cell residue and mamillate excrement content when compared with at least one other field class. The sandstone content of Field Class 3 was found to differ significantly from Field Classes 1, 2 and 7. The differences between Field Class 3 and Field Classes 1 and 2 have already been established in the discussion of *Field Class 1* and *Field Class 2* above. The median results in Table 7.21 show that there is also a large difference between the median value for Field Class 3 and Field Class 7 for this parameter. The cross-tabulation data further confirms that there are considerable differences in the distribution of the sandstone content data for these two field classes. The percentage of slides containing >25% sandstone content is 20% for Field Class 3 and 46% for Field Class 7. This 26% difference is the second largest for a comparison of Field Class 3 with any other field class. Indeed, the three largest differences are found for comparisons of Field Class 3 with Field Classes 1, 2 and 7, just as the Kruskal-Wallis test results suggest.

The cell residue content of Field Class 3 merely differs significantly from that of Field Class 2. Again, this has already been discussed under *Field Class 2* above and no benefit is drawn from repeating these findings here. The main point to note from the cell residue data given in Table 7.24 is that the cell residue data distributions for Field Classes 1, 3, 5 and 7 are all very similar and cell residue content cannot, therefore, be regarded as a particularly important distinguishing feature of Field Class 3 alone.

The gridsquares in Field Class 3 differ significantly (95% C.I.) in mamillate excrement content to those grouped in Field Classes 1 and 2. Again, these results have already been discussed in the context of these latter two field classes and have been confirmed as accurate results (see Table 7.23). The distribution of the mamillate excrement content data of the five field classes represented during the Level 2 work do show that the data distribution of Field Class 3 is too similar to that of Field Classes 5 and 7 to produce a statistically significant results.

Field Class 5 - Polygons with lynchets only

Field Class 5 differs significantly (95%C.I.) only in cell residue and mamillate excrement content to any other field class. The gridsquares in Field Class 5 differ significantly from those in Field Classes 2 and 7 with regard to cell residue content. As discussed in *Field Class 2* above, the median values (Table 7.21) do not support these findings. The differences between Field Classes 2 and 7 have already been established. Examination of the cross-tabulation data and the calculations of the percentage of gridsquares in each field class which contain >5% cell residue content (Table 7.24) also shows that the greatest difference of 36% is achieved when Field Class 5 is compared with Field Class 7. However, these calculations also show that a comparison of Field Class 5 with Field Class 1(which was not found to be statistically significant) actually produces a greater difference than a similar comparison of Field Class 5 with Field Class 2 (which was found to be statistically significant). This casts doubt on the Kruskal-Wallis test results. If the threshold is changed to >0% cell residue, however, it can be shown that the greatest differences occur between Field Class 5 and Field Classes 2 and 7 (Table 7.25). A comparison of the number of gridsquares in Field Class 5 containing >0% cell residue with Field Class 2 gives a difference of 17% whilst a similar comparison with Field Class 1 shows a difference of only 3%. There are, therefore, subtle differences in the Field Class 1 and 3 results which cannot be appreciated from the median data or the calculation of >5% cell residue content threshold.

Percentage of gridsquares in each field class containing >0% cell residue				
Field Class 1	**Field Class 2**	**Field Class 3**	**Field Class 5**	**Field Class 7**
100	70	87	97	88

Table 7.25 - Proportion of gridsquares per field class with >0% cell residue content - Boyken, Level 2.

Field Class 5 differs significantly from Field Classes 1, 2 and 7 for mamillate excrement content. The results for a comparison with Field Classes 1 and 2 have already been examined and accepted as valid. The median results in Table 7.21 also suggest that there is a difference in the mamillate excrement content of Field Classes 5 and 7. Cross-tabulation of the mamillate excrement content data and calculation of the percentage of gridsquares in each field class which contain >10% of this pedofeature also shows that there is a considerable difference in the results for these two field classes. Of the four possible comparisons with Field Class 5, the comparison with Field Class 7 produces the third largest difference at 15%. It is, therefore, possible to accept the Kruskal-Wallis test results.

Field Class 7 - Outwith polygons

Field Class 7 shows statistically significant differences in sandstone, cell residue and mamillate excrement content when compared to Field Classes 3 and 5. No statistically significant differences are found between Field Class 7 and Field Classes 1 and 2 for any parameter. A difference in sandstone content occurs between Field Class 7 and Field Class 3. This has already been discussed under *Field Class 3* above. The fact that no statistically significant difference is found for a comparison of Field Class 7 with Field Classes 1, 2 and 5 for this parameter suggests that this is not a particularly diagnostic feature for Field Class 7.

Field Class 7 shows significant (95% C.I.) differences in cell residue and mamillate excrement content with Field Class 5 (see *Field Class 5* above). No purpose is served by repeating the discussion here but, again, it should be noted that only one statistically significant comparison suggests that these micromorphological features are not particularly useful for distinguishing Field Class 7 from all other field classes.

Summary

Only three micromorphological parameters have been found to show statistically significant differences (95% C.I.) between the field classes represented by the slides described during the Level 2 work. Whilst few field classes can be shown to have unique properties for one micromorphological parameter, relative differences can be shown (Table 7.26). The slides representing Field Class 1 contain moderate amounts of sandstone and high amounts of mamillate excrement. The Field Class 2 slides are characterised by high sandstone contents, low-moderate cell residue content and high mamillate excrement contents. In contrast, Field Class 3 contains low amounts of sandstone, moderate-high cell residue content and low-moderate mamillate excrement content. Field Class 5 only shows differences in cell residue and mamillate excrement content. The slides representing this field class contain high amounts of cell residue and, conversely, low amounts of mamillate excrement content. The slides from Field Class 7 have moderate sandstone content, low cell residue content and moderate mamillate excrement content.

Field Class	Field type	Micromorphological characteristics
Field Class 1	Truncated with rig and/or lynchets	• Moderate sandstone content • High mamillate excrement content
Field Class 2	Short rig	• High sandstone content • Low-moderate cell residue content • Moderate-high mamillate excrement content
Field Class 3	No rig	• Low sandstone content • Moderate-high cell residue content • Low-moderate mamillate excrement content
Field Class 5	Lynchets with no rig	• High cell residue content • Moderate mamillate excrement content
Field Class 7	Outwith polygons	• Moderate sandstone content • Low cell residue content • Moderate mamillate excrement content

Table 7.26 - Summary of micromorphological characteristics of each field class using Level 2 data - Boyken.

7.2.2 Interpretation - Level 2 data grouped by Field Class, Boyken

The small amount of micromorphological evidence which indicates differences between the soils of the field classes represented at Level 2 severely limits the interpretation of these soils. Whether any of these micromorphological "indicators" can be associated with particular agricultural practises during the working life of the Boyken field system is debatable. This is mainly because no micromorphological feature displays characteristics for one field class which are distinctly different (95% C.I.) to all other classes. For example, the mamillate excrement content of the slides representing Field Class 7 (outwith polygons) cannot be shown to differ statistically from Field Classes 1, 2 and 3. As discussed previously, evidence of increased faunal activity is often regarded as the only remaining clue to historical anthropogenic influences on soils (Courty *et al*, 1989). Given that Field Classes 1 and 2 both contain evidence of past human activity in the form of rig and furrow or built turf banks, the lack of differentiation between these soils and those sampled from outwith the field system seems to indicate that the mamillate excrement content of these soils is not a useful indicator of past agricultural activity.

Evidence of differences in microstructure according to the type of cultivation remains sampled has not been found. Gebhardt's experimental results (Gebhardt, 1992) cannot therefore be shown to apply under "real" circumstances. This is not to say that the characteristic microstructures identified during her research were not produced at the time of cultivation at Boyken. The results from this research merely suggest that other factors, such as bioturbation and podzolisation which have continued apace since the abandonment of the site for arable cultivation, have removed all trace of these micromorphological clues to the nature of the cultivation implements used on these soils in the past. Similar conclusions were also drawn from the micromorphological study of the soils from a range of different cultivation remains in the Bowmont Valley in southern Scotland (Davidson, *personal communication*).

Field Class 1 - Truncated polygons with rig and/or lynchets

Field Class 1 was represented by the slides from Trench 13/22 for the Level 2 work. The four polygons which constitute this field class are truncated by post-Improvement re-organisation of the landscape and contain either rig and/or lynchets. However, the "lynchets" in Polygon 22, identified during the RCAHMS survey of the site, have been re-interpreted during the archaeological field work associated with this research as built turf boundary banks. The Level 2 micromorphological results for the Field Class 1 samples illustrate little in the way of distinguishing features which can be associated with past anthropogenic activity. However, this is not unexpected as no evidence of arable cultivation remains occurs in this polygon apart from these slight banks. As discussed in Chapter 3, these features are considered part of an earlier land organisation, probably under a tenurial system. It is, therefore, likely that these soils have not been physically disturbed to any great depth by humans for several centuries. Evidence for physical disturbance by soil fauna, however, is found in the form of relatively high amounts of mamillate excrement. This result is particularly influenced by the recordings of this parameter for Slide 13/22B. A very high mamillate excrement content of 45% was recorded for one gridsquare in this slide and three others contained 20-25% of this pedofeature. It is likely that the 45% recording, in particular, has biased these results. Despite, this apparent biasing of the results, a statistically significant difference is not found between these soils and those sampled from outwith the field system (Field Class 7). These results are therefore treated with caution and no conclusive interpretation can be made to associate them with former manuring practises.

The sandstone content of the Field Class 1 samples only differs significantly to Field Class 3 (no rig). The sandstone content of the Field Class 1 soils cannot, therefore, be regarded as a particularly good indicator for the Field Class 1 soils. No explanation can be given for the difference in sandstone content between Field Classes 1 and 3 in terms of the former function of these polygons.

The lack of micromorphological evidence to distinguish the Field Class 1 soils from the others may be due to the small number of samples. Only the two slides from Trench 13/22 were described at Level 2 and these may not adequately represent the soils in the Field Class 1 polygons. However, the samples from the three trenches in Polygon 22 which were described during the Level 1 work did not demonstrate any major differences. These slides can, therefore, be regarded as representative of the slides sampled from Polygon 22. However, the question of their representativeness of the soils from the 4 polygons in this field class remains unanswered. As discussed in Section 7.1.2, this apparent lack of micromorphological results might be symptomatic of the problems faced in trying to classify this field system using only the available survey maps and aerial photographs. This, of course, applies to all the field classes and not just to Field Class 1.

Field Class 2 - Polygons with short rig

Field Class 2 (short rig) was represented by the thin sections from Trench 1 in Polygon 56 during the Level 2 descriptive work. Once again, no uniquely distinguishing characteristics were revealed for this field class. Indeed, the fact that no statistically significant differences were found between this field class and Field Classes 1 (rig and/or lynchets) and 7 (outwith polygons), makes any interpretation of these results as indicating past anthropogenic activity unconvincing. The relatively high sandstone content given in Table 7.26 as a feature of the Field Class 2 soils is more accurately described as a feature of Slide 1/56B sampled from the bAp horizon (Appendix 8). Although the brown podzols of this site have a naturally high stone content and therefore did not require further additions of coarse mineral material in order to deliberately improve drainage conditions, it may be that the increased numbers of sandstone fragments recorded in this buried A horizon originate from the application of soiled turf bedding from the byre. This practise was common throughout Scotland and the close proximity of settlement structures to this polygon would mean that minimum effort would be required in transporting this material from the byre to this small area of land. There is no obvious area of land close to the Boyken site which shows any evidence of past turf-stripping activities such as are found at Badentarbat, however, and this interpretation is thus treated with caution. The micromorphological evidence is clearly slight and other evidence must be sought in order to support such an interpretation. Certainly, both Ap horizons in Trench 1/56 present other evidence of intensive cultivation in the past in the form of numerous charcoal fragments and high amounts of amorphous black fine organic material in the soil. However, the particularly stony nature of the bAp horizon suggests that a slightly different form of management occurred during the initial cultivation of this small area. It may be that soiled turf from the byre was the main form of manure during the initial use of the soils for cultivation and domestic waste was predominantly applied during the later use of this area of land. Certainly, the presence of two late 18th/early 19th Century clay pipe bowls in this trench suggests that domestic waste may have been applied to this area late in its cultivation history. However, without evidence of the source of the "soiled turf sandstone" in the bAp horizon, this interpretation remains speculative.

The representativeness of this trench of the 27 polygons grouped in Field Class 2 must also be questioned. The different rig morphologies of the polygons in Field Class 2 has already been discussed in Section 7.1.2. It is clearly inappropriate to extrapolate the results for this trench to explain such a diverse range and large number of polygons. However, the lack of any good, unique micromorphological evidence from the Level 2 description of this trench, despite the supporting evidence for past anthropogenic influences can be interpreted in several ways. Useful micromorphological evidence of past agricultural activities particularly associated with the Field Class 2 polygons can only be achieved through similar Level 2 work on samples from other trenches in this group. Alternatively, it is possible that the wrong micromorphological parameters were described at Level 2. The third, and favoured opinion, is that the Level 2 method of description, although more detailed and labour-intensive, does not add significantly to the understanding of these soils. The Level 1 method of description provides similar amounts of information on a larger number of parameters and samples in order to test for the relationship between the form and function of the field units.

Field Class 3 - Polygons with no rig

The slides described at Level 2 from Field Class 3 come from Trenches 11/36 and 5/52. Field Class 3 groups together all the polygons which contain no rig cultivation remains. These slides contain the least amounts of sandstone. This is in accordance with the low amounts of siltstone found during the Level 1 description of the slides from this field class and would appear to suggest that there is some positive correlation between siltstone and sandstone content in these soils. A slight increase in sandstone content with depth in the profile can also be identified from Appendix 8.

This is particularly true for Trench 11/36. The gridsquares described in Slide 11/36A contain no more than 15% sandstone whilst the majority of gridsquares from Slides 11/36B and C contain >15% of this feature. Polygon 36 is part of the large upper complex of polygons in the eastern part of the site which have clearly been subjected to periodic re-organisation (See Figure 2.5). This small polygon has been interpreted as the vestigial remains of a previous larger unit and lies on the downslope side of this complex of polygons. This lower position on the slope relative to the main complex of polygons may provide a clue to the apparent lack of sandstone in the upper 11cm of this soil. Because Polygon 36 is long and narrow, the trench was dug fairly close to the downslope boundary bank. This bank is likely to have halted the movement of the fine fraction of the soil downslope caused by cultivation activity in the polygons above. This 11cm of topsoil with relatively little in the way of sandstone fragments may, in fact, be an accumulation of fine soil particles eroded downslope during cultivation of the land above. However, Trench 5/52 is located on an even steeper slope, midway between the upper and lower boundary banks of Polygon 52 and the sandstone content data for this trench does not demonstrate a similarly strong trend. Evidence of early human disturbance has been found in this trench in the form of a substantial, localised layer of charcoal. The overlying soil horizon was interpreted as inwash during the field description (Simpson, *personal communication*) but there is little evidence to show that the upper few centimetres of this profile contain less sandstone than those further down the profile. The interpretation for Trench 11/36 is therefore not supported by the evidence from Trench 5/52. It might equally be argued that the low sandstone and siltstone content of these soils is due to the lack of disturbance by cultivation, allowing the fine fraction of the soil to remain *in situ*. It may be that the first interpretation is correct for Trench 11/36 whilst the second more accurately explains the situation in Polygon 52.

From this evidence and these interpretations, it would appear that the location of these trenches in relation to other polygons plays an important role. It is, therefore, possible that this micromorphological characteristic does not necessarily reflect the nature of all Field Class 2 polygons with no cultivation remains but is merely symptomatic of the trench locations described here.

The fact that the Field Class 3 results do not differ significantly to those for Field Classes 5 and 7 for any parameter suggests that the soils in these areas may have been subjected to similarly insignificant human impacts. There are no cultivation remains in the Field Class 2 polygons which suggests that these areas were mainly used for pasture. Field Class 5 groups two polygons which contain only "lynchets" which have been re-interpreted in this study as early built boundaries and Field Class 7 constitutes the areas outwith the polygons which were sampled for micromorphological description. However, it must be remembered that the Field Class 7 samples only showed statistically significant differences to Field Class 5.

Field Class 5 - Polygons with lynchets only

Field Class 5 (lynchets only) was represented by two samples from Trench 26 in Polygon 30 located in the upper altitudes of the western part of the site. These samples did show differences in cell residue and mamillate excrement content with Field Classes 1, 2 and 7. Although the Field Class 5 samples have been described as containing relatively high amounts of cell residue, examination of the data for each slide shows that, in fact, only Slide 26/30A demonstrates a particularly high cell residue content (Appendix 8). Similarly, the low mamillate excrement content attributed to Field Class 5 is more accurately associated with Slide 26/30B. These characteristics are clearly associated with depth in the profile. The cell residue content is greatest in the upper few centimetres of the soil profile where organic matter enters the soil system. It might also be assumed that these upper few centimetres are the most likely to be inhabited by the soil fauna which feed on this material. This certainly appears to be the case in this shallow profile. However, in most of the other profiles sampled and described at Level 2, the greatest amounts of mamillate excrement are found at a depth of approximately 20cm. The results for Trench 26/30 may be due to the shallow nature of the soil profile and the presence of shallow bedrock in this area. One trench in this polygon had to be abandoned due to hitting shallow bedrock only a few centimetres below the surface. The soil fauna may prefer to inhabit the better drained upper regions of this soil profile than the more waterlogged area immediately above the impermeable rock surface.

Although only 2 slides represent this field class, it is considered likely that these give a fairly accurate picture of the soils found in these polygons. There are only 2 polygons grouped in this field class and both have been interpreted by the nature of their cultivation remains to be early in origin. It is, therefore, not surprising that little in the way of micromorphological evidence of past agricultural activity has been found in these soils.

Field Class 7 - Outwith polygons

Samples from Trenches 22 and 30(1) were used to represent Field Class 7 (outwith polygons) during the Level 2 descriptive work. Very few differences were found between these samples and those from within the field system. This is the main reason for such tentative and inconclusive interpretation of the micromorphological data as little more than natural spatial variability. As discussed in Section 7.1.2, the presence of sheep and cattle across the entire Boyken site since abandonment may have played an important role in masking any differences in soil characteristics which may have existed immediately prior to abandonment. The results for both trenches in this field class are fairly similar although Slides 22B and C contain slightly higher amounts of sandstone fragments and mamillate excrement than Slide 30(1)B. There is, therefore, no apparent biasing of the Field Class 7 results by those from one trench.

Summary

The Level 2 micromorphological results are disappointing but not unexpected. Little in the way of additional information has been gained from this more detailed level of description but this may be due to the limited number of slides described at this level. The lack of micromorphological evidence may also be because the wrong parameters were selected for description during the Level 2 work. Equally, the slides chosen for the Level 2 work may not provide accurate representations of the soils from each field class. However, as discussed in Chapter 6, Section 6.8, the slides chosen from Boyken for the Level 2 work appear to be more representative of the field class from which they were sampled than of the Level 1 cluster to which they were assigned during the Hierarchical Cluster Analysis procedure. Few distinguishing micromorphological features were found between the Level 2 clusters produced during the HCA of the Level 2 data and those that were identified could mainly only be associated with natural pedological processes such as bioturbation and podzolisation. Little or no association occurred between the Level 2 clusters (see Chapter 6) and the field classes from which the samples originate. It is not surprising, therefore, that manual grouping of the slides according to field class produces similarly disappointing results. These poor results may be because the sampling procedure was based on inaccurate field classification information. However, similarly disappointing results were obtained from a study of ancient cultivation remains in the Bowmont Valley, southern Scotland (Davidson, *personal communication*). Bioturbation and natural pedogenesis was also considered to have eradicated any previously existing evidence of cultivation in these soils. The poor micromorphological results from this site are, therefore, considered to be mainly due to loss of evidence in the soil rather than major errors with the field classification procedure.

7.2.3 Results - Level 2 data grouped by Field Class, Badentarbat

The Badentarbat data recorded at Level 2 comes from a selection of slides chosen to represent each of the main field classes identified during the desk-top field classification. A description of the types of cultivation remains and general characteristics of each field class and the trenches selected for use during the Level 2 work is provided in Table 7.27. Field Class 4 was not represented during the Level 2 results as this field class merely constituted one polygon containing reverse-S rig which was not found elsewhere in the site.

The Level 2 data for Badentarbat produces statistically significant differences (95% C.I.) between the different field classes for five different ordinal parameters; quartz, sandstone, cell residue and mamillate and spheroidal excrement content. No statistically significant results are found from cross-tabulating the nominal variables by field class and testing using Chi-square for differences. However, a large number of the gridsquares from slides representing Field Class 5 do demonstrate the same microstructure and related distribution characteristics, although these properties are not unique to this field class alone. The median results for each ordinal parameter per field class are presented in Table 7.28.

Field Class No.	Field Class Description	Trenches sampled from each Field Class (Trench No./Polygon No.)
0	Outwith polygons	49
1	Short rig	36/5, 44/35
2	No rig	54/45
3	Long rig	46/22
5	Rig on steep slope, higher altitude	42/44

Table 7.27 - Trenches representing each field class described during the Level 2 description work - Badentarbat.

	Median of each ordinal parameter per field class sampled (percentage)				
Micromorphological Parameter	**Field Class 0**	**Field Class 1**	**Field Class 2**	**Field Class 3**	**Field Class 5**
Quartz content	55	10	30	30	35
Sandstone content	0	0	5	5	5
Cell residue content	5	5	5	5	5
Mamillate excrement content	0	0	0	0	0
Spheroidal excrement content	0	0	0	0	0

Table 7.28 - Medians per field class for each ordinal parameter recorded during the Level 2 description work - Badentarbat.

Field Class 0 - Outwith polygons

The samples taken from outwith the field system polygons are termed Field Class 0. These samples were found to differ significantly from at least one other field class in terms of quartz and sandstone content only. A statistically significant difference (95% C.I.) in quartz content was only found for a comparison of Field Class 0 with Field Class 1. The median data given in Table 7.28 appear to support these findings as Field Class 0 has the highest median value of 55% whilst Field Class 1 has the lowest value of 10%. Cross-tabulation of the quartz content data provides further evidence to allow the Kruskal-Wallis test results to be accepted as valid. From the distribution of the data and the calculation of the percentage of gridsquares in each field class which contain >25% quartz, it can be seen that a comparison of Field Classes 0 and 1 gives the largest difference (56%) in these values of any comparison with Field Class 0. The values for Field Classes 2, 3 and 5 are all too similar to that of Field Class 0 to produce a statistically significant result.

In contrast to the quartz content results, a comparison of the sandstone content of the Field Class 0 slides with the other field classes shows a statistically significant difference (95% C.I.) to Field Classes 2, 3 and 5 for this parameter. These results are supported by the median data in Table 7.28. Field Classes 0 and 1 both have median values of 0% whilst Field Classes 2, 3 and 5 all have median values of 5%. The cross-tabulation of the sandstone content data and calculation of the percentage of gridsquares in each field class which contain >0% sandstone content further supports the Kruskal-Wallis test results. From these results, it can be seen that the values for Field Classes 0 and 1 are too similar to produce statistically significant results whilst the values for Field Classes 2, 3 and 5 are 38-55% higher than for Field Class 0. The Kruskal-Wallis results can, therefore, be accepted as valid.

Field Class 1 - Polygons with short rig

Field Class 1 shows statistically significant differences (95% C.I.) to the other field classes for quartz, sandstone, cell residue and mamillate and spheroidal excrement content. The quartz content of the slides in this field class are found to differ significantly to all other field classes. This suggests that this is a particularly important distinguishing characteristic of the Field Class 1 samples. The median results support these findings (Table 7.28), as do the cross-tabulation results and the calculations of the percentage of gridsquares per field class which contain >25% of quartz (Table 7.29). The median value for Field Class 1 is 10%, compared to between 30-55% for all other field classes. Similarly, only 19% of the gridsquares in Field Class 1 contain >25% quartz. In contrast, between 64-91% of the gridsquares in all other field classes contain this amount of quartz. The Kruskal-Wallis results are therefore accepted as accurate.

The sandstone content of the slides in Field Class 1 differs significantly (95% C.I.) from that of Field Classes 3 and 5. However, these results do not appear to be supported by the median values for each field class (Table 7.28), as Field Classes 2, 3 and 5 all have the same median value of 5%. The cross-tabulation of the sandstone data shown in Table 7.30 does appear to indicate subtle differences in the data distribution of each field class for this parameter but the results of the calculation of the percentage of gridsquares in each field class containing >0% sandstone do not show this conclusively. From these calculations, a slightly greater difference in values is found for a comparison of Field Class 1 with Field Class 2 than a similar comparison with Field Class 3. No single calculation can be shown to conclusively support the findings of the Kruskal-Wallis tests. By moving the threshold to >5% sandstone content (Table 7.31), it can be shown that a comparison of Field Class 1 with Field Classes 3 and 5 produces greater differences (8% and 6%, respectively) than a similar comparison with Field Class 2 (5% difference). However, these results also indicate that a statistically significant difference should occur for a comparison of Field Class 1 with Field Class 0 as an even larger difference of 29% is found for this comparison. These results are due to the large numbers of gridsquares in Field Classes 0, 2, 3 and 5 which were recorded as containing 5% sandstone. If the percentage of gridsquares which contain <5% sandstone is also calculated, it can be shown that the results for Field Classes 0 and 1 are too similar to produce a statistically significant result at the 95% confidence level. However, this calculation once again shows there to be a slightly greater difference between Field

Field Class	Quartz content (%) per field class (No. of gridsquares)																					Percentage of gridsquares containing >25% quartz
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	
Field Class 0	0	10	1	0	0	3	6	0	3	0	4	5	1	1	3	0	7	8	4	0	0	75
Field Class 1	2	59	34	10	5	6	15	11	1	1	0	0	0	0	0	0	0	0	0	0	0	19
Field Class 2	0	3	1	3	7	10	19	21	8	0	0	0	0	0	0	0	0	0	0	0	0	67
Field Class 3	0	2	3	7	12	10	14	20	11	8	4	2	2	0	0	0	0	0	0	0	0	64
Field Class 5	1	0	0	1	1	2	11	23	15	0	0	0	0	0	0	0	0	0	0	0	0	91

Table 7.29 - Cross-tabulation of quartz content data per field class - Badentarbat, Level 2.

Field Class	Sandstone content (%) per field class (No. of gridsquares)														Percentage of gridsquares containing >10% sandstone
	0	5	10	15	20	25	30	35	40	45	50	60	85	100	
Field Class 0	32	24	0	0	0	0	0	0	0	0	0	0	0	0	0
Field Class 1	84	18	4	9	6	7	3	1	4	3	3	0	1	1	26
Field Class 2	14	41	7	3	3	0	2	0	1	0	0	1	0	0	14
Field Class 3	19	49	16	7	1	1	1	1	0	0	0	0	0	0	12
Field Class 5	1	34	14	3	0	0	0	1	0	0	1	0	0	0	9

Table 7.30 - Cross-tabulation of sandstone content data - Badentarbat, Level 2.

Classes 1 and 2 than between Field Classes 1 and 3. The Kruskal-Wallis test results cannot, therefore, be convincingly shown to be accurate from a single calculation alone and the difference between sandstone data distribution for Field Classes 2 and 3 must be considered to be very slight. Nevertheless, through a number of different methods of examining the data, the Kruskal-Wallis results can be accepted.

Field Class	Percentage of gridsquares containing <5% sandstone	Percentage of gridsquares containing >5% sandstone
Field Class 0	57	0
Field Class 1	58	29
Field Class 2	19	24
Field Class 3	20	37
Field Class 5	2	35

Table 7.31 - Comparison of the percentage of gridsquares per field class which contain <5% and >5% sandstone - Badentarbat, Level 2.

Only a comparison of Field Class 1 with Field Class 5 produces a statistically significant (95% C.I.) result for the cell residue content data. However, this is not upheld by the median data in Table 7.28 as all field classes have a median value of 5%. Again, the cell residue content data must be cross-tabulated and examined to elucidate subtle differences in the data distribution per field class which cannot be appreciated through median calculations alone (Table 7.32). Table 7.32 shows the results of the calculation of the percentage of gridsquares which contain >5% cell residue in each field class. From these calculations, it can be shown that the largest percentage (47%) occurs for Field Class 1 whilst the lowest value of 0% is found for Field Class 5. This agrees with the Kruskal-Wallis test results.

	Cell residue content (%) per field class (No. of gridsquares)						
Field Class	0	5	10	15	20	30	Percentage of gridsquares containing >5% cell residue
Field Class 0	7	34	2	1	7	5	27
Field Class 1	18	58	46	14	6	2	47
Field Class 2	0	55	17	0	0	0	24
Field Class 3	0	79	16	0	0	0	20
Field Class 5	5	49	0	0	0	0	0

Table 7.32 - Cross-tabulation of cell residue content data - Badentarbat, Level 2.

Comparison of the Field Class 1 mamillate excrement results with those for Field Classes 3 and 5 produces statistically significant results at the 95% confidence level. However, the median results, once again, do not support these findings and indicate that the distribution of the mamillate excrement data is very similar for all field classes (Table 7.28). Cross-tabulation confirms that the majority of gridsquares in each field class contain no mamillate excrement but it also shows that some of the gridsquares in Field Class 1 contain the highest amounts of this pedofeature of any described. Calculation of the percentage of gridsquares in each field class which contain >0% mamillate excrement clearly shows this trend for Field Class 1, with a value of 40% (Table 7.33). In contrast, only 20% of the gridsquares in Field Class 3 contain similar amounts of this pedofeature whilst none of the gridsquares in Field Class 5 contain mamillate excrement. Comparisons of these figures produces the greatest possible differences for a comparison with Field Class 1 and the Kruskal-Wallis test results can, therefore, be accepted as valid.

The Kruskal-Wallis test results indicate that there is a statistically significant difference (95% C.I.) between Field Class 1 and Field Classes 2 and 3 for spheroidal excrement. Again, the median results do not support these findings as all field classes have a median value of 0% (Table 7.28). Cross-tabulation of the spheroidal excrement data, however, shows that the distribution for Field Class 1 differs from the other classes (Table 7.34). Indeed, any calculation of the percentage of gridsquares containing a certain amount of spheroidal excrement data shows that the results for Field Class 1 are very different and the results for Field Classes 0, 2, 3 and 5 are all very similar. This suggests that a statistically significant difference (95% C.I.) should be obtained for any comparison with Field Class 1. The Kruskal-Wallis test results obtained can, therefore, be shown to be valid but there appear to be discrepancies which cannot easily be explained. These results must, therefore, be regarded with caution.

	Mamillate excrement content (%) per field class (No. of gridsquares)						
Field Class	**0**	**5**	**10**	**15**	**20**	**25**	**Percentage of gridsquares containing >0% mamillate excrement**
Field Class 0	41	14	1	0	0	0	27
Field Class 1	86	19	11	10	15	3	40
Field Class 2	53	15	4	0	0	0	26
Field Class 3	76	17	1	1	0	0	20
Field Class 5	54	0	0	0	0	0	0

Table 7.33 - Cross-tabulation of mamillate excrement content data - Badentarbat, Level 2.

	Spheroidal excrement content (%) per field class (No. of gridsquares)			Percentage of gridsquares containing mamillate excrement at specified level		
Field Class	**0**	**5**	**10**	**0%**	**>0%**	**>5%**
Field Class 0	41	14	1	98	2	0
Field Class 1	86	19	11	74	26	2
Field Class 2	53	15	4	100	0	0
Field Class 3	76	17	1	99	1	0
Field Class 5	54	0	0	100	0	0

Table 7.34 - Cross-tabulation of spheroidal excrement content data - Badentarbat, Level 2.

Field Class 2 - Polygons with no rig

The Field Class 2 slides show statistically significant differences (95% C.I.) for quartz, sandstone and spheroidal excrement content. A statistically significant difference in quartz is only found for a comparison of Field Class 2 with Field Class 1. The median results (Table 7.28) support these findings, given that there is a 25% difference in the median values for these two field classes for this parameter. The cross-tabulation results in Table 7.29 also support these results, showing that 67% of the gridsquares in Field Class 2 contain >25% quartz whilst only 19% of those in Field Class 1 contain similar amounts. A comparison of these two results produces the largest possible difference for all comparisons with Field Class 2. The Kruskal-Wallis test results can, therefore, be accepted as valid.

The sandstone content of the Field Class 2 slides was found to differ significantly (95% C.I.) from Field Class 0. However, as discussed under *Field Class 0*, the median results in Table 7.28 do not fully support these findings as both Field Class 0 and 1 have the same median value of 0%. Cross-tabulation of the sandstone content data is required in order to confirm the Kruskal-Wallis test results. From Table 7.30, it can be shown that a comparison of the percentage of gridsquares containing >10% sandstone in Field Classes 0 and 2 gives a difference of 14%. This is the largest possible difference for a comparison with Field Class 2 and, therefore, the Kruskal-Wallis test results may be regarded as accurate.

The spheroidal excrement content of the Field Class 2 slides is found to differ significantly from only Field Class 1. Again, the median results do not provide enough detail in order to accept these findings (Table 7.28). However, cross-tabulation of the data and the three threshold calculations given in Table 7.34 clearly show that the spheroidal excrement content of the Field Class 2 slides only show large differences to the Field Class 1 results. The Kruskal-Wallis test results can, therefore, be accepted as valid.

Field Class 3 - Polygons with long rig

The slides which represent Field Class 3 show statistically significant differences (95% C.I.) with other field classes for quartz, sandstone and mamillate and spheroidal excrement content. The quartz content of the Field Class 3 slides differed significantly to that for Field Class 1. The median results support these findings (Table 7.28) and the cross-tabulation information given in Table 7.29 also confirms that only the distribution of the Field Class 1 sandstone data differs sufficiently from that of Field Class 3 to be regarded as significant. The Kruskal-Wallis results are, therefore, accepted.

The sandstone content of the Field Class 3 slides differs significantly from that of Field Class 0 and 1. The median results (Table 7.28) support these findings. The calculations of the percentage of gridsquares per field class which contain >10% sandstone given in Table 7.30 also confirms these results. A comparison of the values for Field Class 3 with those for Field Classes 0 and 1 gives differences of 12% and 14%, respectively. In contrast, similar comparisons with Field Class 2 and Field Class 5 show only 2% and 3% differences, respectively. The Kruskal-Wallis test results can thus be accepted.

The Field Class 3 slides are only found to differ significantly (95% C.I.) to Field Class 1 in terms of mamillate excrement content using the Kruskal-Wallis one-way analysis of variance by ranks test. However, the median data in Table 7.28 shows that there is no variation in the median for each field class. This clearly does not support the Kruskal-Wallis test results. Similarly, the calculation of the percentage of gridsquares in each field class which contain >0% mamillate excrement shows that a 20% difference can be found, not only for a comparison of Field Class 3 with Field Class 1, but also for a comparison of Field Classes 3 and 5 (Table 7.33). Again, this does not provide convincing evidence in order to accept the Kruskal-Wallis test results. However, if the threshold for calculation is moved to >5%, rather than >0%, then it can be shown that only the value for Field Class 1 shows a considerable difference to the value for Field Class 3 (Table 7.35).

Percentage of gridsquares containing >5% mamillate excrement				
Field Class 0	Field Class 1	Field Class 2	Field Class 3	Field Class 5
2	27	6	2	0

Table 7.35 - Comparison of the percentage of gridsquares in each field class containing >5% mamillate excrement - Badentarbat, Level 2.

The spheroidal excrement content data has already been called into question under *Field Class 1*. However, the statistically significant result obtained for a comparison of Field Class 3 with Field Class 1 can be supported by the cross-tabulation evidence given in Table 7.34. From this table, it can be seen that only 1% of the gridsquares in Field Class 3 contain >0% spheroidal excrement. In comparison, 26% of the gridsquares in Field Class 1 contains similar amounts of this pedofeature. The values of 2%, 0% and 0% for Field Classes 0, 2 and 5, respectively, are too similar to the value for Field Class 3 to be statistically significant. The results for this particular comparison can, therefore, be accepted as valid.

Field Class 5 - Polygons with rig on steep slope

The slides representing Field Class 5 show statistically significant differences (95% C.I.) for quartz, sandstone, cell residue and mamillate excrement content. The quartz content of this field class only differs significantly from that of Field Class 1. Evidence to support these findings is provided by the median results in Table 7.28. Field Class 5 has a median sandstone content of 35% compared to only 10% for Field Class 1. This gives a 25% difference between these values which is the largest possible for any comparison of field classes with Field Class 5. The distribution data provided in Table 7.29 also confirms the Kruskal-Wallis test results. Ninety-one percent of the gridsquares in Field Class 5 contain >25% quartz whilst only 19% of those in Field Class 1 contain similarly high amounts of this feature. In contrast, the values for Field Classes 0, 2 and 3 only show differences of 16%, 24% and 27%, respectively. The Kruskal-Wallis test results can therefore be accepted.

The sandstone content of the Field Class 5 slides differs to that of the Field Class 0 and Field Class 1 slides. This is supported by the median data (Table 7.28). Similarly, the cross-tabulation data given in Table 7.30 also confirm these results. The calculation of the percentage of gridsquares which contain >10% sandstone shows that a difference of 9% and 17% are found between Field Class 5 and Field Classes 0 and 1, respectively. In comparison, only a difference of 5% and 3% are found for comparisons of Field Class 5 with Field Classes 2 and 3, respectively. These results can, therefore, be accepted as valid.

A statistically significant difference (95% C.I.) in cell residue data was only found for a comparison of Field Class 5 with Field Class 1. This is not supported by the median data, however (Table 7.28). Subtle differences in the distribution of the cell residue data can be better appreciated by cross-tabulating the cell residue data by field class and calculating the percentage of gridsquares per field class which contain >5% of this feature (Table 7.32). From these calculations, it can be shown that the largest difference in these values occurs for a comparison of Field Classes 5 and 1. The Kruskal-Wallis test results are thus accepted as valid.

Again, only a comparison of Field Class 5 with Field Class 1 provided a statistically significant result (95% C.I.) in the mamillate excrement content data grouped by field class. As previously discussed, this cannot be appreciated from the median data alone (Table 7.28). However, the cross-tabulation of the data and the calculated percentages of gridsquares per field class containing >0% and >5% mamillate excrement, given in Tables 7.33 and 7.35 indicate that the largest differences in these values occurs for a comparison of Field Classes 5 and 1 at both thresholds. The Kruskal-Wallis test results can, therefore, be accepted as accurate.

The Field Class 5 slides also show the greatest uniformity of microstructure and related distribution of any field class, although this is not found to be a statistically valid trend. Ninety-four percent of the gridsquares from the slides representing Field Class 5 demonstrate an intergrain microaggregate microstructure and a gefuric related distribution. However, these characteristics are not exclusive to this field class. The intergrain microaggregate microstructures grouped in Field Class 5 merely constitute 30% of the total number of such microstructures described during the Level 2 work for Badentarbat. Similarly, the recordings of a gefuric related distribution in the Field Class 5 samples merely represents 30% of the site total. Whilst these features cannot be shown to be unique to Field Class 5, it does demonstrate a uniformity for these slides which does not appear to exist for those grouped in other field classes.

Summary

Although several parameters have been identified which show statistically significant differences between field classes, most of these results indicate that Field Class 1 is uniquely different to all the other field classes for each identified parameter. Field Class 1 contains the lowest amounts of quartz and the highest amounts of sandstone, cell residue and mamillate and spheroidal excrement content of any field class. In contrast, the quartz content of Field Classes 0, 2, 3 and 5 do not differ sufficiently to be statistically significant. Similarly, no statistically significant difference between these four classes can be found with regard to cell residue and mamillate and spheroidal excrement content. The sandstone content of Field Class 0 is particularly low with no more than 5% being recorded in any of the 95 gridsquares described for this field class at Level 2. This characteristic distinguishes this field class from Field Classes 2, 3 and 5. No characteristics have been found which differentiate Field Classes 2, 3 and 5 from each other. Table 7.36 summarises the micromorphological characteristics of each field class which have shown a statistically significant difference (95% C.I.) between that field class and at least one other. This merely describes each characteristic in relative terms and it must be noted that relative differences between Field Classes 0, 2, 3 and 5 are much smaller than those for any comparison with Field Class 1.

Field Class	**Field type**	**Micromorphological characteristics**
Field Class 0	Outwith polygons	• High quartz content • Low sandstone content
Field Class 1	Short rig	• Low quartz content • High sandstone content • High cell residue content • High mamillate excrement content • High spheroidal excrement content
Field Class 2	No rig	• Moderate quartz content • Moderate sandstone content • No spheroidal excrement content
Field Class 3	Long rig	• Moderate quartz content • Moderate sandstone content • Low mamillate excrement content • Very low spheroidal excrement content
Field Class 5	Rig on steep slope	• Moderate quartz content • Moderate sandstone content • Low cell residue content • No mamillate excrement content

Table 7.36 - Summary of micromorphological characteristics of each field class using Level 2 data - Badentarbat.

7.2.4 Interpretation - Level 2 data grouped by Field Class, Badentarbat

Several micromorphological parameters have been identified from the Level 2 data which show statistically significant differences between the field classes represented at this level. However, from the results, it would appear that the majority of these parameters are merely distinctive for Field Class 1. This would suggest that very different activities and processes have occurred in the Field Class 1 polygons in the past which have resulted in the soils of these areas having very distinct properties. However, the lack of any real differentiation between the micromorphological properties of the soils in Field Classes 2 (no rig), 3 (long rig) and 5 (rig on steep slope) suggests that the micromorphological differences identified cannot be attributed to the type of implement used for cultivation in the past. The Badentarbat soils showed some variation in microstructure but this was not found to be statistically significant between field classes. Gebhardt's findings from her experimental work on the relationship between the use of different cultivation tools and microstructure are, therefore, not supported by the evidence from this study (Gebhardt, 1992).

Field Class 0 - Outwith polygons

Field Class 0 is the convenient description for those areas which were sampled from outwith the field system. This field class was represented by the slides from Trench 49 for the Level 2 work. The slides from this trench demonstrated a high quartz content and, conversely, low sandstone content. Trench 49 contained peat with several lenses of more sandy material in the Of horizon (0-18 cm) of the profile from which the upper 2 samples were taken and the lowest slide (Slide 49C) was taken crossing the boundary of the Om/Ah (peat/loamy sand) horizons at 19-27cm. The high quartz content is thus not unexpected and, indeed, the Level 2 results for each slide grouped by field class presented in Appendix 8, shows that the highest quartz recordings come from Slide 46C. The lack of sandstone may be attributed to two possible factors; mechanical and chemical weathering.

The area outwith the head-dyke on both sides of the field system has a much greater cover of surface boulders and exposed bedrock than the area within the head-dyke. This is especially noticeable on the eastern side where this trench is located and it is considered likely that this area has been subjected to turf-stripping in the past to provide fuel, building materials and manure for the field system and settlement sites (see Section 7.1.4). The peat in this area is relatively shallow (21cm in this trench) when compared to the south end of the field system (60cm of peat in Trench 46). The angle of slope is similar for both trenches and the area around Trench 49 was certainly very waterlogged at the time of sampling (late November) although this may, of course, be a consequence of the shallow bedrock reducing throughflow. Was it the presence of exposed bedrock which reduced the possibilities for peat growth in this area due to lack of vegetation or has the peat been stripped for human use in the past? The evidence of an old track, called "the peat road" by the locals, on the upper slopes to the west of the field system would suggest the latter to be the most likely explanation. The physical disturbance caused by these stripping activities, coupled with the increased exposure to the elements, may have caused the accelerated weathering and loss of sandstone fragments in the soil. However, it must be noted that sandstone content was not found to be high in any of the peat soils sampled at Badentarbat. Trench 36 in Field Class 1 (short rig) is the only other peat profile described at Level 2 and very similar recordings of sandstone content were also obtained for these samples (Appendix 8). The Field Class 1 results do not show a statistically significant difference in sandstone content to those for Field Class 0, indicating the influence of this peaty profile on the Field Class 1 results. It must, therefore, be considered that the low amounts of sandstone in the Field Class 0 soils is due to the peaty nature of the soil profile.

Field Class 1 - Polygons with short rig

Trenches 36 and 44 represent Field Class 1 which is described as polygons containing short rig and furrow, from the desk-top field classification. However, the soils of these two trenches are very different. Trench 36 has peat to a depth of 66cm on to a loamy sand B horizon whilst Trench 44 has a thin peaty turf mat on to a sandy clay loam A horizon to a depth of 52cm at its point of maximum depth below the surface of the rig. Five of the eight slides sampled are from Trench 36 (Appendix 8) and most of the differentiating characteristics given for this field class appear to be biased by this weighting towards the peat profile. This field class was found to be micromorphologically characterised by containing low amounts of quartz and high amounts of sandstone, cell residue and mamillate and spheroidal excrement.

The very low amounts of quartz can be attributed to the almost pure peat horizons in Trench 36. Analysis of the Level 2 results for this parameter show that no grid square from any thin section in

Trench 36 contained more than 15% quartz whilst the quartz content for Trench 44 ranged from 5-45% (Appendix 8). This low level of quartz for Field Class 1 cannot, therefore, be attributed to a particular management technique associated with this field class of polygons with short rig. Similarly, only a handful of grid squares from the Trench 36 samples contain any sandstone (5%) whilst the Trench 44 samples contain up to 100%. The Trench 44 results have, therefore, clearly influenced the results for this parameter. It would appear that differences in the natural soil characteristics are still more predominant at this level of micromorphological description than any signatures of anthropogenic activity.

Although this field class is also shown by the statistical analysis to contain high amounts of cell residue and both mamillate and spheroidal excrement, closer examination of the Level 2 data shows that these are merely characteristics of Trench 36 (Appendix 8). The slides in Trench 44 contain only 0-5% of cell residue. In comparison, the 5 slides from Trench 36 contain between 0-30%, with only one gridsquare in slide 36B actually containing no cell residue. The high mamillate and spheroidal excrement content attributed to Field Class 1 can only truly be attributed to the peaty soils of Trench 36. None of the slides from Trench 44 contain mamillate excrement and only 1 gridsquare in Slide 44A contains 5% spheroidal excrement whilst all others contain none of this pedofeature. It would, therefore, appear that these micromorphological characteristics are not associated with the type of cultivation remains in the Field Class 1 polygons but is more accurately attributed to the two soil types represented here.

The rig in the area of Trench 36 have an amplitude of 35cm and a width of 4m, similar to that found in Trench 38 (Field Class 5). Although these trenches are classified in different field classes, it is considered possible that these rig are of similar origin. They are both located mid-slope on deep peat and have similar widths and amplitude, although the rig around Trench 38 are curvi-linear rather than linear. They are both also in very wet areas which would most probably have been conceived as undesirable for cultivation under normal circumstances. The area represented by Trench 36, then, is suggested as a late addition to the field system to address the problems of feeding a rapidly increasing population. The regular characteristics of the rig suggest that it was ploughed rather than dug by spade or *cas-chrom* and was probably not in cultivation for any great length of time. The high amplitude was probably an attempt to gain better drainage for crops.

Trench 44 appears also to have been cultivated by plough although the amplitude here is only 12cm with a greater width of 6m. Again, the rig and furrow are regular and straight and slight multiple crests are found on the apex of each rig. Shards of relatively modern glazed pottery (19th century at the earliest), small pieces of coal and a piece of slate were retrieved from this trench which are interpreted as inclusions from household midden waste used as manure. However, no other evidence of anthropogenic inclusions was found during sampling in the field and the complete lack of excrement, both spheroidal and mamillate does not appear to uphold this manuring theory.

A shallow feature of approximately 15cm depth was detected directly at the base of the current rig of Trench 44 and has been tentatively interpreted by the archaeological team at AOC Scotland Ltd as the base of an earlier pre-existing furrow. This evidence seems to support the theory of constant prolonged agricultural use of this area. Perhaps sea-ware was added to this soil but the evidence has since vanished due to accelerated breakdown of the organic material by rapid throughflow in this freely draining podzol. One would, however, expect to find some excremental remains, at least in the upper few centimetres of the profile. Some evidence of excremental remains was recorded during the Level 1 description of these slides. Differences in the estimation of mamillate excrement content at Levels 1 and 2 are also discussed in Chapter 6. These differences may be due to the size of these excremental pedofeatures in relation to the 1cm^2 gridsquares described at Level 2. If these features are coalesced and have a similar area to the gridsquare, then it is possible that they have been regarded as a soil aggregate rather than an excremental pedofeature using the Level 2 method of description. Problems with consistently differentiating between excremental pedofeatures and microstructure have already been discussed in Section 4.2, Chapter 4. Indeed, similar differences in the Level 1 and Level 2 excremental pedofeature results can be identified for Trench 46 in Field Class 3 and Trench 42 in Field Class 5. This is a problem that was discussed with Dr Simpson during the recording of the data and is regarded as one of the many problems associated with the subjective nature of micromorphological description. It is doubtful whether image analysis techniques can bring some degree of objectiveness into the identification of this type of pedofeature given the heterogeneous nature of excrement, both in terms of colour and shape. They are also very rarely seen as discrete elements disassociated from the surrounding groundmass making it difficult for image analysis to define the correct features without some subjective input from the operator.

The other possible interpretation for the area surrounding Trench 44 is that the area was merely rigged to provide better drainage and, therefore, a better grass sward for animal grazing. The ongoing invasion of wetland vegetation from the margins of these small areas of close-cropped, rigged grass and in the furrows gives an indication of the wet nature of this area. However, these areas are too few (only 3 in total) and too small to sustain even one dairy cow. Also, if this area was merely rigged for drainage, why is there no peat horizon? It seems unlikely that the inhabitants expended the time and energy to strip the peat cover before ploughing just for a few small areas of better grass for animal fodder. Despite the lack of evidence for any great amounts of manuring activity in this area, the interpretation that the area has been in prolonged agricultural use seems to be the most appropriate.

Field Class 2 - Polygons with no rig

Field Class 2 groups together all the polygons which contain no evidence of rig and furrow within their boundaries. Trench 54 provides the only samples from this field class and its representativeness of this large group of polygons has already been debated elsewhere. The Level 2 results cast further doubts on the representativeness of these samples. These samples show no micromorphological characteristics which can be said to be unique to this field class. The moderate quartz and low sandstone content of these samples is also a feature of Field Classes 3 (long rig) and 5 (rig on steep slope) and cannot, therefore, be interpreted as a particular feature of these apparently uncultivated polygons. The slides sampled for Field Classes 2, 3 and 5 all come from trenches containing soils with a high mineral content rather than pure organic peats. Trench 54 (Field Class 2) contains sandy peat, loamy sand and loamy peat horizons to a depth of 60cm. Trench 46 (Field Class 3) contains sandy clay loam and loamy sand horizons to a depth of 52cm and Trench 42 (Field Class 5) also contains sandy clay loam and loamy sands horizons to a depth of 40cm. These moderate amounts of quartz and sandstone minerals are, therefore, more plausibly attributable to the mineral nature of the soils rather than any type of past agricultural practise.

Field Class 3 - Polygons with long rig

Field Class 3 groups together two large polygons containing long rig. Trench 46 was selected to represent this field class. The mineral content of the Field Class 3 soils has already been discussed under *Field Class 2*. However, the loamy nature of the peat soils of Trench 46 may not be particularly representative of the Field Class 3 soils. One other trench (51) is also located in Polygon 22 from this field class but was not described during the Level 2 work. The deep peats in this trench are highly organic, with little or no evidence of mineral inclusions. This further strengthens the interpretation that the Level 2 results more accurately reflect the different soil types found throughout the Badentarbat site rather than any differences in past management.

In addition, these soils are also found to have low mamillate excrement and very low spheroidal excrement contents. In fact, only one gridsquare from the five slides from Trench 46 described at Level 2 contains any spheroidal excrement at all. However, as discussed in *Field Class 1* above, these Level 2 descriptions differ quite substantially from the Level 1 excremental results for the Trench 46 slides. It may be that the excremental pedofeatures in these soils are too large to be identified as anything other than peds when studied in individual 1cm^2 gridsquares. These results must, therefore, be treated with caution. It has been shown from examination of the excrement results for Field Class 1 that considerable differences in mamillate excrement content can be found between the peaty soils and the more mineral soils found in small patches across this site. However, the peat soils in Trench 46 in Field Class 3 actually contain higher amounts of mineral material than the peat soils from Trench 36 representing Field Class 1, yet have been shown to contain less mamillate and spheroidal excrement. These results cannot be easily interpreted or explained and doubts about the identification of excremental pedofeatures using the Level 2 method remain.

Field Class 5 - Polygons with rig on steep slope

Field Class 5 groups together the polygons which contain rig and furrow and are generally located on the steeper western slopes of the site and at slightly higher altitudes. Trench 42 represents this field class at Level 2, although it is located on the lower slopes of the western side of the site. The quartz, cell residue and mamillate excrement content of these slides was only found to differ significantly from the results for Field Class 1. This is because the results for these parameters in Field Class 1 were greatly biased by the peaty soils of Trench 36 rather than the results for Trench 44, also described for this field class (see *Field Class 1* above). The results for Trenches 42 and 44 are actually very similar, but have been obscured by the Trench 36 results. Trench 42 (Field Class 3) is located on another of the improved grass swards on the lower slopes to the west of the *Allt an Fhealing* burn, similar to that of Trench 44. The profiles of these two trenches are very similar, both containing a sandy clay loam of approximately 38cm thickness below a shallow peaty turf mat. The moderate amounts of quartz and the low amounts of cell residue and lack of mamillate excrement for Trench 42 are almost identical to that of Trench 44 (Field Class 1). This suggests that these are characteristics of the natural soil profile rather than of any particular agricultural activity associated with the Field Class 3 polygons.

It would appear that the areas containing Trenches 42 and 44 should have been classified in the same field class and this highlights one of the main problems in attempting to create a field classification for open field systems. Very few physical boundaries exist in this type of landscape to identify the limits of each polygon for classification. Given the limited information available on these sites, without a full detailed ground survey of each one, the best considered approach was to attempt to distinguish distinct "blocks" of agricultural activity using the aerial photograph for the area and as many natural boundaries as possible. Natural boundaries such as watercourses are well documented in the historical literature as land boundaries. This necessarily produces large polygons as the number of "artificial" boundaries superimposed on the landscape is kept to a minimum.

The aerial photograph used for this site was produced from a flight undertaken in 1951. The close cropped grass sward of 47 years ago can be seen to cover much greater areas around Trenches 42 and 44 than it does today. However, vegetation cover was not a criterion for distinguishing polygon boundaries for the field classification and these areas were thus incorporated in larger expanses of landscape to conform to the minimum artificial boundaries approach.

The sandstone results of the Trench 42 slides showed a difference to those for both Field Classes 0 (outwith polygons) and Field Class 1 (short rig). However, this difference can also best be explained by the difference in the type of soils rather than any differences in management practise in these areas. The relative sandstone content of Field Classes 0 and 1 has already been discussed and attributed to the peaty nature of the soils from Trenches 49 (Field Class 0) and 36 (Field Class 1). Similarly, the sandy clay loams of Trench 42 have been discussed and, once again, the conclusion must be that these differences in sandstone content can only be associated with soil texture.

Summary

It would therefore appear that natural soil properties are much more dominant than any possible micromorphological signatures which may be attributable to different agricultural practises. This may be because the desk-top field classification is incorrect due to lack of information and current data. As discussed in Chapter 6, the slides selected for description at Level 2 were chosen to represent a particular field class. However, an examination of the micromorphological characteristics of the Badentarbat slides selected for the Level 2 work revealed that these slides were actually much more representative of the Level 1 clusters in which they were grouped during the HCA of the Level 1 data (Chapter 6) than of the field class which they were chosen to represent (see Tables 7.35 and 7.36). The natural heterogeneity of the soils within this site is clearly a very important feature which makes it very difficult to identify characteristics which can be categorically identified as distinguishing features of different types of agricultural practise.

It must also be considered that, according to the evidence from the historical documentation, Badentarbat had been abandoned to sheep farming by the late 18th/early 19th century and became a shooting lodge around the 1840's. The land has, thus, had almost 200 years of minimal disturbance to any great depth by human activities and natural soil processes must have eradicated or masked a considerable amount of the evidence for this past human influence, leaving only the surface morphology of the landscape as a clue to the past.

7.2.5 Comparison of Level 2 results for Boyken and Badentarbat

The Level 2 results for Boyken and Badentarbat have led to very similar interpretations, despite a difference in the number of parameters which show statistically significant differences between the field classes for each site. All five of the ordinal parameters show some difference between at least 2 field classes for Badentarbat whilst only three are found to show any significant variation between the field classes at Boyken. None of the nominal variables described at Level 2 show statistically significant differences between the field classes for either site and examination of the cross-tabulation of this data does not reveal any identifiable trends specific to one particular field class. Although these micromorphological characteristics can be taken at face value to characterise the different field classes, closer examination of the Level 2 data for both sites reveals that many of the identified characteristics are actually more accurately displayed by only one slide or one trench in each field class rather than all slides showing similar characteristics for that group.

The samples from outwith the polygons at both sites do not display any unique micromorphological characteristics to distinguish them from all of the samples taken from within the field system. This suggests that the soils within the field system do not contain any micromorphological indicators which can be associated with past agricultural practises. This suggests, therefore, that traditional styles of arable practice in Scotland had little long term impact on soil properties. Arable activity clearly does not significantly alter the soil environment, or move it to a new equilibrium. This interpretation is further strengthened by the fact that the soils in the polygons which contain no evidence of rig and furrow cannot be shown to possess micromorphological properties to distinguish them from those that do contain evidence of cultivation remains. This is not to say that these micromorphological characteristics did not exist during the working life of either site. It merely indicates that any such evidence has been eradicated by pedological processes such as bioturbation and podzolisation which have continued to act on these soils since their abandonment for arable agriculture 150-200 years ago.

It is also possible that the wrong micromorphological parameters have been selected for description using the Level 2 method. The same parameters were described for both sites. However, it has been shown that the soils at these two sites are very different. In fact, only two of the statistically significant parameters identified for the Badentarbat slides during the Level 1 work are described at Level 2. This may mean that much of the micromorphological evidence for differences in the Badentarbat slides has been missed during the Level 2 work. The selection of parameters for description at Level 2 has been discussed in Section 4.4.1 in Chapter 4. Reservations about the validity of the statistical analyses carried out on the Level 1 data at that time in order to devise the Level 2 description method were acknowledged and the selection of parameters for description at Level 2 was therefore made using a combination of the statistical test results and knowledge from previous studies of useful micromorphological indicators of past anthropogenic influences. The post-hoc analysis of the Level 1 results using appropriate tests has revealed a number of statistically significant parameters for Badentarbat which possibly should have been examined further at Level 2. These doubts can only be answered by further study using different sets of parameters. This research project was a first step towards trying to describe and interpret historical agricultural soils using soil micromorphology and field classification and the lessons learned can only help in further developing and testing these techniques in the future over a wider range of sites and soils.

There are a number of other possible reasons for the apparent lack of any micromorphological evidence to distinguish between the field classes using the Level 2 data. Firstly, it could be argued that the samples selected for description at Level 2 are not particularly representative of the field class in which they are grouped. This argument is particularly strong for the Badentarbat site where it has been shown that the slides described at Level 2 show greater similarities to the Level 1 clusters in which they were grouped during the HCA of the Level 1 data than of the field class in which they were placed during the desk-top field classification. However, the Boyken slides can be shown to have more affinity with their field class allocation than their Level 1 cluster membership (see Chapter 6).

It can also be argued that an insufficient number of slides have been described at Level 2 in order to give a true representation of the nature of the field units and their associated soils grouped in each field class. This has already been discussed in Chapter 6. Settlement of this particular argument is only likely to be reached by further description of all of the slides from both sites at Level 2. However, the analysis of such a large set of data could prove problematic and greatly improved computer facilities will need to be available in order for such further research to take place in the future.

It must be considered that the field classification of these two sites using only the available survey data does not accurately reflect the nature of the different units in each field system. This apparent lack of conclusive micromorphological results may be symptomatic of the erroneous classification of these landscapes. Certainly, when testing for a relationship between the form and function of field units within any field system, medieval or otherwise, consideration must be given to the nature of the soils within each site. This was not a factor which could be incorporated into the field classification using the available data. Clearly, if a farmer wishes to grow oats or barley and has a choice of peat or sandy clay loam soils on which to grow this crop (as at Badentarbat), then he will choose the more freely draining mineral soils. The wet areas of deep peat are obviously less conducive to the growth of cereal crops and require considerably more effort to drain and prepare the soil for sowing than the mineral soils. These peat soils would merely be taken into this type of cultivation in times of desperate need or where no alternative soil types were available. Such areas, however, provided the grazing necessary to maintain the livestock which produced the manure for arable crops.

The nature of the soil, as well as the landscape topography, also has an influence on the cultivation implement used. Producing rig and furrow with a high enough amplitude to produce effective drainage in peat soils is difficult using only a plough. These rig must be further enhanced by use of the delling spade or *chas-crom* in order to create the necessary relief to effectively drain such wet areas. Such considerations need to be incorporated into the recording method for field systems before a field classification can be devised which reflects more than just the morphology of the landscape. This is particularly true for sites such as Badentarbat where a variety of distinctly different soil types exist.

The uniformity of the soils at Boyken does not present such problems, however, and problems with fitting the micromorphological evidence to the field classification results must be due to other factors. As discussed in Chapters 2, 3, 5 and 6, the main problem with classifying the Boyken field system is the complex chronology of the different elements of the landscape. However, this problem is not unique to Boyken. Badentarbat also revealed evidence of several phases of landuse. Agricultural landscapes evolve in response to a wide variety of factors, of which change of ownership, developments in technology and management practises, fluctuations in population and changes in climate are only a few examples (Foster & Hingley, 1994; Grant, 1930; Rackham, 1986). The "field system" remains that can be seen across Scotland today reflect a constantly changing combination of these factors through time rather than a one-off response to subsistence needs as is suggested by the title "field system". Each stage in this evolutionary process need not completely eradicate all the evidence of past landscape organisations and uses. The challenge facing researchers of these agricultural landscapes today is to unravel the complex field remains into their respective contexts. The current methods of archaeological survey and mapping of these landscapes clearly do not provide enough information to address this need. The recording of these complex landscapes must acknowledge and accommodate the complexity of these archaeological remains. This includes the nature of the rig and furrow contained within the built elements of the agricultural landscape. Efforts need to be made to distinguish between the different degrees of "preservation" of the rig and furrow throughout a site. For example, the rig and furrow of the upper eastern complex of polygons at Boyken are very slight in comparison to those located on the lower slopes. This simple information provides significant clues to the function, lifespan and chronology of these features. None of these differences in rig morphology could be appreciated at Boyken from the survey data alone and it is possible that this has resulted in the inaccurate classification of the field remains of this agricultural landscape.

Finally, the lack of good micromorphological indicators for both sites may be because the wrong cluster solution has been selected from the Hierarchical Cluster Analysis of the field system data. As discussed in Chapter 2, subjective decision-making cannot be avoided using any classification technique and it may be that the best cluster solution was not chosen for each site. This can only be checked by testing the micromorphological data against other cluster solutions. However, great care was taken in selecting a cluster solution for the field classification results and, indeed, statistical analysis of the initial cluster solution chosen to represent the landscape at Learable proved that this was not a useful or accurate representation of the landscape. An alternative solution was therefore selected which showed clear statistically significant differences between the field classes. It is, therefore, considered that the lack of sufficiently detailed survey data has caused greater difficulties during the field classification work than the final selection of field classes from the Hierarchical Cluster Analysis results.

7.3 Comparison of Level 1 and Level 2 results

The Level 1 and Level 2 results for both sites have been discussed at length in previous sections in this chapter. Several of the points made in Section 7.2.5 also apply to a comparison of the Level 1 and Level 2 results. The results of this research project suggest that the Level 1 method of description provides more useful information upon which to base an interpretation of soils of medieval or later Scottish field systems than the Level 2 method. The wider range of parameters described at Level 1 and the large number of slides examined provides a more complete impression of the site than the limited, yet extensive data set obtained from the Level 2 method of description.

The Level 2 method of description could be further improved by more targeted selection of micromorphological parameters for description according to the characteristics of the site being studied. Many of the nominal variables chosen for description at this level have shown little variation and have not proved useful. A range of different sets of parameters could be further tested in an attempt to find the most useful set of micromorphological characteristics to distinguish particular agricultural practises in the past. However, the very large data set produced during this research, using a limited number of slides, has proved difficult to analyse and doubts remain about the representativeness of the slides used during the Level 2 work. These doubts can only be answered by describing a greater range of soil thin sections but this clearly enlarges the data set considerably, causing further problems for analysis and interpretation of the results.

From the evidence presented from this research, the micromorphological evidence produced from the Level 1 method of description provides sufficient evidence upon which to base an interpretation. The fact that this interpretation does not categorically state that these micromorphological characteristics indicate past agricultural practises does not invalidate the soil micromorphological techniques used here. Evidence can only be found if it exists and similar previous studies have also returned poor results.

The Level 2 method of description has satisfied one of its aims; it has shown that the between-slide variability identified during the Level 1 work is greater than the variability within each slide. This suggests that the Level 1 results provide a fairly accurate reflection of the micromorphological characteristics of each slide. Some problems with identifying and estimating the content of certain features have been shown by this research. Estimations of quartz grains, sandstone fragments and excrement vary according to the description method used. The abundance of quartz grains tends to be over-estimated at Level 1. This is probably due to the wide range of shapes and sizes and the generally scattered distribution of these throughout a slide, making it difficult to give accurate estimates. Sandstone fragments, however, are generally over-estimated at Level 2 due to their large size relative to the 1cm^2 gridsquares described at this level. These are not regarded as major problems. As long as each parameter is consistently estimated using a clear set of guidelines, then relative differences between the samples should still be evident. This is clearly the most important factor when looking for differences between soils from different areas or with different functions in the past. The different estimations of excremental pedofeatures recorded at Levels 1 and 2 is a slightly more complex problem.

Differentiation of these pedofeatures from microstructure features requires some degree of subjective interpretation rather than pure description. Such interpretation can differ markedly when considering a 1cm^2 area rather than an entire slide, even at the same magnification and is also clearly dependent on the size, shape and "distinctiveness" of the excremental pedofeatures. It is, therefore, impossible to conclude with certainty that one method of description allows more accurate identification and estimation of these pedofeatures than the other but the difficulty in interpreting the excremental content results from the Level 2 work for Badentarbat suggests that the Level 1 results provide a more accurate estimation of these micromorphological features.

The Level 1 method of description is therefore considered to be the most efficient method of analysing soil thin sections from medieval or later Scottish field systems. A wide range of parameters and a large number of slides can be described in a relatively short time using the coding and recording system devised for this research project. The Level 2 method of description may be improved through further refinement but it has achieved its goal of confirming that the differences identified for the Level 1 results are more important than any within-slide variability not tested during the Level 1 description work.

8. Summary of findings and conclusions

8.1 Introduction and key findings from the research project

The research design of this project has been developed in two main parts: the desk-top field system classification and the soil micromorphological investigation (Figure 1.3). Whilst the soil micromorphological research was the main focus of the project, it relied heavily on the results of the field system classification work. In this way, possible relationships between the form and function of the various field units found within medieval or later field systems in Scotland were explored and tested using soil micromorphology and quantitative analysis techniques. The current lack of understanding of these Scottish "cultural landscapes" is, at last, being addressed by bodies such as Historic Scotland, the academic research community and other bodies concerned with the interpretation, preservation and management of these geographical "history books". The scientific approaches employed during this research project are, to the best of the author's knowledge, unique and innovative and much has been learned in attempting to understand and interpret historic agricultural landscapes in Scotland through the soils contained within them. The key findings from this research project are summarised as follows:

- Image analysis is a particularly useful tool for the quantitative measurement of extant cultivation remains.

- Hierarchical Cluster Analysis can successfully be applied to medieval or later Scottish field systems to produce classification maps but further detailed field survey is required to improve the accuracy of the classification.

- The Level 1 description method developed during this research project provides sufficiently detailed and accurate information to be able to describe a large number of soil thin sections efficiently in order to examine extensive areas of the landscape.

- The Level 2 description work confirms that between-slide variation, identified using the Level 1 data, is greater than any within-slide variation.

- Pedogenic processes which have continued since abandonment of the two studied field systems have eradicated or masked much of the micromorphological evidence of past anthropogenic activity in these areas, especially with reference to tillage systems.

- The micromorphological evidence of past anthropogenic activity that does remain can be attributed to different manuring practises rather than differences in the method of tillage used to create the extant cultivation remains.

8.2 Field Classification - Testing Hypothesis 1

The first hypothesis to be tested during this research project was:

- Image analysis techniques and the use of statistical packages can be applied to existing data on medieval or later field systems in Scotland to generate maps indicating areas of distinctive land use and management in the past.

The desk-top field classification study has demonstrated that there is considerable potential for the use of image analysis and hierarchical cluster analysis to quantitatively analyse historic field systems. Image analysis is particularly useful for the quantitative measurement of rig and furrow and field morphology. The quantitative statistical methods employed during this research effectively handled a large amount, and diverse range, of data to produce classification maps which clearly distinguished between field units, mainly on the basis of rig morphology. However, the soil micromorphological work carried out as the main part of this research project clearly indicates that field units differ in far more than just morphology. The currently available survey information for Scottish medieval or later field systems is inadequate to be able to create field classification maps for all known historic field systems in Scotland without further field work and some degree of interpretation of the different elements of the field system. The hypothesis that Scottish medieval or later field systems in Scotland can be classified using *existing* data is therefore not proven.

This does not imply that the information required to produce accurate field system classifications cannot be obtained; it merely highlights the fact that current recording methods need to be re-assessed to identify and prioritise the type of information gathered during field survey in order to fully appreciate and measure the complexity of these landscapes. Chapter 2 provides a full discussion of this point. Many of the sites initially considered for inclusion in the desk-top field classification study could not be used because the survey map did not cover the entire field system. If field systems are to be understood and managed, the information must be recorded to allow them to be studied in detail. Emphasis is normally given to recording the settlement structures. This is clearly indicated in Piers Dixon's paper presented to the MOLRS Advisory Group in 1992. However, it is hoped that the increased interest in understanding cultural landscapes, shown by bodies such as English Heritage and Historic Scotland, may initiate a change in recording practise.

Some attempt was made to acknowledge this complexity during this research by the use of a truncation variable but, as discussed in Chapter 2, truncation could only be identified with any great certainty from the existing survey maps, between post- and pre-Improvement land organisations. Simple, fully enclosed field systems with no evidence of multiple land organisations such as at Laughengie, Kirkcudbrightshire are relatively easy to classify and require virtually no interpretation prior to measurement of the various parameters used for this field classification. However, such compact and apparently one-phase field systems are rare in Scotland and the complex field systems of Boyken, Badentarbat, Dùnan and Learable must be considered the norm.

It is impossible to distinguish the stratigraphic relationship between different components of the field system using current survey map notations. The archaeological work carried out by AOC (Scotland) Ltd during this project has shown that, although these relationships are not always fathomable even with excavation, the stratigraphic sequence of field boundaries can often be teased out through detailed surveying. Whilst it is clearly impractical to suggest that entire sites are surveyed with such detail, it is considered feasible that certain "problem areas" can be identified from the office-based examination of the AP and these can be targeted during subsequent field work. It may be possible to depict the stratigraphic sequence of coinciding boundaries on survey maps using different line styles.

Considering and measuring only the morphology of the field system components has been shown by this research to be insufficient to produce an accurate classification of field systems. This view is also held by Austin (1985). Other factors such as climate, location and the socio-economic environment clearly played an important role in the formation of these historic agricultural landscapes. The easily measured topographic features of the field systems have been included in this field classification exercise. Although they do not appear to be particularly important variables in the HCA procedure, it would be to the detriment of the classification procedure to omit them and rely completely on the morphological data. From the results of this research, the function of different field units in historic field systems clearly relates to much more than the morphological form of these units and it is strongly suggested that some indication of soil texture should be included in the recording system for field systems in future and should be included in the classification procedure.

It is clearly impossible to undertake a full-blown soil survey of every site and existing soil maps are not produced at a suitable scale to provide useful information on the diversity of soils found within a single field system. It will also often be undesirable to dig even small trenches in order to establish the nature of the soils at certain sites. However, it may be possible to carry out a number of test samples with an auger to establish the general nature of the soils. This information need not be detailed: even an indication of the soil texture of the soils would be useful. Alternatively, or possibly additionally, a very general vegetation survey would provide some indication of the drainage properties and fertility of the soils without any intrusive excavation. Any classification of field systems must consider the function of the various field units as well as their form. Even today, the use of a piece of land for arable agriculture is still heavily dependent on the nature of the soil. Basic, non-detailed vegetation survey or random augering may provide an efficient means of identifying areas within a field system which were particularly suited to certain types of agricultural management. Inputting information on the soils of each site into the classification procedure may produce a classification which more accurately reflects the range of factors which determined the function of the field units within a site. Adding information gained through field work to the field classification system was not an objective of this research project and this hypothesis, therefore, remains untested. Section 8.7 discusses this point further under "Recommendations for further work".

Further appreciation of the function of the field units within a particular field system may be built into the classification procedure by measuring the distance of each field unit from the associated settlement structures. However, it is often difficult to associate particular settlement clusters with certain field units, as in the cases of the Boyken and Badentarbat sites where several settlement clusters are present in an apparently "seamless" field system. Interpretations would therefore have to be made prior to measurement which adds further subjectivity to the classification procedure. This measurement was not attempted during this research in an attempt to minimise the subjective nature of the classification. It may, however, provide useful information for sites with only single or particularly nucleated settlement clusters.

Simple measurements show a broad east/west split in the field systems studied during this research project. Calculation of the ratio of the area of land per field system which contains no rig and furrow to the area that does contain rig and furrow provides a useful indication of the type of farming practised in these field systems. The field systems on the east have proportionately more land under arable cultivation than those in the west of Scotland. The proposed variable distribution of rig type (Dixon, 1994) has not been demonstrated during this study but further sites must be examined before it can be concluded that no such regional differences exist. However, the range of types of rig and furrow found at the Badentarbat site alone suggests that it may be difficult to show distinct differences between sites. Many of these sites have long agricultural histories and contain the remnants of several different phases of cultivation illustrating the technological developments in agricultural implements. Such temporal variations within a single site clearly complicates any interpretation of geographical variation between sites.

Analytical tools, therefore, exist which can be applied to the interpretation of medieval or later field systems in Scotland. However, the data recorded must cover a wider range of variables than just the morphology of the extant cultivation remains in order to develop a classification system which reflects the complexity of these historic agricultural landscapes. A more sophisticated method of recording and depicting the upstanding elements of these agricultural landscapes will do much to improve the possibility of creating a field classification system which reflects the complex stratigraphy of these sites. However, this research has shown that the function of the field units within these "systems" is determined by more than just the morphology of the extant cultivation remains. The recording of environmental parameters such as soil texture, depth of cultivated topsoil and vegetation assemblages across each site will provide useful additional information which can be added to the classification procedure in order to produce a classification which reflects, to some degree, the function as well as the form of these historic agricultural landscapes.

8.3 Soil Micromorphology - Testing Hypothesis 2

The second hypothesis to be tested during this research project was:

- The soils in these functional areas will have distinctive signatures in terms of micromorphology which can be recorded using microscopic examination and analysed using quantitative statistical techniques.

The results from this research project disprove this hypothesis. The micromorphological features of the soils from the two studied sites were not shown by quantitative analysis to be associated with field class. This could be for several reasons:

1. The soils have lost most of the micromorphological evidence of past land use due to the ongoing processes of pedogenesis such as bioturbation and podzolisation since abandonment.
2. The wrong micromorphological parameters were described during the soil thin section description work.
3. The field classification is inaccurate and does not correctly identify the different functional units of the field system.
4. The quantitative analysis techniques used cannot "overlook" the features of natural pedogenesis and identify the more subtle evidence of anthropogenic activity.

Some slight micromorphological evidence could be tentatively interpreted as indicative of past anthropogenic activity in certain field units when supported by archaeological or historical documentary evidence. However, this was identified through manual examination and regrouping of the data rather than via automated computer analysis using quantitative analysis techniques and, again, was found to be specific to the field unit rather than the field class to which it had been assigned during the HCA procedure. The micromorphological evidence on its own was not sufficient to allow a firm interpretation of past farming practises. The archaeological and historical documentary information also obtained during this research has played an important role in allowing the studied field systems to be interpreted. The presence of some micromorphological evidence of past anthropogenic activity in these soils, albeit slight, suggests that pedological processes such as bioturbation, cheluviation and podzolisation which have carried on apace since abandonment of these sites has erased most, but not all, of the evidence of human influence on these soils in the past. There is little evidence to support the hypothesis that the soils subject to past anthropogenic influences have evolved in different pedogenetic directions to those soils not demonstrating human modification in the past. A key finding is that the micromorphological evidence of past human activity that does remain in these soils relates to manuring practises rather than the nature of the cultivation implements used to produce the extant cultivation remains. This is a similar finding to that for the soils of a recently abandoned field system in Papa Stour (Carter & Davidson, in press) and further collaborative research of the evidence of manuring practises at this site begins this summer. The complete loss of micromorphological evidence is therefore not considered to be the reason for this hypothesis not being upheld although it is acknowledged that very little micromorphological evidence of past human activity exists in the soils today.

The argument that the wrong micromorphological parameters were described during this work is also rejected. Although only a selection of micromorphological features were described, the selection process was based on knowledge of past micromorphological studies of anthropogenic soils in archaeological contexts. All of the features chosen for description during this work have been identified in previous studies as indicative of certain anthropogenic influences in the past. Thirty-three variables were described during the Level 1 work and the five variables estimated during the Level 2 work were also described for basic distribution whilst the referred distribution and shape of quartz grains was also recorded. This represents a comprehensive description of the mineral and organic components of the soils as well as their inter-relationships and a comprehensive range of pedofeatures was also described in terms of content. The micromorphological description method used for this research is, therefore, considered sufficient to identify any existing evidence of anthropogenic influences on these soils.

The two methods of description using estimates for the whole slide at Level 1 and a 1cm^2 grid for Level 2 also provided information at two levels of detail which could then be compared. Slight differences in the estimation of quartz, sandstone and mamillate excrement were identified using these two levels of description but the distribution pattern at both levels was generally similar, indicating that estimates of content were consistent during each method of description. Although a difference in estimation was found between the Level 1 and Level 2 results, this was rarely more than one frequency class and does not pose any real problems for interpretation of the results.

Although the sampling strategy for both sites was based on the field classification results, the lack of good distinctive micromorphological evidence associated with all thin sections from each field class cannot be solely attributed to possible inaccuracies in the field class allocation. A selection of field units containing a diverse range of cultivation remains were sampled at both Boyken and Badentarbat. The archaeological field excavation and survey carried out at both sites confirms the diverse nature and chronology of these remains. Putting aside the field classification, it would still seem reasonable to expect to see differences between the soils sampled from such a variety of different morphological contexts. This is not the case. The micromorphological evidence of anthropogenic activity which has been found is interpreted as indicative of particular manuring practises rather than particular methods of creating the rig and furrow or lazybeds. The micromorphological evidence is, therefore, highlighting differences in management practises which cannot be appreciated from the extant cultivation remains alone. The field classification process employed for this research may, therefore, provide an accurate assessment of the morphology of the field units within a particular field system but it does not accurately reflect the other management practises associated with arable cultivation. If further environmental information can be entered into the field classification process which provides some indication of the nature of the soils in each field unit, then it may be possible to find a greater correlation between the micromorphological evidence for past anthropogenic activity and the type of field unit from which the soil sample was obtained (Section 8.2 provides a more detailed discussion).

From this research, it would appear that differences in rig morphology are not reflected by differences in the soil micromorphological data and that areas demonstrating similar rig morphologies may have been subjected to different manuring practises. The morphological emphasis of the field system classification, driven by the nature of the available data, means that no association between manuring practises and field class could be found. Individual field units within certain field classes displayed evidence of varying manuring practises but these characteristics were not demonstrated by all the field units which were grouped together in one field class. The principles of equifinality and indeterminacy are equally likely to operate in Scottish field systems for the medieval or later period and must always be borne in mind. Many of the fields studied and considered similar now may have had very different forms previously and have originated in different ways. Equally, similar processes acting in different areas at different times can result in very different field structures (Butlin, 1973).

The quantitative analysis of the micromorphological data clearly identifies the features which are associated with pedogenetic processes such as bioturbation by soil fauna, illuviation of clay, podzolisation and organic matter decomposition. This indicates that the pedogenetic processes in these soils are of greater significance than any evidence of past anthropogenic activities. This is, indeed, the case but some micromorphological evidence such as the presence of charcoal, can be attributed to past anthropogenic activity when supported by additional evidence from the historical documentation or the archaeological fieldwork. It would, therefore, appear that quantitative analysis can successfully identify the dominant processes in the soil but "overlooks" the more subtle evidence of human influence which may also be present.

The lack of success in proving that the soils from the functional areas, identified during the field classification, contain distinctive micromorphological signatures is, therefore, due to a combination of two factors:

1. The lack of sufficient environmental information in the field classification process to indicate possible differences in land management other than the actual creation of rig and furrow.

2. Quantitative analysis techniques identify only the dominant evidence of pedogenetic processes rather than the more subtle evidence of past anthropogenic activities, where it exists.

However, it must be remembered that the micromorphological evidence can only be interpreted as indicative of anthropogenic activity when supported by further archaeological and historical documentary evidence of past human activities. Soil micromorphology cannot provide all the answers and any future work on field systems should endeavour to combine soil micromorphological techniques with archaeological fieldwork, historical documentary research and other palaeoenvironmental studies such as pollen analysis.

8.4 Comparison of soil thin section description methods

The Level 1 method of soil thin section description is considered to be the more efficient and useful method of identifying and describing the micromorphological features of soils from historic field systems. One hundred and twenty-six slides were described relatively rapidly during this research project for a substantial number of micromorphological features using the coding method devised during this research. Hierarchical cluster analysis of the Level 1 data produces similar results to those for the Level 2 data. However, it is much easier to interpret the results from the smaller Level 1 data set. The hierarchical cluster analysis and Kruskal-Wallis one-way analysis of variance by ranks test proved sensitive to very small differences between groups when analysing the large Level 2 data set. The large volume of Level 2 data was also particularly hard to interpret and did not add sufficient additional data to the findings from the Level 1 work to merit the time and effort required to record, analyse and interpret the results. However, the level 2 method did achieve one of its aims. Comparison of the results of the Level 1 and Level 2 work confirmed that the between-slide variability identified during the Level 1 description work was, indeed, greater than any possible within-slide variability.

It was acknowledged during the Level 1 work that the single recording of each micromorphological parameter for each slide did not reflect any possible variability within each soil thin section. The multiple descriptions per slide achieved through using the 1cm^2 grid system of recording in Level 2 demonstrated that within-slide variability was not as significant as the variability between slides identified during the hierarchical cluster analysis of the Level 1 data. The Level 1 method of description can, therefore, be considered to provide an accurate record of the nature of each soil thin section and provides a fast and efficient method of describing a large number of soil thin sections from a large geographical area. This is particularly important when the extensive nature of historic agricultural landscapes is considered in comparison to the size of soil thin sections.

8.5 Comparison of Boyken and Badentarbat sites

The Boyken and Badentarbat sites provided an excellent opportunity to compare and contrast two historic agricultural landscapes from very different contexts. The inland site of Boyken in the steep uplands of Eskdalemuir in Dumfries and Galloway is an extensive area on uniform brown podzolic soils which is delimited by post-Improvement land reorganisation and land use. The close proximity of a *Birren*, tentatively dated to the first century AD on the basis of similar structures in Eskdalemuir, indicates that this site has been occupied for at least 1000 years and evidence of agricultural activity has clearly been truncated by the post-Improvement landscape. In contrast, the site at Badentarbat is neatly enclosed by a head dyke which follows the contours of this low-lying coastal valley. This site is predominantly covered by peats but also contains pockets of sandy podzolic loams and contains a wide variety of rig morphologies in both small enclosures and relatively open contexts. The Badentarbat site appears, at face value, to represent a field system predominantly from the medieval or later period, although radiocarbon dating and excavation provided some evidence to suggest that early human occupation of this site occurred at least 4000 years ago. Both sites were abandoned for arable cultivation around the late 18th/early 19th centuries. Neither of these sites can, therefore, be described accurately as "medieval or later field systems"; rather they are the remains of a long history of evolving agricultural landscapes in Scotland. It is, therefore, very difficult to attribute any soil micromorphological evidence to a particular period in the history of these field systems without further archaeological evidence and dating of structures which have a clear stratigraphical relationship with the cultivated soils.

The cultivation remains remaining today at Boyken indicate at least 3 phases of land use. The area to the west of the post-Improvement stone dyke which bisects the site contains evidence of an earlier phase of land organisation where the land was subdivided by a series of parallel, low turf banks. This suggests that some form of tenurial system was formerly applied in this area. The rig and furrow in the field units below the substantial turf bank that runs along the contours mid-slope to the east of the post-Improvement dyke have a relatively high relief in comparison to the very slight, sometimes impossible to determine, rig and furrow found in the upper complex of polygons also in the east of the site. The difference in relief of the rig and furrow in these two areas is interpreted as indicative of varying intensities and length of use; the rig and furrow of higher relief on the lower slopes are interpreted as part of the infield of the "field system" which was under continuous cultivation throughout the medieval period and the less well-defined rig and furrow in the upper complex of polygons are associated with a late and transient period of arable agriculture prior to abandonment of the site.

The cultivation remains at Badentarbat also demonstrate the use of different cultivation implements which can be associated with different periods of its history. The lazybedding cannot be dated to any particular period as this form of cultivation is well documented to have carried on well into the 20th century in some areas of western Scotland (Baldwin, 1994; Fenton, 1976). However, rig and furrow which was created by a plough drawn by draught animals is also found throughout the site and comes in a variety of forms; reverse-S, straight narrow with high amplitude and broad straight rigs with multiple crests and narrow furrows. The reverse-S rig and furrow is associated with the fixed mouldboard plough pulled by a large team of draught animals. This plough was superseded by the lighter swing plough which required fewer draught animals and men to operate it and produced straight or curving rig and furrow. The curving rig and furrow found at Badentarbat is interpreted as a late phase of arable cultivation prior to abandonment of this site and is associated with the pressures of a rapidly expanding population. This type of rig and furrow is on particularly wet peat soils and, in contrast to the similarly late and transient rig and furrow at Boyken, has a very high relief. The high relief of these rig and furrow was clearly an attempt to improve the drainage of these heavy peat soils and there is some evidence that mineral material was added in order to further improve drainage. In comparison, the broad multi-crested rig and furrow located on the pockets of mineral soils found within the Badentarbat field system have a relatively low relief. However, the lack of any substantial peat horizon in these areas suggests that a similar interpretation to that for the upper complex of polygons to the east of the Boyken site may not be appropriate in this context. The lack of peat is interpreted as indicating possible extended use of this area of relatively freely draining soils rather than merely a late and transient phase of arable agriculture. Different rig morphologies are, therefore, interpreted differently according to their environmental *and* temporal context rather than purely on the basis of rig morphology being associated with different cultivation implements from different periods of history as proposed by Dixon (1994) and Parry (1976).

Despite very different contexts and clear evidence of former anthropogenic activity at both sites in the form of extant cultivation remains, little micromorphological evidence which could be attributed to past human influences on the soils was found at either site. This is primarily due to the eradication of much of the micromorphological evidence for anthropogenic activity at each site through continuing pedogenesis since the abandonment of the sites. No association was found between field class and the slight micromorphological evidence which indicated anthropogenic activity at either site. However, the reasons for this vary for each site.

At Boyken, this may be due to the fact that, as discussed earlier in this section, the difference in the nature of the rig morphology of the upper and lower slopes could not be appreciated and recorded during the desk-top field classification system. The field classification of Boyken did not, therefore, reflect the distinct differences between these two areas noted during the field work for this project. Similarly, the classification of the Badentarbat site did not reflect a true picture of the agricultural landscape but this was because differences in soil type could not be appreciated and recorded from the available data, although the field work clearly demonstrated that both mineral and organic soils were present at Badentarbat. The micromorphological evidence was, therefore, dominated by the evidence for the different pedological contexts from which the soil samples were obtained and showed no association with the field classes determined from the predominantly morphological classification of the Badentarbat field system.

The Boyken and Badentarbat sites, therefore, produced very similar micromorphological results with regard to evidence of past anthropogenic activity but the lack of association with the field classification results for both sites is due to different reasons. Although the geographical locations of these sites are very different, both are subject to relatively high rainfall and have subsequently been primarily used for pastoral farming activities. Both of these sites have been recently abandoned compared to earlier medieval or prehistoric agricultural landscapes and the lack of micromorphological evidence of anthropogenic activity at these sites casts doubt on the possibility of finding such evidence in soils sampled from within field units in earlier agricultural landscapes.

8.6 Recommendations for further work

This is clearly only the first stage in attempting to quantitatively analyse and classify field systems. The methods developed during this research need to be further tested on a greater number of field systems and soil types. The development of more detailed and comprehensive recording methods, concentrating equally on the settlement structures and the field system remains will provide the potential for further development of the field system classification. The next logical step from this research project is to use the information gained from the field work at Boyken and Badentarbat to test whether the inclusion of this information in the classification procedure improves the classification results to more accurately reflect the morphology of the field units and their environmental context, thus providing a better indication of their possible functions in the field system.

With the further recording and classification of other field systems throughout Scotland, possible regional variation in field systems should become clearer. For conservation and management purposes, it may be useful to use the classification system developed here in conjunction with terrain maps indicating rural settlement dispersal similar to those devised by Roberts and Wrathmell (1996) as part of the Monuments Protection Programme for English Heritage. This may provide the best indication of the nature and geographical spread of medieval or later field systems in Scotland in order to allow informed decisions on the preservation and management of these landscapes. However, it has become clear over the past four years of this project that only a small handful of the historic agricultural landscapes in Scotland have already been surveyed and mapped and much remains to be done before the knowledge of field systems in Scotland can be said to be adequate to devise well-informed management policies for these areas. Even in central Scotland, where the population of Scotland is concentrated, extant cultivation remains of historic agricultural landscapes are not infrequent. These are surely the areas that are under greatest threat from various forms of development and priority should be given to identifying and recording existing sites in the relatively highly populated central and lowland regions of Scotland before the evidence is lost forever.

Admittedly, these agricultural landscapes are more commonly truncated by subsequent land use than sites in the marginal areas of Scotland such as the Highlands and Islands, making their interpretation more difficult. These issues have already been debated and discussed by the MOLRS Advisory group (Hingley, 1993) and it is hoped that debate will lead to action.

Several of the findings or tentative interpretations of the micromorphological data presented in this thesis need to be further explored. Examination of soil thin sections sampled on transects oriented downslope in areas both with and without extant cultivation remains will prove or disprove the theory that increased coarse mineral content in soil thin sections is indicative of exposure of the soil surface in the past and subsequent downslope erosion of the fine mineral material due to cultivation.

One of the key findings from this research is that the little micromorphological evidence of past anthropogenic activity which does remain in the soils today relates to the manuring practises carried out on these soils rather than the type of cultivation implement employed to create the extant cultivation remains. Gebhardt's (1992) findings of differences in microstructure according to the cultivation implement employed under experimental conditions do not, therefore, appear to extrapolate to real situations with ancient soils. Evidence of manuring practises is also the main micromorphological evidence found during an examination of soil thin sections from a recently abandoned field system in Papa Stour, Shetland (Carter & Davidson, in press) and this site will be the focus of further research into identifying the cycling of organic and manuring material throughout a farm system using soil micromorphology, image analysis and bio-markers. The quantitative analysis of organic material using automated methods is particularly difficult due to the diverse nature of the material. However, Bryant and Davidson (1996) demonstrated the potential of image analysis for this type of work and this will be further developed during the Papa Stour project. Such research can only improve our knowledge of historic agricultural landscapes and the management practises used throughout them.

It may be argued that the apparent inability of soil micromorphology to recover the cultural information of historic agricultural landscapes is due to the sample location. Because the emphasis of this project was on testing for a relationship between the form and function, virtually all the samples came from the topsoils within a field unit as it can be argued that this is where the "functioning" of a farming system takes place. However, it is acknowledged that topsoils are subject to a range of influences which complicate or mask the micromorphological evidence. Bioturbation and mixing during cultivation eradicates any stratigraphy which may have originally existed in these soils making it impossible to relate the evidence to other built elements of the landscape. Climatic influences, such as rainfall and frost, on these soils also plays an important part in the pedogenetic modification of these soils which further masks any possible evidence of human modification. It would, therefore, seem reasonable to recommend that future soil sampling in these cultural landscapes should be done in well-protected locations such as under later boundary walls and other structures. However, does this then provide evidence of the function of the worked soils? How do you identify soil used for agriculture in the past if not on the basis of extant rig and furrow? Certainly, soils buried underneath upstanding elements of the landscape may contain micromorphological evidence to suggest occupation of the site and will be more likely to provide stratigraphically secure contexts for this occupation but whether this will provide any indication of past agricultural practises is questionable. It should be remembered that it was rarely possible to establish the relationship between the rig and furrow contained within a field and the boundary which surrounded it at both Boyken and Badentarbat. Future soil micromorphological work on historic agricultural landscapes should thus aim to sample from a range of locations, both within and without the field units, as well as under the boundaries and other structures such as cairns and kilns. Such a sampling strategy may not provide any more information on the functional nature of the various field units but it should provide a greater understanding of the chronological relationships between the various elements which comprise historic agricultural landscapes.

8.7 Key implications for the archaeological management of historic field systems

This research has clearly demonstrated that there is a long way to go in understanding and effectively managing historic agricultural landscapes in Scotland. Analytical tools and methods exist which can be applied to these landscapes but the information gathered must be sufficiently detailed and comprehensive to be useful. The interpretation of Scottish cultural landscapes can only ever be as good as the information gathered; partial evidence results in partial interpretations. The historical information of these landscapes exists in a variety of forms and all, or at least a range of these, should be explored in order to gain as complete a picture as possible of each site. What is then done with this knowledge is dependent on the attitudes of the various groups of people affected. Bodies responsible for the preservation and appreciation of Scotland's cultural heritage need to set out policies which determine which parts of the landscape are preserved and which may be allowed to continue their "historic evolution" in a managed fashion. This can only be achieved by gaining an appreciation of which landscapes are characteristic of an area and which are unique.

The extensive nature of many of these historic agricultural landscapes means that decisions will also have to be made as to which elements of the landscape are preserved. This research project has not considered shielings but they are a well-documented part of Scottish farm systems in the past. They are, however, often far removed from the in-bye land and it may be more difficult to gain support for the preservation of these often less "obvious" historic landscapes. This research has demonstrated that single-phase field systems are rare in Scotland and that most historic agricultural landscapes contain a palimpsest of vestigial remains of multi-phase occupation and use. Should the later elements therefore be removed to preserve an earlier "system"? The argument that the most well-protected evidence of early occupation of these sites may remain under the later structures strongly suggests that removal of these late additions to the landscape may, in fact, jeopardise the preservation of the earlier evidence. This may also mean that future additions to these landscapes will, in turn, protect the evidence of their past. Indeed, Graham Fairclough of English Heritage writes "the aim of landscape assessment should be to manage the landscape - to influence its future evolution - rather than to strive for its finite protection" (Fairclough, 1996, p.23). If historic landscapes are to be preserved it must be clear what is being preserved and why. This will only be achieved by further detailed, inter-disciplinary research of a wide range of historic agricultural landscapes across mainland Scotland and the islands in order to place a particular site in its rightful place in the general context of the Scottish cultural landscape.

There is enormous potential for the use of historic agricultural landscapes as a tool in educating both the native population and visitors in the cultural evolution of the Scottish rural landscape. It also provides an excellent opportunity to demonstrate the benefits of inter-disciplinary research in gaining the "bigger picture". Proposed future work currently being pursued by the National Trust for Scotland in collaboration with a large number of other organisations and individuals at Ben Lawers demonstrates the commitment to this type of approach. Whilst undertaking research on historic agricultural landscapes is a rewarding challenge in itself, it is given far more value when the results are applied and communicated.

8.8 Conclusion

The application of the term "field system" to these historic agricultural landscapes is a misnomer. This implies a single-phase, planned simplicity which rarely exists in reality. These agricultural landscapes record a long and complex history of land use and reorganisation of which only fragments of the earlier evidence remain. The function of the various field units relates to far more than just the morphology of the cultivation remains. The recording and analysis of these historic landscapes must reflect their complex nature in order to fully appreciate and understand the difficult decisions taken by the farmers of these historic landscapes in the past. Complex landscapes require suitably sophisticated examination. Inter-disciplinary exploration of these agricultural landscapes provides a holistic view which, it is argued, cannot be achieved through one avenue of research alone. This research has shown that the analytical tools and methods required to interpret these landscapes exist and that useful interpretation of these areas is best achieved by using a combination of different types of evidence. The different disciplines currently working on these cultural landscapes must begin to work together to further develop the understanding of these areas. Only then can informed decisions be made as to the future preservation and management of these cultural landscapes.

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Appendix 1

Badentarbat - Field Classification measurements and HCA results

FIELD CLASS	POLYGON	TOTAL RIG LENGTH	MEAN RIG LENGTH	SD RIG LENGTH	MEAN RIG WIDTH	SD RIG WIDTH	RIG SHAPE	BOUN-DARY	TRUN-CATE	ASPECT	FIELD AREA	FIELD PERIMETER	FIELD SHAPE	AVERAGE SLOPE	UPPER ALTITUDE	LOWER ALTITUDE
1	1	659.44	65.94	12.13	4.25	.56	3	0	1	2	4231.7	263.66	.76	8	5	5
1	3	441.47	31.53	12.55	4.62	1.08	4	0	1	2	3245.1	222.76	.82	6	5	4
1	4	539.33	23.45	8.36	4.03	.83	11	0	1	2	4150.9	385.01	.35	10	8	4
1	5	1041.26	69.42	9.71	5.88	.48	1	0	1	2	7146.6	333.41	.81	9	6	4
1	7	912.33	36.49	9.67	6.01	1.34	4	0	1	2	158.0	850.58	.00	7	5	3
1	10	179.55	29.92	2.36	4.36	.77	5	0	1	2	1234.5	138.43	.81	4	4	3
1	11	68.39	17.10	.40	5.54	1.44	4	0	1	4	1368.3	159.19	.68	3	3	3
1	14	57.14	19.05	.37	6.42	.25	4	0	1	2	504.1	89.60	.79	4	3	2
1	19	290.09	22.31	6.51	4.27	1.05	5	0	0	2	4370.0	295.03	.63	4	3	3
1	20	224.39	20.40	7.62	3.65	.97	5	1	0	2	2386.8	229.46	.57	5	3	1
1	21	456.15	32.58	3.41	3.43	.61	5	1	0	4	1643.5	161.84	.79	2	3	1
1	25	242.38	13.46	5.32	4.12	.92	5	1	1	4	102.2	381.16	.01	10	7	4
1	28	70.22	14.04	2.16	3.94	.67	5	1	1	4	389.1	78.73	.79	6	6	6
1	31	1888.35	30.96	16.85	5.35	2.11	4	0	1	2	14578.5	645.81	.44	7	3	1
1	32	471.37	13.47	8.37	5.36	2.97	4	1	1	2	5141.9	528.71	.23	5	3	1
1	33	358.43	25.60	3.92	6.38	1.79	1	1	1	2	2450.7	207.31	.72	6	3	2
1	34	482.44	24.12	8.81	4.67	1.00	5	1	1	2	5021.0	402.85	.39	11	5	2
1	35	462.24	42.02	6.10	8.20	2.36	1	1	1	2	4659.4	279.86	.75	6	5	2
1	40	552.25	36.82	12.15	4.43	1.32	8	1	1	2	4981.9	335.69	.56	10	10	7
1	42	369.87	33.62	4.30	4.94	.52	3	1	1	3	2432.9	193.02	.82	9	5	3
1	43	340.13	34.01	16.44	5.18	1.05	6	1	1	2	5750.7	316.20	.72	13	10	5
1	47	758.68	37.93	14.29	5.66	1.54	13	1	1	2	7771.5	349.03	.80	12	7	4
1	48	399.44	24.96	12.79	5.36	1.34	4	1	1	3	4658.2	361.12	.45	8	4	3
1	49	307.55	21.97	14.50	3.79	1.23	5	0	1	2	1822.8	203.92	.55	12	7	3
2	2	.00	.00	.00	.00	.00	0	0	1	0	1123.5	146.05	.66	3	5	5
2	6	.00	.00	.00	.00	.00	0	0	1	0	264.1	87.34	.44	8	4	4
2	8	.00	.00	.00	.00	.00	0	0	1	0	222.6	60.27	.77	8	4	4
2	9	.00	.00	.00	.00	.00	0	0	1	0	1344.6	154.73	.70	5	4	3
2	12	.00	.00	.00	.00	.00	0	0	1	0	9568.8	507.42	.47	4	3	2
2	13	.00	.00	.00	.00	.00	0	0	1	0	6067.0	374.09	.54	8	4	4

Badentarbat - Field Classification measurements and HCA results

FIELD CLASS	POLYGON	TOTAL RIG LENGTH	MEAN RIG LENGTH	SD RIG LENGTH	MEAN RIG WIDTH	SD RIG WIDTH	RIG SHAPE	BOUN-DARY	TRUN-CATE	ASPECT	FIELD AREA	FIELD PERIMETER	FIELD SHAPE	AVERAGE SLOPE	UPPER ALTITUDE	LOWER ALTITUDE
2	15	.00	.00	.00	.00	.00	0	0	0	0	2093.9	208.04	.61	4	3	2
2	16	.00	.00	.00	.00	.00	0	0	0	0	4911.6	299.28	.69	4	4	3
2	17	.00	.00	.00	.00	.00	0	0	0	0	1557.0	161.86	.75	5	4	3
2	18	.00	.00	.00	.00	.00	0	0	0	0	762.8	158.30	.38	4	3	3
2	24	.00	.00	.00	.00	.00	0	1	0	0	24950.8	707.42	.63	7	8	3
2	26	.00	.00	.00	.00	.00	0	0	0	0	1161.4	167.57	52	5	6	5
2	27	.00	.00	.00	.00	.00	0	0	1	0	497.0	87.41	82	3	8	7
2	37	.00	.00	.00	.00	.00	0	0	1	0	351.4	73.94	.81	9	8	7
2	39	.00	.00	.00	.00	.00	0	0	1	0	252.7	59.90	.88	5	9	9
2	41	.00	.00	.00	.00	.00	0	0	1	0	9099.9	406.11	.69	13	11	4
2	45	.00	.00	.00	.00	.00	0	0	1	0	171.4	49.24	.89	9	9	8
2	46	.00	.00	.00	.00	.00	0	0	1	0	158.7	48.97	.83	8	8	8
3	22	4534.21	73.13	51.05	4.40	1.41	5	1	0	11	27728.4	777.47	.58	4	3	1
3	23	5836.29	106.11	54.81	4.24	.92	14	1	0	8	22444.0	706.59	.56	2	2	1
4	29	1254.06	78.38	53.34	5.18	1.18	12	1	1	12	327.6	1241.00	.00	10	9	3
5	30	783.06	31.32	25.43	4.64	1.35	5	1	1	2	249.8	859.62	.00	13	9	3
5	36	726.36	51.88	25.36	10.15	5.28	9	1	1	2	10747.8	413.65	.79	11	7	5
5	38	382.90	27.35	15.14	4.52	.66	3	0	1	2	21460.7	637.53	.67	13	9	3
5	44	1190.00	31.32	23.71	6.26	2.05	10	1	1	2	16417.2	875.73	.27	12	9	2
5	50	1160.35	82.88	35.50	5.17	.96	2	0	1	2	7771.9	434.59	.52	11	9	3
5	51	1614.74	35.10	13.21	5.52	1.67	7	0	1	2	15280.3	648.99	.46	10	11	8

Boyken - Field classification measurements and HCA results

FIELD CLASS	POLYGON	TOTAL RIG LENGTH	MEAN RIG LENGTH	SD RIG LENGTH	MEAN RIG WIDTH	SD RIG WIDTH	RIG SHAPE	TOTAL LYNCHET LENGTH	MEAN LYNCHET LENGTH	SD LYNCHET LENGTH	LYNCHET SHAPE	BOUN-DARY	TRUN-CATE	ASPECT	FIELD AREA	FIELD PERI-METER	FIELD SHAPE
1	1	2260.00	164.62	13.01	5.54	.63	6	.00	.00	.00	0	0	0	3	15093.7	530.46	.67
1	8	510.00	63.75	14.08	8.25	.43	1	312.00	62.40	13.00	1	1	0	2	6629.3	336.13	.74
1	22	169.00	42.25	12.07	4.00	.00	3	664.00	51.08	27.97	2	0	0	3	36046.1	858.60	.61
1	32	556.00	79.43	9.18	11.33	2.56	2	.00	.00	.00	0	0	0	5	36890.0	756.59	.81
2	2	35.00	8.75	2.59	5.33	.47	1	.00	.00	.00	0	0	1	2	331.1	107.09	.36
2	3	417.00	46.33	9.86	6.25	.83	1	.00	.00	.00	0	0	0	3	4182.6	268.56	.73
2	4	115.00	57.50	2.50	5.00	.00	2	.00	.00	.00	0	1	1	3	885.6	149.39	.50
2	5	247.00	30.88	9.60	5.00	.00	1	.00	.00	.00	0	1	0	3	1527.2	172.48	.64
2	6	146.00	18.25	4.29	6.22	2.10	1	.00	.00	.00	0	1	0	3	1666.7	177.12	.67
2	7	174.00	43.50	3.84	12.67	2.05	4	.00	.00	.00	0	1	0	1	2911.9	237.92	.65
2	9	187.00	23.38	6.00	5.00	.00	1	.00	.00	.00	0	1	1	2	1606.2	152.33	.87
2	10	149.00	18.62	7.46	5.00	.00	1	.00	.00	.00	0	1	1	2	1203.9	137.00	.81
2	11	45.00	15.00	.00	2.50	.50	3	.00	.00	.00	0	1	1	2	302.6	72.00	.73
2	12	52.00	17.33	2.05	2.50	.50	3	.00	.00	.00	0	0	1	2	452.9	79.56	.90
2	13	55.00	13.75	2.59	3.67	.94	3	.00	.00	.00	0	1	1	2	255.4	63.73	.79
2	14	109.00	12.11	2.60	4.12	.60	3	.00	.00	.00	0	0	1	6	674.4	108.27	.72
2	15	59.00	9.83	3.29	4.00	.63	3	.00	.00	.00	0	0	1	3	431.3	86.78	.72
2	16	411.00	45.67	8.25	5.88	1.96	7	.00	.00	.00	0	0	1	2	3877.6	266.20	.69
2	18	760.00	84.44	28.15	7.00	1.50	2	.00	.00	.00	0	0	1	2	8382.4	412.25	.62
2	19	20.00	10.00	.00	5.00	.00	1	.00	.00	.00	0	0	0	2	1432.8	214.06	.39
2	20	280.00	46.67	28.60	6.25	2.49	8	.00	.00	.00	0	0	0	3	2183.4	217.59	.58
2	21	904.00	64.57	22.51	5.08	.28	10	.00	.00	.00	0	0	0	3	5809.5	318.79	.72
2	24	290.00	41.43	12.61	5.25	.43	1	20.00	20.00	.00	1	0	1	8	16077.6	532.24	.71
2	31	102.00	17.00	10.23	4.25	1.30	5	.00	.00	.00	0	0	1	1	2243.8	192.56	.76
2	35	672.00	48.00	18.82	5.33	.85	12	.00	.00	.00	0	0	0	2	12636.7	433.64	.84
2	38	95.00	31.67	9.43	5.00	.00	1	.00	.00	.00	0	0	1	2	6356.2	330.65	.73
2	40	440.00	44.00	12.98	6.75	1.85	9	.00	.00	.00	0	0	0	2	5651.8	317.61	.70
2	45	95.00	23.75	2.16	12.33	1.25	4	.00	.00	.00	0	0	1	4	2274.8	208.72	.66
2	50	1496.00	48.26	20.34	5.44	1.91	13	.00	.00	.00	0	0	1	7	13803.8	491.77	.72
2	55	289.00	20.64	1.67	3.08	1.14	11	.00	.00	.00	0	1	1	2	1387.2	149.62	.78

Boyken - Field classification measurements and HCA results

FIELD CLASS	POLYGON	AVERAGE SLOPE	UPPER ALTITUDE	LOWER ALTITUDE
1	1	5	2	1
1	8	16	7	5
1	22	17	12	3
1	32	6	17	14
2	2	5	1	1
2	3	5	1	1
2	4	7	2	2
2	5	7	2	2
2	6	8	3	2
2	7	18	4	3
2	9	19	8	7
2	10	19	8	7
2	11	18	8	8
2	12	18	10	9
2	13	19	9	9
2	14	16	10	9
2	15	15	10	10
2	16	13	10	9
2	18	14	12	9
2	19	14	10	9
2	20	12	11	9
2	21	15	11	8
2	24	14	8	5
2	31	5	14	14
2	35	11	17	14
2	38	10	10	15
2	40	9	16	14
2	45	10	15	13
2	50	16	15	12
2	55	24	10	9

Boyken - Field classification measurements and HCA results

FIELD CLASS	POLYGON	TOTAL RIG LENGTH	MEAN RIG LENGTH	SD RIG LENGTH	MEAN RIG WIDTH	SD RIG WIDTH	RIG SHAPE	TOTAL LYNCHET LENGTH	MEAN LYNCHET LENGTH	SD LYNCHET LENGTH	LYNCHET SHAPE	BOUN-DARY	TRUN-CATE	ASPECT	FIELD AREA	FIELD PERI-METER	FIELD SHAPE
2	56	172.00	24.57	1.05	2.00	.00	3	.00	.00	.00	0	0	1	2	447.5	88.01	.72
3	17	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	1	0	2522.8	216.36	.68
3	23	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	1	0	3809.3	273.54	.64
3	25	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	1	0	631.2	122.79	.53
3	26	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	1	0	4876.7	282.78	.77
3	33	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	0	0	600.7	179.60	.23
3	34	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	1	0	575.7	144.01	.35
3	36	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	1	0	905.3	181.54	.34
3	37	.00	.00	.00	.00	.00	0	.00	.00	.00	0	1	1	0	242.2	67.58	.67
3	39	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	0	0	2256.6	224.05	.56
3	41	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	0	0	1334.6	159.12	.66
3	42	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	0	0	1265.3	168.29	.56
3	43	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	0	0	965.7	171.57	.41
3	44	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	1	0	128.2	49.54	.66
3	46	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	1	0	581.6	159.51	.29
3	47	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	0	0	2565.1	296.74	.37
3	48	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	1	0	589.0	121.85	.50
3	49	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	1	0	1045.3	208.92	.30
3	51	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	1	0	858.6	147.96	.49
3	52	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	1	0	5310.9	290.65	.79
3	53	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	1	0	6417.1	313.55	.82
3	54	.00	.00	.00	.00	.00	0	.00	.00	.00	0	0	1	0	9510.7	582.58	.35
4	27	2612.00	118.73	36.90	5.62	2.55	14	140.00	140.00	.00	1	0	1	1	17430.4	554.05	.71
5	28	.00	.00	.00	.00	.00	0	920.00	83.64	39.68	3	0	1	1	34747.8	747.57	.78
5	30	.00	.00	.00	.00	.00	0	1184.00	45.54	33.71	5	1	0	9	34253.7	994.38	.44
6	29	1600.00	145.45	52.16	6.20	.75	4	1509.00	65.61	47.00	4	1	1	10	40246.9	901.02	.62

Boyken - Field classification measurements and HCA results

FIELD CLASS	POLYGON	AVERAGE SLOPE	UPPER ALTITUDE	LOWER ALTITUDE
2	56	18	7	6
3	17	16	12	10
3	23	20	11	8
3	25	20	11	11
3	26	24	11	9
3	33	13	17	16
3	34	14	16	15
3	36	24	14	14
3	37	19	15	14
3	39	7	16	15
3	41	7	16	15
3	42	8	16	15
3	43	6	15	15
3	44	8	15	15
3	46	10	15	13
3	47	6	15	15
3	48	7	15	15
3	49	6	15	14
3	51	23	12	10
3	52	21	13	10
3	53	19	13	10
3	54	18	13	10
4	27	14	9	5
5	28	16	10	5
5	30	14	13	10
6	29	17	14	11

Cleish - Field classification measurements and HCA results

FIELD CLASS	POLYGON	TOTAL RIG LENGTH	MEAN RIG LENGTH	SD RIG LENGTH	MEAN RIG WIDTH	SD RIG WIDTH	RIG SHAPE	BOUN-DARY	TRUN-CATE	ASPECT	FIELD AREA	FIELD PERI-METER	FIELD SHAPE	AVERAGE SLOPE	UPPER ALTITUDE	LOWER ALTITUDE
1	1	.00	00	00	.00	00	0	0	1	0	4151 40	270 22	.71	39	12	9
1	14	.00	00	00	00	.00	0	0	1	0	23679 50	623 18	77	49	11	3
1	15	00	00	00	00	00	0	0	1	0	13590 70	547 39	57	54	13	10
1	16	.00	00	00	.00	00	0	0	1	0	14707 20	500.73	74	29	15	13
1	17	.00	00	.00	00	00	0	0	1	0	9634.40	458.89	.57	40	8	1
1	18	.00	00	.00	00	00	0	0	1	0	679.00	106.57	.75	43	9	8
1	22	.00	.00	.00	.00	.00	0	0	1	0	10758.80	452.89	.66	45	10	3
1	23	.00	.00	.00	.00	.00	0	0	1	0	899.00	121.19	.77	49	11	9
1	24	.00	.00	.00	.00	.00	0	0	1	0	2008.10	185.65	.73	43	11	9
1	25	.00	.00	.00	.00	.00	0	0	1	0	3233.60	251.80	.64	34	13	11
1	26	.00	.00	.00	.00	.00	0	0	1	0	4477.00	274.03	.75	37	13	10
2	2	266.76	53.35	12.54	10.58	4.57	3	0	1	1	5414.80	286.70	.83	42	14	11
2	3	843.65	105.46	9.11	9.15	2.57	6	0	1	1	10273.90	398.12	.81	39	13	9
2	4	80.83	40.41	8.18	6.13	.00	1	0	1	1	4163.30	303.66	.57	34	14	12
2	5	480.05	96.01	5.88	10.91	5.90	1	0	1	1	7015.00	353.86	.70	41	13	9
2	6	334.10	66.82	17.53	14.46	4.51	1	0	1	1	6602.00	327.31	.77	37	15	13
2	7	361.39	180.70	8.82	14.76	.00	2	0	1	1	16267.30	577.99	.61	46	15	8
2	13	1166.02	145.75	6.20	5.72	1.79	2	0	1	1	9077.00	431.92	.61	33	15	12
2	19	132.41	66.20	19.08	6.82	.00	1	0	1	1	3116.10	253.16	.61	40	12	9
2	20	239.48	79.83	19.96	18.75	.00	5	0	1	1	9211.10	392.74	.75	46	9	3
2	21	782.14	86.90	22.53	11.46	1.78	3	0	1	1	12778.90	447.99	.80	42	13	8
3	8	189.32	23.66	12.76	25.94	38.42	1	0	1	1	4101.90	397.07	.33	33	10	8
3	11	50.72	10.14	1.02	9.89	1.86	1	0	1	1	1453.20	224.50	.36	24	15	15
3	12	175.78	19.53	4.57	5.57	2.38	6	1	1	1	2317.00	248.87	.47	50	12	8
4	9	1994.46	124.65	37.24	7.62	3.43	4	0	1	1	15998.50	535.02	.70	41	15	10
4	10	1489.11	148.91	36.39	9.40	1.41	1	0	1	1	16518.30	542.88	.70	32	15	10

Dúnan, Lewis - Field classification measurements and HCA results

FIELD CLASS	POLYGON	TOTAL RIG LENGTH	MEAN RIG LENGTH	SD RIG LENGTH	MEAN RIG WIDTH	SD RIG WIDTH	RIG SHAPE	BOUN-DARY	TRUN-CATE	ASPECT	FIELD AREA	FIELD PERI-METER	FIELD SHAPE	AVERAGE SLOPE	UPPER ALTITUDE	LOWER ALTITUDE
1	1	3870.75	26.33	15.56	6.31	1.66	4	1	0	4	67125.6	1201.83	.58	38	6	2
1	2	6191.21	61.91	110.64	6.32	1.76	4	1	0	1	56667.3	1066.34	.63	29	10	4
1	3	313.95	24.15	12.70	6.81	2.18	4	0	0	3	22223.5	957.01	.33	11	11	9
1	5	1457.41	66.24	32.00	6.60	1.16	4	1	0	1	7488.6	395.87	.60	6	11	10
1	6	578.65	44.51	21.41	5.92	1.20	4	1	0	2	9721.9	451.31	.60	21	11	10
1	8	2823.64	37.65	25.06	6.13	1.31	4	0	0	1	35058.6	869.90	.58	29	11	8
1	9	5132.88	45.42	25.89	6.21	1.77	4	1	0	1	41857.3	983.23	.54	27	10	6
2	4	475.24	31.68	7.57	4.04	1.03	5	0	1	2	2190.7	184.18	.81	14	11	10
2	10	542.11	18.07	9.22	6.83	2.50	4	1	1	1	8395.4	434.06	.56	22	5	2
2	11	179.62	14.97	16.02	5.62	1.12	4	0	0	1	6949.8	527.20	.31	22	2	1
2	12	82.49	20.62	3.28	8.56	.59	4	0	1	2	20986.5	647.97	.67	20	3	1
2	21	210.94	17.58	3.20	7.04	.97	4	1	1	6	13564.9	585.25	.50	21	2	1
3	7	.00	.00	.00	.00	.00	0	0	1	0	2019.9	173.60	.84	4	11	11
3	13	.00	.00	.00	.00	.00	0	0	1	0	254.6	62.22	.83	12	2	1
3	14	.00	.00	.00	.00	.00	0	0	1	0	149.5	45.76	.90	22	2	2
3	15	.00	.00	.00	.00	.00	0	0	1	0	405.4	79.56	.80	11	2	1
3	16	.00	.00	.00	.00	.00	0	0	1	0	146.6	45.48	.89	22	2	2
3	17	.00	.00	.00	.00	.00	0	0	1	0	347.0	69.87	.89	22	2	1
3	20	.00	.00	.00	.00	.00	0	0	1	0	14156.0	605.27	.48	16	2	1
4	18	8708.74	35.12	24.80	7.84	3.15	4	1	1	5	99450.5	1508.10	.55	19	6	1
5	19	.00	.00	.00	.00	.00	0	1	0	0	89540.1	1881.31	.32	30	8	1

Laughengie - Field classification measurements and HCA results

FIELD CLASS	POLYGON	TOTAL RIG LENGTH	MEAN RIG LENGTH	SD RIG LENGTH	MEAN RIG WIDTH	SD RIG WIDTH	RIG SHAPE	ASPECT	FIELD AREA	FIELD PERI-METER	FIELD SHAPE	AVERAGE SLOPE	UPPER ALTITUDE	LOWER ALTITUDE
1	1	749.00	35.67	5.36	4.56	.76	3	3	4111.38	266.98	.72	8	7	6
1	3	800.00	53.33	9.64	2.71	.70	15	3	2942.03	228.90	.70	8	8	7
1	4	2363.00	78.77	19.62	2.97	.84	3	4	7613.06	381.10	.66	9	9	7
1	6	200.00	18.18	5.52	2.70	.90	3	4	2808.60	215.29	.76	10	8	7
1	7	1273.00	41.06	6.61	2.33	.54	3	3	4056.00	252.50	.80	10	8	7
1	10	418.00	46.44	3.98	3.00	.50	3	3	1658.80	169.80	.72	9	9	8
1	11	1427.00	43.24	10.11	2.10	.30	3	3	3366.40	247.26	.70	7	10	9
1	19	270.00	33.75	11.36	4.14	.35	3	3	1818.73	172.59	.77	9	9	8
2	2	3664.00	51.60	29.92	3.46	.99	15	4	13717.30	567.93	.53	8	10	8
2	8	2803.00	87.59	25.46	2.51	.50	3	3	7911.40	365.53	.74	9	10	8
2	12	1790.00	71.60	18.75	3.79	.86	15	3	7182.45	332.65	.82	10	11	10
2	14	1999.00	51.26	15.63	2.83	.83	3	3	8170.89	419.40	.58	11	12	10
2	15	1960.00	61.25	14.36	4.59	7.52	3	3	7379.55	337.90	.81	9	12	10
2	16	2937.00	77.29	27.25	3.24	.89	3	3	10299.60	420.68	.73	9	10	9
2	17	4356.00	63.13	32.88	2.86	.87	3	3	23564.60	693.14	.61	8	11	8
2	18	3196.00	114.14	35.00	3.33	.94	3	3	12432.80	470.97	.70	9	10	8
3	5	.00	.00	.00	.00	.00	0	0	2593.68	221.36	.66	10	8	7
3	9	.00	.00	.00	.00	.00	0	0	362.00	74.19	.83	9	8	8
3	13	.00	.00	.00	.00	.00	0	0	699.60	107.55	.76	10	11	10

Learable - Field classification measurements and HCA results

FIELD CLASS	POLYGON	TOTAL RIG LENGTH	MEAN RIG LENGTH	SD RIG LENGTH	MEAN RIG WIDTH	SD RIG WIDTH	RIG SHAPE	BOUN-DARY	TRUN-CATE	ASPECT	FIELD AREA	FIELD PERI-METER	FIELD SHAPE	AVERAGE SLOPE	UPPER ALTITUDE	LOWER ALTITUDE
1	1	160.13	40.03	17.63	7.84	1.41	9	0	1	1	1738.3	242.34	.37	24	16	15
1	4	401.08	80.22	26.32	6.45	1.30	7	1	1	1	3829.4	290.91	.57	22	14	13
1	6	117.81	14.73	7.63	6.56	1.17	1	1	1	6	6075.2	413.18	.45	21	15	13
1	7	194.50	64.83	15.77	2.59	.20	3	1	1	1	1222.1	203.76	.37	19	12	13
1	13	123.02	41.01	2.18	5.10	.29	2	1	1	3	1838.4	197.26	.59	18	9	11
1	14	185.37	46.34	30.92	7.04	.97	2	1	0	5	2192.2	258.72	.41	34	9	10
1	20	263.52	43.92	9.15	6.45	1.81	7	0	1	1	2715.5	203.14	.83	23	13	13
1	21	37.57	37.57	.00	.00	.00	5	0	1	1	475.3	119.10	.42	22	12	13
1	24	659.49	65.95	44.22	6.35	1.43	15	1	1	1	6086.0	412.68	.45	22	10	6
1	25	218.78	43.76	17.18	7.00	1.04	14	1	1	1	2299.7	205.65	.68	29	13	6
1	26	245.45	49.09	24.28	6.57	.00	14	1	1	1	3353.6	319.77	.41	30	8	3
1	28	107.86	26.96	16.57	2.73	.00	3	1	1	1	892.6	201.07	.28	36	8	4
1	34	48.32	24.16	.28	7.93	.00	1	1	1	2	698.1	101.01	.86	24	5	6
1	39	155.93	17.32	5.41	7.13	1.32	10	0	1	4	5633.3	337.60	.62	22	13	11
2	2	225.30	56.32	20.96	8.47	.25	1	1	1	1	2244.6	221.66	.57	1000	15	15
2	3	149.08	49.69	26.40	8.30	3.45	1	1	1	1	3140.1	268.02	.55	1000	15	15
2	5	74.10	37.05	11.09	4.55	.00	4	1	1	1	1867.9	215.26	.51	1000	14	13
2	8	126.29	31.57	29.87	3.70	.62	3	1	1	1	1456.2	211.75	.41	1000	12	12
2	9	105.98	26.50	33.80	4.90	.00	1	1	1	1	1687.6	242.09	.36	1000	12	11
2	10	336.49	67.30	19.84	5.73	1.57	2	1	1	1	2339.7	219.16	.61	1000	11	11
2	11	370.25	92.56	25.87	6.32	.31	12	1	1	1	3702.0	354.37	.37	1000	11	8
2	16	332.89	30.26	14.76	4.35	1.04	8	1	1	4	2487.8	206.76	.73	1000	9	9
2	18	72.81	24.27	9.40	9.94	.00	1	1	1	1	1531.7	174.62	.63	1000	9	10
2	22	162.28	81.14	1.51	6.08	.00	2	1	1	2	1729.9	217.70	.46	1000	12	12
2	23	394.58	56.37	24.36	7.77	.87	2	1	1	2	4686.9	292.08	.69	1000	11	10
2	27	344.65	31.33	20.66	4.71	.88	16	1	1	1	3014.0	239.35	.66	1000	7	3
2	29	314.86	62.97	18.06	5.48	2.31	14	1	1	1	2460.7	220.41	.64	1000	7	4
2	32	128.65	42.88	28.44	8.79	.00	9	1	1	4	2158.8	211.33	.61	1000	8	9
2	36	489.70	61.21	10.60	6.11	1.53	13	1	1	2	4815.2	288.34	.73	1000	7	6
2	37	364.39	36.44	15.90	6.20	1.00	7	1	1	2	5039.5	354.57	.50	1000	9	7
3	12	.00	.00	.00	.00	.00	0	1	1	0	2276.1	251.15	.45	1000	11	12
3	15	.00	.00	.00	.00	.00	0	1	0	0	2659.9	253.95	.52	1000	8	10
3	17	.00	.00	.00	.00	.00	0	1	1	0	187.1	58.33	.69	1000	9	11
3	19	.00	.00	.00	.00	.00	0	1	1	0	922.9	127.31	.72	1000	11	13

Learable - Field classification measurements and HCA results

FIELD CLASS	POLYGON	TOTAL RIG LENGTH	MEAN RIG LENGTH	SD RIG LENGTH	MEAN RIG WIDTH	SD RIG WIDTH	RIG SHAPE	BOUN-DARY	TRUN-CATE	ASPECT	FIELD AREA	FIELD PERI-METER	FIELD SHAPE	AVERAGE SLOPE	UPPER ALTITUDE	LOWER ALTITUDE
3	30	.00	00	00	00	00	0	1	0	0	3174 6	605 37	.11	1000	7	2
3	31	00	00	00	00	00	0	1	1	0	1981.7	171.77	84	27	1	1
3	33	7 87	7 87	00	00	00	6	0	1	3	498 7	93 07	72	23	7	8
3	38	00	00	00	00	00	0	0	1	0	570 2	110 53	59	26	8	10
4	35	805 00	44 72	16 85	5 43	1 10	7	0	1	1	15819 5	698 37	41	1000	12	9

Appendix 2

Note: Horizon notation is according to the Soil Survey Handbook (Hodgson, 1976). Soil texture is assessed using the MAFF (1988) Agricultural Land Classification manual. Schematic soil profile diagrams are only provided where horizon sequences and depths are not uniform across the profile.

Boyken Soil Pit Descriptions

Profile Description: Trench 1, Polygon 56

(See Diagram)

Horizon	Depth	Description
Ah	0-5cm 0-8cm	Many roots (fine-large), few small stones, even distinct boundary. Colour: 10YR/3/2 Structure: Fine-medium subangular blocky Texture: Humose silt loam
Ap	5-40cm 5-42cm 8-39cm	Many stones (small-medium), many roots (fine), charcoal fragments throughout layer, slightly uneven boundary. Colour: 10YR/4/3, charcoal 7.5YR/2/1 Structure: Medium subangular blocky Texture: Silty clay loam
bAp	40-50cm 42-49cm 39-50cm	Many stones (small-medium), some fine roots, very gritty, gradual boundary. Colour: Rig: 10YR/4/3 Furrow: 10YR/4/2, mottles 7.5YR/4/4 and 7.5YR/4/6 Structure: Medium subangular blocky Texture: Silty clay loam
Bw	50-?	Many stones (medium-large), few fine roots. Colour: 10YR/5/6 Structure: Fine-medium subangular blocky Texture: Silty clay loam

Profile Description: Trench 5, Polygon 52

(No diagram)

South side of pit

Horizon	Depth	Description
Ah1	0-29cm	No distinct humic layer, many large and small roots, small-medium stones, fairly stony, much reworking by earthworms and soil fauna. Colour: 10YR/4/4 Structure: Small, subangular blocky Texture: Humose silty clay loam
Ah2	29-39cm	Quite stony (small-medium), many fine roots present, charcoal fragments. Colour: 10YR/3/3, charcoal 7.5YR/2/0 Structure: Small subangular blocky Texture: Silty clay loam
Bw	39-52cm	Stony (medium-large), some fine roots, lower part of horizon becoming very stony with a lot of shale throughout Colour: 10YR/5/6 Structure: Small subangular blocky Texture: Silty clay loam

Profile Description: Trench 5, Polygon 52 (Continued)
(No diagram)

North side of pit

Horizon	Depth	Description
Ah throughout,	0-30cm	No humic top layer. Stony (medium-large), many fine-large roots gradual uneven boundary to B. Colour: 10YR/4/4 Structure: Small subangular blocky Texture: Silty clay loam
Bw	30-48cm	Stony (small-medium), some fine roots. Colour: 10YR/5/6 Structure: Small subangular blocky Texture: Silty clay loam

Profile Description: Trench 6, Polygon 10
(See Diagram)

Horizon	Depth	Description
Ah	0-7cm 0-6cm	Many roots, few small stones, even distinct boundary. Colour: 10YR/2/1 Structure: Fine-medium subangular blocky Texture: Humose silt loam
Ap	6-14cm 7-15cm	Many roots (fine-large), some stones (small-medium), some slight downward mixing into next horizon in furrow, gradual boundary. Colour: 10YR/4/4 Structure: Medium subangular blocky Texture: Silty clay loam
bAp	15-43cm 14-28cm	Many stones (small-medium), some fine roots, gradual boundary. Colour: 10YR/5/4 Structure: Medium subangular blocky Texture: Silty clay loam
Bw	43-72cm 28-47cm	Many stones (small-large), few fine roots. Colour: 10YR/5/6 Structure: Medium subangular blocky Texture: Silty clay loam

Profile Description: Trench 7, Polygon 40
(No diagram)

Horizon	Depth	Description
Ah1	0-8cm	Many roots (fine-medium), few stones, deepening slightly to N end of pit (0-10cm), distinct even boundary Colour: 10YR/3/2 Structure: Medium subangular blocky Texture: Humose silty clay loam
Ah2	8-17cm	Many stones (medium-large) and many fine roots, very gradual boundary to B. Colour: 10YR/4/2 Structure: Small subangular blocky Texture: Silty clay loam
Bw	17-30cm	Very shaly (medium-large stones), few roots Colour: 10YR/4/4 Structure: Small subangular blocky Texture: Silty clay loam

Profile description: Trench 8, Polygon 38
(See diagram)

Profile 1 - across slope

Horizon	Depth	Description
Ah	0-7cm	Some small gritty stones, many medium-fine roots, fairly abrupt boundary to A. Colour: 10YR/3/3 Structure: Small subangular blocky Texture: Silty clay loam
Ah/Ap	7-21cm 7-24cm	Some small and medium stones, many fine roots. Colour: 10YR/4/3 Structure: Small subangular blocky Texture: Silty clay loam
Ap	14-26cm 7-21cm	More silty than 2nd horizon described above, some small-medium stones, some fine roots, gradual boundary with B horizon. Colour: 10YR/4/4 Structure: Small subangular blocky Texture: Silt loam
Bw	26-30cm	Many stones (small-large), high percentage of shale. Colour: 10YR/4/6 Structure: Small subangular blocky Texture: Silty clay loam

Profile description: Trench 8, Polygon 38 (Continued)
(See diagram)

Profile 2 - downslope

Horizon	Depth	Description
Ah	0-20	This horizon deepens from 7cm thick to 20cm thick across 1m downslope profile. Some small-medium stones, many fine-medium roots. Colour: 10YR/3/3 Structure: Small subangular blocky Texture: Humose silty clay loam
Ap	7-21cm 13-21cm	Horizon not continuous across 1m profile. Some small, stones, some fine roots, gradual boundary with B horizon. Colour: 10YR/4/4 Structure: Small subangular blocky Texture: Silt loam
Bw	20-30cm	Many stones (small-large), very shaly with solid bedrock at base. Colour: 10YR/4/6 Structure: Small subangular blocky Texture: Silty clay loam

Profile Description: Trench 10, Polygon 37
(No diagram)

Horizon	Depth	Description
Ah1	0-6cm	Gritty, many fine roots, abrupt boundary to A. Colour: 10YR/3/2 Structure: Small subangular blocky Texture: Humose silt loam
Ah2	6-17cm	Gritty, many fine roots, gradual boundary to B. This horizon not continuous across profile. Colour: 10YR/4/3 Structure: Small subangular blocky Texture: Silty clay loam
Bw	6-24	Many stones (medium-large), some fine roots. Colour: 10YR/4/4 Structure: Small subangular blocky Texture: Silty clay loam

Profile Description: Trench 11, Polygon 36
(No diagram)

Profile 1 - across slope

Horizon	Depth	Description
Ah1	0-9cm	Many roots, few small stones, distinct, even boundary. Colour: 10YR/4/3 Structure: Small subangular blocky Texture: Silty clay loam
Ah2/Ah1	9-30cm	Very mixed layer, evidence of severe bioturbation, many small-medium stones, some fine roots, very gradual boundary to B horizon. Colour: 10YR/4/4 Structure: Small subangular blocky Texture: Silty clay loam
Bw	30-40cm	Very stony (small-large), few roots. Colour: 10YR/5/6 Structure: Small subangular blocky Texture: Silty clay loam

Profile Description: Trench 11, Polygon 36 (Continued)
(No diagram)

Profile 2 - Downslope

Horizon	Depth	Description
Ah1	0-7cm	Few small stones, many fine roots, distinct, even boundary. Colour: 10YR/4/3 Structure: Small subangular blocky Texture: Humose silty clay loam
Ah2/Ah1	7-28cm	Mixed horizon, many small-medium stones, many roots, very gradual boundary to B horizon. Colour: 10YR/4/4 Structure: Small subangular blocky Texture: Silty clay loam
Bw	28-36cm	Few roots, many stones (small-large). Colour: 10YR/5/6 Structure: Small subangular blocky Texture: Silty clay loam

Profile Description: Trench 13, Polygon 22
(No diagram)

Horizon	Depth	Description
Ah1	0-8cm	Many roots, some small stones, distinct even boundary. Colour: 10YR/3/2 Structure: Fine subangular blocky Texture: Silt loam
Ah2/Ah1	8-19cm	Very mixed horizon, resulting in mixture of colours (appears to be from faunal activity and disturbance by bracken roots), many stones (small-medium), uneven indistinct boundary. Colour: 10YR/5/6, 10YR/3/2 Structure: Fine-medium subangular blocky Texture: Silty clay loam
Bw	19-36cm	Very stony (almost gritty, small-large), some roots. Colour: 10YR/5/6 Structure: Medium subangular blocky Texture: Silty clay loam

Profile Description: Trench 19, Polygon 47 (next to Trench 14)
(No diagram)

Horizon	Depth	Description
Ah1	0-5cm	Some small stones, many roots, thin iron pan at base, abrupt boundary. Colour: 10YR/2/1 Structure: Fine subangular blocky Texture: Humose silty clay loam
Ah2	5-24cm	Very stony (small-medium), many fine roots, abrupt boundary Colour: 10YR/5/6 Structure: Fine subangular blocky Texture: Silty clay loam
Ea	24-43cm	Very stony (small-medium), highly bleached, inorganic, many roots, gradual boundary. Colour: 10YR/5/4 Structure: Fine-medium subangular blocky Texture: Silty clay loam
Bt(g)	43-67cm	Very stony, some roots (small-large), some black mottles (charcoal?) Colour: 10YR/5/6, mottles 7.5YR/2/1 Structure: Fine-medium subangular blocky Texture: Silty clay loam

Profile Description: Trench 20, Polygon 22
(No diagram)

Horizon	Depth	Description
Ah	0-16cm	Many roots (fine-large), many stones (small), several bracken roots, distinct boundary. Colour: 10YR/4/2 Structure: Medium subangular blocky Texture: Humose silty clay loam
Ah/Bw(g)	16-31cm	Many roots (fine and large bracken), many stones (small-medium), horizon appears to be a mix between A & B, very gradual uneven boundary. Colour: 10YR/5/3 Structure: Medium subangular blocky Texture: Silty clay loam
Bw(g)	31-48cm	Some fine roots, many stones (small-large), gleying with red mottles, very compacted. Colour: 10YR/6/4 Structure: Medium subangular blocky Texture: Silty clay loam

Profile Description: Trench 21, Polygon 22
(No diagram)

Horizon	Depth	Description
Ah	0-18cm	Many fine-large roots, bracken roots across profile at ~13cm depth, many small-medium stones, larger stones associated with and under bracken root line, gradual boundary. Colour: 10YR/4/2 Structure: Medium subangular blocky Texture: Silty clay loam
Bw	18-50cm	Many fine roots, many stones (small-large), no mottling or gleying evident. Colour: 10YR/5/4 Structure: Fine subangular blocky Texture: Silty clay loam.

Profile Description: Trench 22, outwith polygons (above Polygon 22)
(No diagram)

Horizon	Depth	Description
Ah1	0-5cm	Many roots, some small stones, distinct boundary. Colour: 10YR/2/1 Structure: Medium subangular blocky Texture: Humose silty clay loam
Ah2	5-19cm	Many roots (fine-large), many small-large stones, gradual uneven boundary. Colour: 10YR/3/3 Structure: medium subangular blocky Texture: Silty clay loam
Bw	19-50cm	Many fine roots, many small-large stones. Colour: 10YR/5/6 Structure: Fine subangular blocky Texture: Silty clay loam

Profile Description: Trench 23, outwith polygons (above polygon 28)
(See diagram)

Horizon	Depth	Description
Ah1	0-6cm	Many roots (fine-medium), some small stones, distinct even boundary. Colour: 10YR/3/3 Structure: Fine subangular blocky Texture: Humose silty clay loam
Ah2	6-18cm	Many roots (fine-medium), many small-large stones, gradual boundary. Colour: 10YR/4/4 Structure: Medium subangular blocky Texture: Silty clay loam
Ah2/Bw (lighter areas)	6-18cm	Many fine-medium roots, many stones (small-medium), gradual boundary. Colour: 10YR/4/6 Structure: Medium subangular blocky Texture: Silty clay loam
Bw	18-47cm	Several fine roots, many small-medium stones. Colour: 10YR/5/6 Structure: Medium subangular blocky Texture: Silty clay loam

Profile Description: Trench 25, Polygon 30
(No diagram)

Horizon	Depth	Description
Ah1	0-5cm	Many roots, dense turf mat, few small stones, distinct even boundary. Colour: 10YR/2/1 Structure: Fine subangular blocky Texture: Humose silty clay loam
Ah2	5-7cm	Leached layer, many fine roots, few small stones, gradual uneven boundary. Colour: 7.5YR/3/2 Structure: Medium subangular blocky Texture: Humose silty clay loam
Ah3	7-29cm	Several fine roots, many stones (small-medium), gradual uneven boundary. Colour: 10YR/4/4 Structure: Fine subangular blocky Texture: Silty clay loam
Bw	29-37cm	Few fine roots, many small-large stones. Colour: 10YR/5/6 Structure: Fine-medium subangular blocky Texture: Silty clay loam.

Profile Description: Trench 26, Polygon 30
(No diagram)

Horizon	Depth	Description
Ah1	0-6cm	Dense turf mat, many fine-medium roots, few small stones, distinct uneven boundary. Colour: 10YR/3/2 Structure: Medium subangular blocky Texture: Humose silty clay loam
Ah2	6-26cm	Many fine roots, many stones (small-large), gradual uneven boundary. Colour: 10YR/5/4 Structure: Medium subangular blocky Texture: Silty clay loam
Bw	26-36cm	Few fine roots, many stones (small-large). Colour: 10YR/5/6 Structure: Medium subangular blocky Texture: Silty clay loam

Profile Description: Trench 27, Polygon 38
(See diagram)

Horizon	Depth	Description
Ah1	0-5cm	Many fine-medium roots, few small stones, abrupt even boundary. Colour: 10YR/3/1 Structure: Medium subangular blocky Texture: Humose silty clay loam
Ah2	5-33cm	Many fine roots, many small-large stones, gradual uneven boundary. Colour: 10YR/4/3 Structure: Medium subangular blocky Texture: Silty clay loam
Ah2/Ah1	4-26cm	Many fine roots, many small-large stones, distinct uneven boundary to both A and B. Colour: 10YR/3/4 Structure: Medium subangular blocky Texture: Silty clay loam
Bw	33-38cm	Some fine roots, many small-large stones. Colour: 10YR/5/6 Structure: Medium subangular blocky Texture: Silty clay loam

Profile Description: Trench 28, Polygon 47

(No diagram)

Horizon	Depth	Description
Ah1	0-8cm	Many fine-medium roots, few small stones, gradual even boundary. Colour: 10YR/3/2 Structure: Medium subangular blocky Texture: Humose silty clay loam
Ah2	8-25cm	Many fine roots, many small-medium stones, gradual uneven boundary. Colour: 10YR/5/4 Structure: Medium subangular blocky Texture: Silty clay loam
Bw	25-38cm	Some fine roots, many small-large stones. Colour: 10YR/5/6 Structure: Medium subangular blocky Texture: Silty clay loam

Profile Description: Trench 29, Polygon 52

(No diagram)

Horizon	Depth	Description
Ah1	0-8cm	Many fine-medium roots, few small stones, distinct uneven boundary. Colour: 10YR/3/2 Structure: Medium subangular blocky Texture: Silty clay loam
Ah2	8-18cm	Many fine-large roots, especially bracken (probably cause of mixed colour of this horizon), many sm-med stones,gradual indistinct and uneven boundary. Colour: 10YR/4/3, 10YR/4/4 Structure: Medium subangular blocky Texture: Silty clay loam
Bw	18-50cm	Several fine roots, many small-large stones, weathered bedrock at 50cm. Colour: 10YR/5/6 Structure: Medium subangular blocky texture: Silty clay loam

Profile Description: Trench 30, outwith polygon (SE of bottom corner of polygon 34)

(No diagram)

Horizon	Depth	Description
Ah1	0-5cm	Many fine-medium roots, few small stones, gradual even boundary. Colour: 10YR/3/3 Structure: Fine subangular blocky Texture: Humose silty clay loam
Ah2	5-15cm	Many fine-large roots, many small-large stones, gradual uneven boundary. Colour: 10YR/4/4, mottles 10YR/3/4 Structure: Medium subangular blocky Texture: Silty clay loam
Bw	15-40cm	Several fine roots, many small-large stones. Colour: 10YR/5/6 Structure: Medium subangular blocky Texture: Silty clay loam

Badentarbat Soil Pit Descriptions

Profile Description: Trench 32, Polygon 7
(See diagram)

Current Rig Profile

Horizon	Depth	Description
Of	0-8	Many fine/medium roots, no stones, gradual and even boundary. Colour: 10YR/2/2 Structure: Massive Texture: Peat
Op/Ap	8-24	Many fine roots, no stones, bleached quartz grains throughout, gradual even boundary Colour: 7.5YR/2.5/1 Structure: Subang blocky Texture: Loamy peat
Op2/Ap2	24-36 32-50	Many fine roots, one or two small stones, less quartz and wetter than above layer, distinct even boundary Colour: 7.5YR/2.5/1 Structure: Subang blocky Texture: Loamy peat
Ohh	36-49 50-57	Wetter layer, some fine roots, no stones, some black "smears", uneven abrupt boundary Colour: 10YR/3/2 Structure: Massive Texture: Peat
Bw(g)	49-56 57-70	Some fine roots, many small-large stones, some light mottling. Colour: 10YR/3/4, 10YR/6/4(M) Structure: Subang blocky Texture: Loamy sand

Current Furrow Profile (See diagram)

Horizon	Depth	General Features
Of	0-9	Many fine/medium roots, no stones apparent in profile but chaining arrow found several medium-large ones, distinct even boundary Colour: 10YR/2/1 Structure: Massive Texture: Peat
Of/Ap	9-23	Several fine/med roots, several med-large stones, distinct uneven boundary Colour: 10YR/4/3, 10YR/2/1(M) Structure: Coarse subangular blocky Texture: Peaty sand
Ap	23-29	Some fine roots, some medium-large stones, distinct uneven boundary Colour: 10YR/5/4 Structure: Medium subangular blocky Texture: Sand
Bw	29-47	Few roots, many weathered stones (medium-large) Colour: 10YR/4/4 Structure: Medium subang blocky Texture: Sand

Profile Description: Trench 34, Polygon 4
(See diagram)

Horizon	Depth	Description
Of	0-5 0-6	Many roots, no stones, even and distinct boundary. Colour: 10YR/2/2 Structure: Massive Texture: Peat
Op/Ap	5-20 6-30 6-40	Many roots, one or two stones, abrupt, distinct and even boundary Colour: 10YR/2/1 Structure: Coarse subangular blocky Texture: Loamy peat
Bw(g)	20-? 30-? 40-?	Many small-large stones, several fine-medium roots, mixed layer with black mottles. Colour: 7.5YR/4/3, 10YR/4/3(M), 10YR/2/1(M) Structure: Coarse subangular blocky Texture: Loamy sand

Profile Description: Trench 36, Polygon 5
(No diagram)

Horizon	Depth	Description
Of	0-9	Many roots, no stones, distinct even and abrupt boundary Colour: 10YR/2/2 Structure: Massive Texture: Peat
Op/Ap	9-45	Many roots, one medium stone, even abrupt boundary Colour: 10YR/2/2 Structure: Massive Texture: Loamy peat
Ohh	45-47	Few roots, no stones, distinct abrupt and even boundary Colour: Gley N2.5 Structure: Massive Texture: Peat
Om	47-63	Several roots, no stones, gradual even boundary Colour: 10YR/3/2 Structure: Massive Texture: Peat
Oh	63-66	Some roots, no stones, gradual even boundary to Colour: 10YR/2/1 Structure: Massive Texture: Peat
Bw	66-?	Sand, many small-large stones, several roots (humified?). Colour: 10YR/4/3 Structure: Coarse subangular blocky Texture: Loamy sand

Profile Description: Trench 38, Polygon 50
(No diagram)

Horizon	Depth	Description
Of1	0-10 0-7	Many roots, no stones, gradual boundary Colour: 10YR/2/2 Structure: Massive Texture: Peat
Of2	7-10	Many roots, no stones, distinct even boundary Colour: 10YR/2/1 Structure: Massive Texture: Peat
Op/Ap	10-66	Many roots, no stones, distinct, abrupt and uneven boundary Colour: 7.5YR/2.5/1 Structure: Massive Texture: Loamy peat
Bw	68-?	Many large stones, some roots, sandy. Colour: 10YR/4/3 Structure: Medium subangular blocky Texture: Loamy sand

Profile Description: Trench 42, Polygon 44
(No diagram)

Horizon	Depth	Description
Of	0-3 0-5	Many fine/medium roots, no stones, distinct even boundary Colour: 10YR/2/2 Structure: Massive Texture: Peat
Ap	3-40 5-25	Many fine roots, many small-medium stones, some black mottles, abrupt and even boundary Colour: 7.5YR/3/2 Structure: Fine-medium subangular blocky Texture: Sandy clay loam
Bw(g)	40-? 25-?	Some fine roots, many small-large stones, highly weathered. Colour: 7.5YR/3/3 Structure: Coarse subangular blocky Texture: Loamy sand

Profile Description: Trench 43, Polygon 40
(No diagram)

Horizon	Depth	General Features
Of	0-3 0-4 0-8	Many fine/medium roots, no stones, abrupt and even boundary Colour: 10YR/2/1 Structure: Fine-medium subang blocky Texture: Peat
Op	3-43 4-20 8-56	Many fine/medium roots, few small stones, abrupt and even boundary Colour: 10YR/2/1 Structure: Massive Texture: Peat
Bw(g)	43-? 20-? 56-?	Very few roots, gritty sand with many medium-large rounded sandstone boulders (weathered). Colour: 10YR/3/3 Structure: Coarse subangular blocky Texture: Loamy sand

Profile Description: Trench 44, Polygon 35
(See diagram)

Horizon	Depth	Description
Ah	0-6 0-7	Many fine/medium roots, few small stones, gradual even boundary Colour: 10YR/2/1 Structure: Fine subangular blocky Texture: Loamy peat
Ap	6-44 7-52 6-27	Many fine/medium roots, many small-medium stones, distinct uneven boundary Colour: 10YR/2/2 Structure: Fine subangular blocky Texture: Sandy clay loam
Bw	44-? 52-? 27-?	Many stones (small-large), few roots, gravely matrix. Colour: 7.5YR/3/3 Structure: Medium subangular blocky Texture: Sand(+grit)

Profile Description: Trench 45, Polygon 36
(See diagram)

Horizon	Depth	Description
Of	0-4 0-3	Many fine/medium roots, no stones, abrupt even boundary Colour: 10YR/2/1 Structure: Massive Texture: Peat
Ap	4-24 3-41	Many fine/medium roots, several small weathered stones, organic mineral soil, abrupt even boundary Colour: 10YR/2/1, 7.5YR/6/8(M), N2.5(M) Structure: Fine-medium subangular blocky Texture: Sandy clay loam
Ap2	11-21 4-17	Many fine/medium roots, few small stones, distinct uneven boundary to 2nd horizon. Colour: 10YR/2/1 Structure: Medium subangular blocky Texture: Sandy clay loam
Bw(g)	24-? 41-?	Very few roots, many small-large weathered stones. Colour: 7.5YR/4/3, 7.5YR/6/8(M), N2.5(M) Structure: Medium-coarse subangular blocky Texture: Loamy sand

Profile Description: Trench 46, Polygon 22
(See diagram)

Horizon	Depth	Description
Of	0-8	Many fine/medium roots, few small stones, gradual even boundary Colour: 10YR/2/1 Structure: Massive Texture : Peat
Op1/Ap	8-27	Many fine roots, few small stones, lot of bleached quartz grains, distinct uneven boundary Colour: 10YR/2/1 Structure: Massive Texture: Sandy peat
Ap	27-37	Some fine roots, few small stones, some mottling (from peat), gradual uneven boundary Colour: 7.5YR/2.5/2 Structure: Medium-coarse subangular blocky Texture: Loamy sand
Op2	37-60	Some fine roots, very few small stones, abrupt even boundary Colour: 10YR/2/1 Structure: Massive Texture: Loamy peat
BG	60-?	Several fine roots, gritty with medium-large boulders (rounded), heavily mottled and gleyed. Colour: 5Y/5/3(M), 10YR/4/4(M), 10YR/6/6(M), 10YR/2/2(M) Structure: Coarse subangular blocky Texture: Loamy sand

2Op	5-13	Many fine/medium roots, very few small stones, gradual boundary to horizons (furrow) above and below. Colour: 10YR/2/2 Structure: Massive Texture: Peat

Profile Description: Trench 47, Polygon 31

(No diagram)

Horizon	Depth	Description
Ah	0-5	Many fine/medium roots, few stones, gradual even boundary Colour: 10YR/3/2 Structure: Fine subangular blocky Texture: Humose sandy clay loam (with >50%OM)
Ap	5-70	Several fine roots, several small-large stones (many weathered), some black mottles Colour: 7.5YR/4/3 Structure: Fine-medium subangular blocky Texture: Sandy clay loam

Profile Description: Trench 49, Outwith polygons at NE of field system

(No diagram)

Horizon	Depth	Description
Of	0-18	Many fine/medium roots, no stones, several lenses of sandier material, abrupt even boundary Colour: 10YR/2/1 Structure: Massive Texture: Peat
Om	18-21	Many roots, as peat layer above but more humified and blacker (10YR/2/1 closest) Colour: 10YR/2/1 Structure: Massive Texture: Peat
Ah	21-33	Several roots, some weathered stones (small-medium), black lens at 26cm, abrupt even boundary Colour: 10YR/5/4 Structure: Apedal Texture: Loamy sand
Bw(g)	33-?	Several fine roots, several weathered oxidised stones Colour: 10YR/5/4, 10YR/6/6(M) Structure: Apedal Texture: Loamy sand

Profile Description: Trench 50, Outwith polygons at NW of field system
(No diagram)

Horizon	Depth	Description
Of	0-17	Many fine/medium roots, no stones, gradual even boundary Colour: 10YR/2/1 Structure: Massive Texture: Peat
Om	17-29	Many fine/medium roots (much less than above), no stones, gradual even boundary Colour: 10YR/2/1 Structure: Massive Texture: Peat
Oh/Ah	29-33	No stones, some fine roots, abrupt even boundary Colour: 5Y/2.5/1 Structure: Massive Texture: Loamy peat
Ah	33-45	Many small-large stones, few fine roots, abrupt even boundary Colour: 10YR/3/1 Structure: Coarse subangular blocky Texture: Peaty loam
Bw	45-?	Very few roots, many small-large stones. Colour: 10YR/5/3 Structure: Coarse subangular blocky Texture: Loamy sand

Profile Description: Trench 51, Polygon 22
(See diagram)

Rig profile

Horizon	Depth	Description
Of	0-30	Many fine/medium roots, many bleached quartz grains with 2-3 quartz pebbles, gradual indistinct but even boundary Colour: 10YR/2/1 Structure: Massive Texture: Peat
Op	30-85	Many fine roots, no stones, some bark/macroplant remains towards bottom, abrupt even boundary Colour: 5YR/2.5/2 Structure: Massive Texture: Peat
Bw	85-?	Many rounded stones, several roots Colour: 7.5YR/3/4 Structure: Medium subangular blocky Texture: Loamy sand

Furrow profile

Horizon	Depth	Description
Of	0-27	Many fine/medium roots, no stones, gradual distinct even boundary Colour: 10YR/2/1 Structure: Massive Texture: Peat
Op	27-63	Many fine/medium roots, no stones, abrupt even boundary Colour: 10YR/2/1 Structure: Massive Texture: Peat
Bw	63-?	Very few roots, many rounded stones. Colour: 7.5YR/3/4 Structure: Medium subangular blocky Texture: Loamy sand

Profile Description: Trench 52, Polygon 29
(No diagram)

Rig profile

Horizon	Depth	Description
Of1	0-19	Many fine/medium roots, no stones, gradual even boundary Colour: 10YR/2/1 Structure: Massive Texture: Peat
Of2	19-24	As above Colour: 10YR/3/2 Structure: Massive Texture: Peat
Of3	24-35	As above Colour: 10YR/2/2 Structure: Massive Texture: Peat
BG	35-52	Many fine roots, no stones, several black (44-50cm) bands, heavily gleyed. Colour: 10YR/3/2, 10YR/3/1 Structure: Massive Texture: Organic silty clay

Furrow profile (No diagram)

Horizon	Depth	Description
Of	0-37 0-33	Many fine/medium roots, no stones, abrupt even boundary Colour: 10YR/3/2 Structure: Massive Texture: Peat
BG	33-43	Several roots, some small stones. Colour: 10YR/5/4 Structure: Apedal Texture: Loamy sand

Profile Description: Trench 53, Outwith polygon to west of field system

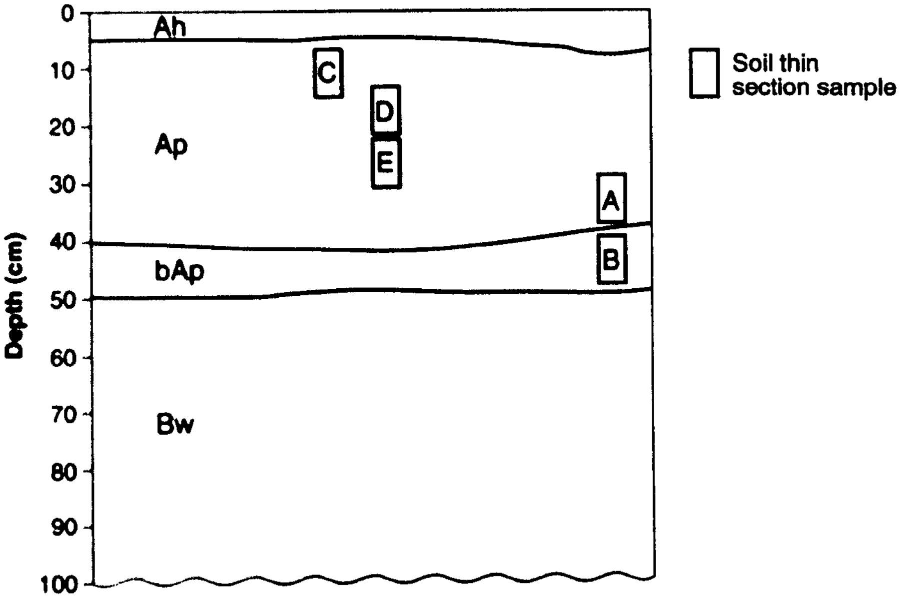
(No diagram)

Horizon	Depth	Description
Of	0-18	Many fine/medium roots, no stones, gradual even boundary Colour: 10YR/2/1 Structure: Massive Texture Peat
Ah	18-27	Several fine/medium roots, many bleached quartz grains, few small stones, abrupt even boundary Colour: 5YR/2.5/1 Structure: Apedal Texture: Loamy sand
Bw	27-37	Few fine roots, many small-large stones. Colour: 5YR/3/2 Structure: Apedal Texture: Loamy sand

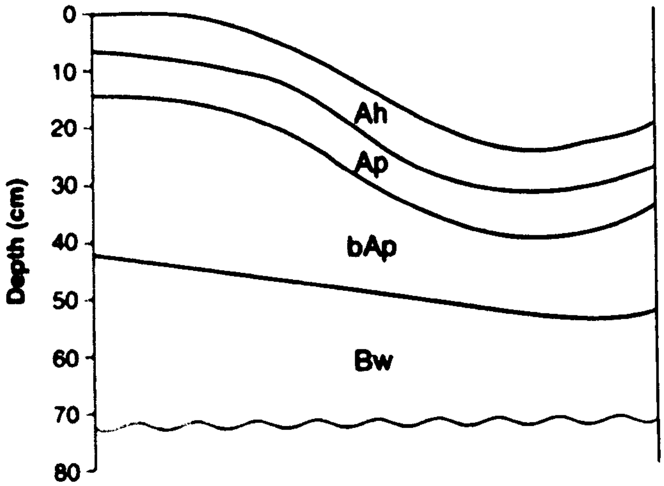
Profile Description: Trench 54, Polygon 45

(No diagram)

Horizon	Depth	Description
Ap	0-43	Many fine/medium roots throughout, several small-medium stones (rounded), many bleached quartz grains, gradual even boundary Colour: 10YR/2/1 Structure: Medium-coarse crumb Texture: Sandy clay loam
bAp	43-52	Several fine/medium roots, many small-large stones, abrupt even boundary Colour: 10YR/2/2 Structure: Medium subangular blocky Texture: Loamy sand
Bw	52-?	Several fine roots, several small-medium stones. Colour: 7.5YR/2.5/3 Structure: Medium subangular blocky Texture: Loamy sand

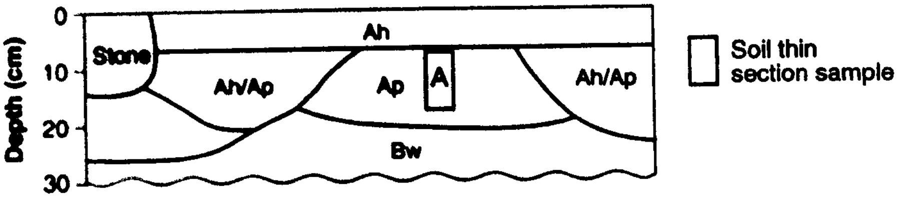


Trench 6/10 - Profile 1 : Across slope

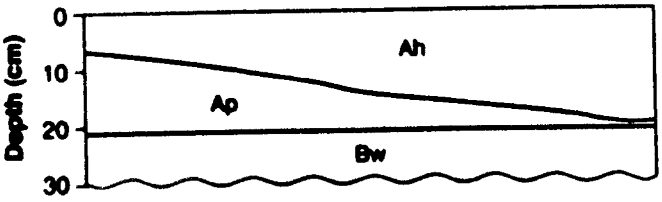


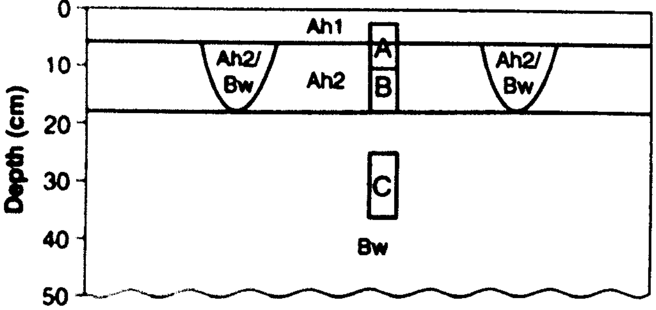
Note.
Samples taken
from Profile 2

Trench 8/38 : Across slope

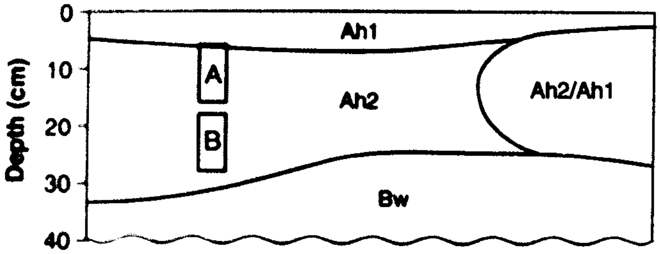


Trench 8/38 : Downslope

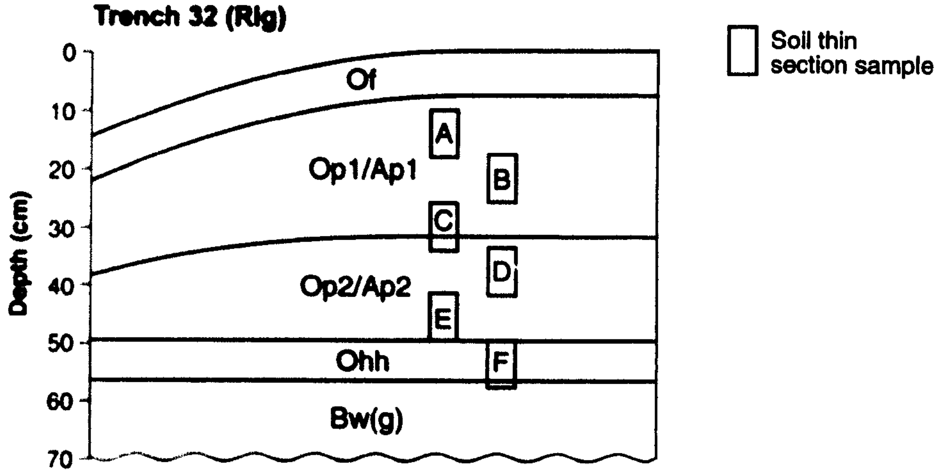




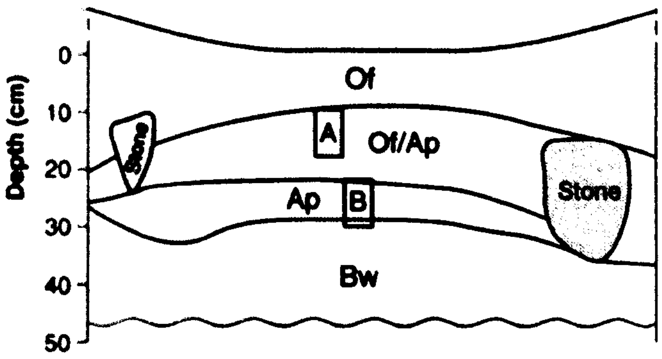
Trench 27/38



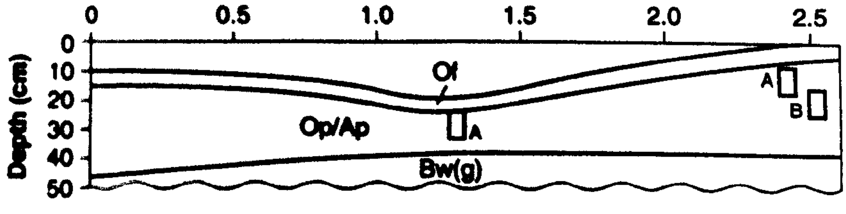
Trench 32 (Rig)

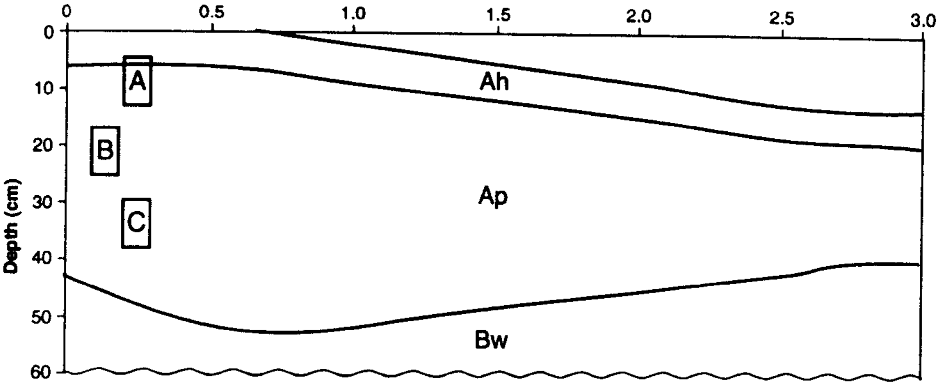


Trench 32 (Furrow)

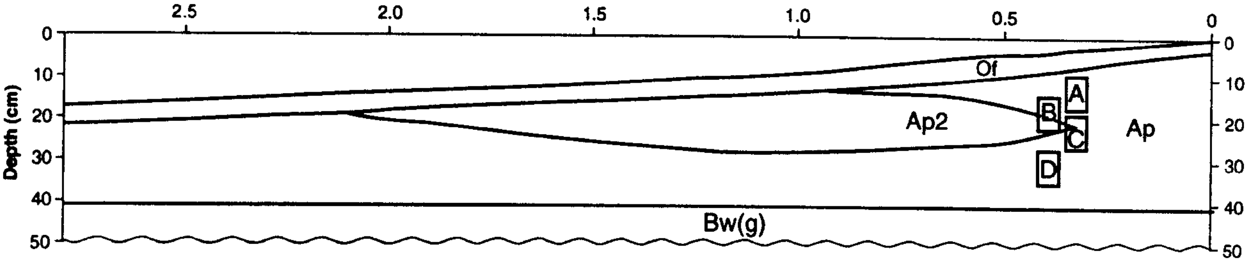


Trench 34

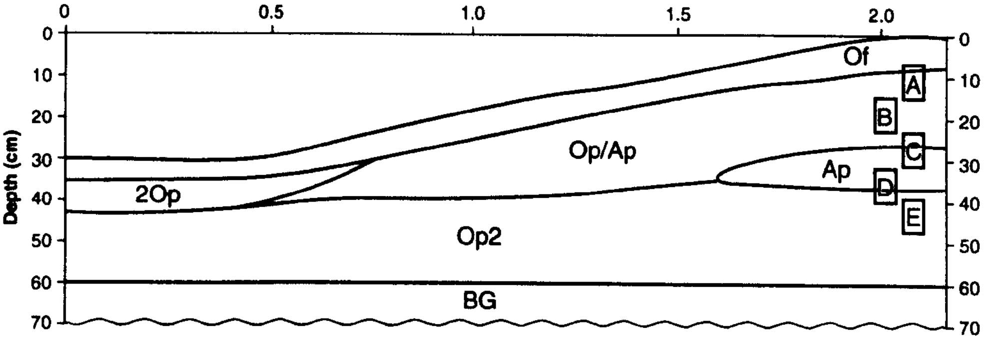




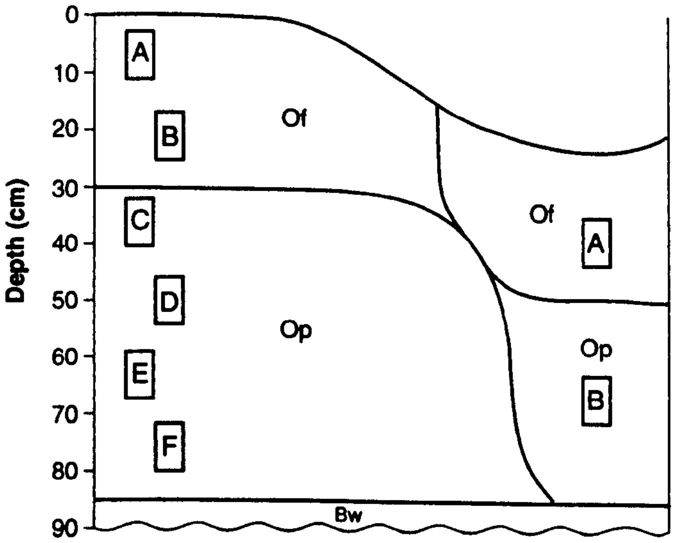
Trench 44



Trench 45



Trench 46



Trench 51

☐ Soil thin section sample

Appendix 3

Standard method of soil thin section preparation used at the Soil Micromorphology Laboratory at Stirling University.

Polyester or epoxy resins are generally used for impregnation which are immiscible with water (Kemp, 1985; Murphy, 1986). It is therefore necessary to remove all water contained in the soil samples. This can be achieved either by air- or oven-drying of the soils over a period of time or by exchanging the water in the soil samples with a substance which is miscible with the selected resin, such as acetone.

Air-drying is a lengthy process and cannot be used on soils which may shrink during drying, thus disturbing the soil structure. Oven-drying, although more rapid than air-drying, may also produce shrinkage, especially in fine-grained soils such as clays. The acetone exchange method limits the possibility of such shrinkage by directly exchanging the water held in the pores of the soil with acetone, thus maintaining the soil structure. This method also significantly cuts the time required for the production of soil thin sections and is the method routinely used in the Micromorphology Laboratory at Stirling University (http://www.stir.ac.uk/envsci/Thin).

The lids from the Kubiena tins are removed and the lower one is replaced with a perforated lid to allow the movement of water from, and acetone into, the sample. The samples are submerged in recovered acetone which is changed every 3-5 days. The recovered acetone is produced by re-distillation of previously used acetone to reduce the water content and is merely used as a cheap method of starting the acetone exchange process in the samples. The recovered acetone is used for the first 3-5 changes and pure "FSA" acetone is then used for the final stages. The water content of the acetone about to be discarded is checked before it is changed for the fifth-seventh time, using a densimetric method devised by Macleod (http://www.stir.ac.uk/envsci/Thin.wremoval.htm). The specific gravity of a range of control solutions containing 1-10% water in acetone was measured at the three most common ambient temperatures, namely 18°C, 20°C and 22°C, to produce a calibration curve for each temperature. A 100ml sample of the used acetone is extracted from the basin and placed in a measuring cylinder. The temperature of the sample is recorded and the specific gravity is measured using a 0.790-0.800 range hydrometer. This reading is checked against the calibration curve for the appropriate temperature to ascertain the percentage of water in the sample. The reading must be below 0.5% water content before impregnation of the soil samples can take place.

The acetone-saturated samples are drained and placed in heavy duty aluminium foil cartons which are marked with the identification and orientation details. A resin mixture is made up using the following ingredients in the given proportions:

B & K Crystic (polyester) resin No. 17449	180ml
B & K MEPK LA3 catalyst	1.8ml
Pure "FSA" acetone	25ml
Keystone Keyplast Blue A dye	0.6ml

The blue dye is used to ease the identification of pores in the soil sample from quartz grains under plane-polarized light. This mixture is multiplied to provide the required quantity of resin for impregnation.

Each carton containing a soil sample is then carefully filled with resin until the soil sample is completely submerged under at least 2-3cm of resin. The samples may have to be topped up several times during the first few minutes until a stable cover of resin is achieved. These samples are then placed in a desiccator attached to a vacuum pump via a cylindrical flask cooled with liquid nitrogen which condenses and collects the styrene and acetone vapours given off during the impregnation process. A vacuum is created in the desiccator which pulls the resin mixture into the soil pore spaces. This process takes up to one working day to complete and the samples require several top-ups of resin before full impregnation is indicated by a marked reduction in bubbling activity and the resin level remaining stable. The samples are then placed in a fume cupboard to cure for approximately 3 weeks. A final few days in an oven at 40°C and then 25°C completes the curing process. The solid resin-impregnated blocks can then be made into soil thin sections.

The soil blocks are cut lengthwise into slices using a Logitech CS10 circular diamond blade saw and water soluble coolant oil, taking care to note the orientation of the sample at all times. A slice from the middle of the block is chosen and one face is polished using a Logitech LP40 auto lapping plate and an abrasive slurry of silicon carbide 600 grit in either water, or ethane diol if the samples are peaty or particularly delicate . A large glass slide (1ccm x 7.5cm) held in a PLJ2 lapping jig is lapped on one side using the same apparatus to produce a slide of even thickness. The polished slice and the ground face of the glass slide are then bonded together using an epoxy bonding resin with the same refractive index as glass (μ=1.54) in the ratio of 3 parts resin to one part hardener and placed in a bonding jig overnight. The bonded soil slice and slide are held on a supporting arm by suction whilst the majority of the soil slice is cut off using the diamond saw, leaving only a few millimetres of impregnated soil bonded to the slide. This is further lapped in a PLJ2 lapping jig on the Logitech LP40 auto lapping machine using silicon carbide abrasive in water or ethane diol to a thickness of approximately 35µm. The slide is then coverslipped and placed in a bonding jig overnight to aid the bonding process and complete the soil thin section preparation process.

The different soils encountered at Boyken and Badentarbat resulted in two different sampling techniques being used in the field. The soils at Boyken are very stony and friable and Kubiena tins could not, therefore, be used. Monoliths, consisting of an entire column of the soil profile, were extracted and taken to the laboratory for processing into soil thin sections. The mainly peaty soils of Badentarbat allowed the use of Kubiena tins for sampling. However, the peaty nature of the soils required the use of special techniques during processing.

Appendix 4

Codes used for recording micromorphological data during soil thin section description.

Frequency classes - all soil thin section features except textural pedofeatures.

Code	Description of Frequency	Percentage range (%)
0	None	0
1	Trace	1
2	Very few	1-5
3	Few	6-15
4	Frequent	16-30
5	Common	31-50
6	Dominant	51-70
7	Very dominant	>70

Frequency classes for textural pedofeatures only

Code	Description of Frequency
0	None
1	Rare
2	Occasional
3	Many

Codes and associated descriptions for recording of the fine mineral material

Mineral Type		Mineral Colour		Limpidity	
Code	Description	Code	Description	Code	Description
1	Mineral	1	Red	1	Limpid
2	Organo-mineral	2	Yellowish brown	2	Speckled
		3	Brown to dark brown	3	Dotted
		4	Grey		
		5	Greenish to greyish green		
		6	Black		

Codes associated with different types of microstructure

Code	Type of Microstructure
1	Single grain
2	Pellicular
3	Vughy
4	Spongy
5	Channel
6	Chamber
7	Crumb
8	Subangular blocky
9	Angular blocky
10	Platy
11	Prismatic
12	Crack
13	Massive
14	Complex
15	Intergrain microaggregate

Codes for standard descriptions of basic distribution, groundmass b-fabric and related distribution as per Bullock *et al*, 1985.

Basic Distribution		Groundmass b-fabric		Related Distribution	
Code	**Description**	**Code**	**Description**	**Code**	**Description**
1	Random	1	Undifferentiated	1	Monic
2	Clustered	2	Crystallitic	2	Gefuric
3	Linear	3	Speckled	3	Chitonic
4	Banded	4	Striated	4	Enaulic
5	Fan-like	5	Strial	5	Porphyric
6	Interlaced				

Appendix 5

SECTION	SUBSCTN	QUARTZ	FELDSPAR	SANDSTNE	SILTSTNE	PHYTOLTH	BONE	CACO3	MNRLTYPE	MNRLCOLR	LIMPIDTY	FUNGAL	LIGNTISS	PRNCHTIS	ORGANRES	BIGCHRCL	FUNGLSML	AMORPBLK	A_YLW.OR	A_RD.BRN	CELLRESD	SLTCLYCT	CLAYCTGS	LPDCLYCT	A_C.NODL	A_C.CTGS	MAMEXCR	SPHREXCR	DEPLETN	MICROSTR	BASCDIST	BFABRIC	RELDISTR
1/56A	Upper	6	1	4	5	1	1	0	2	2	3	1	1	2	1	1	1	4	1	2	2	1	0	0	3	1	5	3	1	3	1	3	5
1/56A	Lwrleft	5	0	3	4	1	0	0	2	2	3	0	0	1	0	0	0	4	1	2	1	1	0	0	3	1	1	0	0	6	1	3	5
1/56B	All	6	3	5	5	0	1	0	2	2	3	1	0	1	0	1	1	3	1	1	1	1	2	2	3	3	4	2	1	4	1	3	2
1/56C	Upper	6	1	3	3	1	0	1	2	2	3	1	2	5	1	0	2	3	1	2	2	0	1	0	3	1	3	1	0	6	1	3	5
1/56C	Lower	6	1	3	2	1	0	1	2	2	3	1	1	2	2	1	1	2	0	1	2	0	0	0	3	1	4	3	0	6	1	3	5
1/56D	Upper	4	1	3	4	2	0	1	2	2	3	1	1	3	2	1	0	2	1	1	2	0	0	0	2	1	3	4	1	6	1	3	5
1/56D	Lower	4	1	2	3	2	0	1	2	2	3	1	1	2	2	1	1	3	2	1	2	0	0	0	2	0	3	2	1	6	1	3	5
1/56E	All	5	1	3	3	2	0	2	2	2	3	1	1	2	2	1	1	3	1	1	2	0	0	0	2	0	4	5	0	4	1	3	5
5/52A	All	5	1	2	1	1	0	0	2	2	3	1	1	2	3	1	2	2	0	1	1	0	0	0	2	1	3	5	1	4	1	3	5
5/52B	All	5	1	2	1	1	1	2	2	2	3	1	1	2	2	1	1	3	0	1	1	0	0	0	3	1	3	5	1	4	1	3	5
5/52C	All	5	1	2	1	2	0	1	2	2	3	2	2	2	1	0	1	2	1	2	1	0	0	0	2	1	3	2	0	6	1	3	5
5/52D	All	5	1	2	1	1	0	1	2	2	3	1	2	2	2	0	1	1	1	1	2	0	0	0	3	1	2	2	0	6	1	3	5
6/10A	All	5	1	2	2	2	0	2	2	2	3	1	1	2	3	0	2	1	2	2	2	0	0	0	1	0	2	5	0	5	1	3	5
6/10B	All	5	1	3	3	1	0	2	2	2	3	1	1	1	1	1	1	1	1	1	1	0	0	0	2	1	3	4	1	4	1	3	5
6/10C	All	5	1	4	3	1	0	1	2	2	3	1	1	1	1	0	1	1	0	0	1	0	0	0	3	1	3	4	0	4	1	3	5
6/10D	All	5	1	4	4	1	0	1	2	2	3	1	1	1	0	1	1	1	0	0	1	0	0	0	3	1	3	2	1	4	1	3	5
8/38A	All	5	1	4	4	0	0	2	2	2	3	1	0	2	0	0	1	1	0	1	1	1	0	0	2	1	3	4	0	6	1	3	5
11/36A	All	5	0	2	2	2	0	1	2	2	3	1	1	3	0	0	1	1	1	1	2	0	0	0	3	0	3	2	0	6	1	3	5
11/36B	All	5	1	3	2	1	0	1	2	2	3	1	0	2	0	0	1	1	0	1	2	0	0	0	3	2	3	2	0	6	1	3	5
11/36C	All	5	1	3	3	0	0	2	2	2	3	1	0	1	0	0	0	1	0	1	1	0	0	0	2	0	3	2	0	4	1	3	5
13/22A	Upper	5	1	4	4	2	0	1	2	2	3	1	2	3	2	0	1	1	1	1	1	0	0	0	2	0	4	4	0	5	1	3	5
13/22A	Lower	5	1	4	4	1	0	2	2	2	3	2	2	3	2	0	1	1	1	1	1	0	0	0	2	1	5	6	0	5	1	3	5
13/22B	All	5	1	4	4	1	0	2	2	2	3	2	1	2	1	0	1	1	0	1	1	0	0	0	2	0	5	5	0	4	1	3	5
19/47A	Upper	5	1	3	3	2	0	2	2	2	3	1	1	2	1	0	1	1	1	1	1	0	0	0	1	1	3	4	1	6	1	3	5
19/47A	Lower	5	1	2	2	2	0	1	2	2	3	1	1	3	1	0	1	1	1	1	2	0	0	0	1	1	3	4	0	5	1	3	5
19/47B	All	6	1	4	4	1	1	2	2	2	3	2	1	2	0	0	1	1	2	1	2	0	1	1	2	2	3	2	0	4	1	3	5
19/47C	All	5	1	2	2	1	0	1	2	2	3	1	0	0	0	0	1	1	1	1	1	0	0	0	3	1	1	0	1	4	1	3	5
19/47D	All	5	1	3	2	1	0	1	2	2	3	1	0	0	0	0	1	1	1	0	1	0	0	0	3	1	1	0	2	4	1	3	5
19/47E	All	5	1	3	2	1	0	1	2	2	3	1	0	1	0	0	1	1	2	1	1	0	0	0	3	2	2	0	2	5	1	3	5

Appendix 5 - Boyken Level 1 data

SECTION	SUBSCTN	QUARTZ	FELDSPAR	SANDSTNE	SILTSTNE	PHYTOLTH	BONE	CACO3	MNRLTYPE	MNRLCOLR	LIMPIDTY	FUNGAL	LIGNTISS	PRNCHTIS	ORGANRES	BIGCHRCL	FUNGLSML	AMORPBLK	A_YLW.OR	A_RD.BRN	CELLRESD	SLTCLYCT	CLAYCTGS	LPDCLYCT	A_C.NODL	A_C.CTGS	MAMEXCR	SPHREXCR	DEPLETN	MICROSTR	BASCDIST	BFABRIC	RELDISTR
19/47F	All	6	1	3	3	0	0	1	2	2	3	1	0	0	0	0	1	1	2	1	0	0	0	0	2	1	1	0	0	4	1	3	5
20/22A	All	5	1	2	3	2	0	1	2	2	3	2	1	2	1	0	1	1	1	1	1	0	0	0	3	1	2	1	0	6	1	3	5
20/22B	All	5	2	2	3	1	0	1	2	2	3	2	2	1	1	0	2	1	1	0	1	0	0	0	2	0	2	2	2	4	1	3	5
21/22A	All	5	1	4	4	1	0	1	2	2	3	1	1	2	1	0	1	1	1	1	2	0	0	0	2	1	2	3	1	6	1	3	5
21/22B	All	6	1	3	3	1	0	2	2	2	3	1	1	1	1	0	1	1	1	0	1	1	1	1	2	0	2	3	1	4	1	3	5
22A	All	4	1	2	2	1	0	1	2	2	3	1	1	3	1	0	1	1	1	1	3	0	0	0	3	1	3	4	0	5	1	3	5
22B	All	5	1	4	4	1	0	2	2	2	3	1	1	2	1	0	1	1	0	0	3	0	0	0	3	1	3	3	0	5	1	3	5
22C	All	5	1	4	4	1	0	2	2	2	3	1	1	2	1	1	1	1	0	1	2	0	0	0	2	1	3	3	0	5	1	3	5
23(1)A	All	5	1	2	1	1	0	1	2	2	3	1	1	2	1	0	1	1	1	0	2	0	0	0	2	0	3	3	0	6	1	3	5
23(1)B	All	5	1	2	1	1	0	0	2	2	3	1	2	2	1	0	1	1	1	1	2	0	0	0	2	1	3	3	1	6	1	3	5
23(1)C	All	5	1	3	3	1	0	0	2	2	3	1	0	1	1	0	1	1	0	0	1	0	1	0	2	0	2	2	1	4	1	3	5
23(2)A	All	5	1	3	2	1	0	1	2	2	3	1	1	3	1	0	2	1	1	1	2	0	0	0	2	0	2	2	0	6	1	3	5
23(2)B	All	5	1	3	2	1	0	0	2	2	3	1	2	1	1	0	1	1	2	1	1	0	0	0	2	0	2	3	0	4	1	3	5
25/30A	Upper	5	1	2	2	1	0	0	2	2	3	1	2	3	0	0	1	1	1	1	2	0	0	0	2	1	2	3	0	4	1	3	5
25/30A	Lower	5	1	3	3	1	0	1	2	2	3	1	0	2	1	1	1	1	0	1	2	0	0	0	2	1	1	2	1	4	1	3	5
25/30B	All	5	1	3	3	0	0	1	2	2	3	1	0	1	0	0	1	1	0	0	1	0	0	0	3	1	1	1	2	4	1	3	5
25/30C	All	5	1	2	4	1	0	2	2	2	3	1	0	1	1	0	1	1	0	0	1	0	0	0	2	1	2	1	1	4	1	3	5
26/30A	All	5	1	3	2	1	0	0	2	2	3	1	0	3	1	0	1	2	1	2	2	0	0	0	3	1	2	2	2	6	1	3	5
26/30B	All	5	2	3	2	1	0	2	2	2	3	1	1	2	0	1	1	1	1	1	2	0	0	0	2	1	1	1	1	4	1	3	5
27/38A	All	5	1	2	3	2	0	1	2	2	3	2	1	2	1	0	1	2	1	0	2	0	0	0	3	1	2	2	1	4	1	3	5
27/38B	All	5	1	2	2	1	0	1	2	2	3	2	1	2	0	0	1	2	0	0	2	0	0	0	3	1	3	3	1	4	1	3	5
28/47A	All	5	1	2	1	2	0	0	2	2	3	1	1	2	1	0	1	1	1	0	2	0	0	0	3	1	2	2	1	6	1	3	5
28/47B	All	5	1	3	3	1	0	2	2	2	3	1	0	1	1	0	1	1	0	1	2	0	0	0	1	0	2	2	1	4	1	3	5
29/52A	All	5	1	3	3	1	0	2	2	2	3	1	2	2	2	0	1	2	2	2	2	0	0	0	2	1	4	3	1	6	1	3	5
29/52B	All	5	1	3	3	1	0	2	2	2	3	1	1	2	2	0	1	3	1	1	2	0	0	0	3	1	4	4	1	4	1	3	5
30(1)A	All	5	1	2	2	1	0	0	2	2	3	1	2	5	2	0	1	3	1	2	3	0	0	0	1	0	2	3	0	6	1	3	5
30(1)B	All	5	1	5	3	1	0	0	2	2	3	1	1	2	2	0	1	2	0	1	2	0	0	0	2	0	4	3	1	6	1	3	5
30(2)A	All	5	1	3	2	1	0	1	2	2	3	1	1	4	2	0	1	1	1	1	3	0	0	0	2	0	3	4	0	6	1	3	5
30(2)B	All	5	1	4	3	1	0	1	2	2	3	1	1	2	0	0	1	2	1	2	3	0	0	0	1	1	3	3	0	6	1	3	5

Appendix 5 - Boyken Level 1 data

SECTION	SUBSCTN	QUARTZ	FELDSPAR	SANDSTNE	SILTSTNE	PHYTOLTH	DIATOMS	CACO3	MNRLTYPE	MNRLCOLR	LIMPIDTY	FUNGAL	LIGNTISS	PRNCHTIS	ORGANRES	BIGCHRCL	FUNGLSML	AMORPBLK	A_YLW.OR	A_RD.BRN	CELLRESD	SLTCLYCT	CLAYCTGS	LPDCLYCT	A_C.NODL	A_C.CTGS	MAMEXCR	SPHREXCR	MICROSTR	BASCDIST	BFABRIC	RELDISTR
32(F)A	Upper left	6	3	0	0	1	1	0	2	2	3	1	1	4	2	0	1	4	3	3	4	0	0	0	0	0	0	0	5	1	3	5
32(F)A	Upper right	6	3	0	0	1	1	0	2	2	3	1	0	5	3	0	1	3	5	4	3	0	0	0	0	0	0	0	5	1	3	5
32(F)A	Btm left	7	3	0	0	1	0	0	2	2	3	0	0	3	1	0	1	1	5	3	3	0	0	0	0	2	0	2	2	1	1	2
32(F)A	Btm right	7	3	0	0	0	0	0	2	2	3	1	0	2	0	0	1	1	4	2	3	0	0	0	0	0	0	0	3	1	3	2
32(F)B	Upper	7	3	0	0	1	0	0	2	2	3	1	0	2	1	0	0	1	5	2	2	0	0	0	1	0	0	1	2	1	3	2
32(F)B	Lower	7	3	0	0	0	0	0	1	4	3	0	0	0	0	0	0	1	2	0	0	0	0	0	2	3	0	1	2	4	1	2
32A	All	4	2	0	0	1	0	0	2	3	3	1	1	4	2	0	1	3	3	3	2	0	0	0	0	0	2	3	4	1	1	5
32B	All	4	2	0	0	0	0	0	2	3	3	1	2	4	0	1	1	3	2	3	3	0	0	0	1	0	1	2	4	1	1	5
32C	All	4	3	0	0	1	1	0	2	3	3	2	2	3	0	1	1	5	4	2	3	0	0	0	0	0	0	0	4	1	1	5
32D	All	4	3	0	0	1	0	0	2	3	3	2	2	3	1	0	1	5	4	2	4	0	1	0	0	1	0	1	3	1	1	5
32E	All	5	3	0	0	1	0	0	2	3	3	1	1	2	0	1	1	5	3	2	4	0	0	0	1	0	0	0	5	1	1	5
32F	Upper	5	3	0	0	1	2	0	2	3	3	1	1	2	0	0	1	5	2	1	3	0	0	1	1	0	0	0	5	1	1	5
32F	Lower	6	3	0	0	1	2	0	2	3	3	1	1	2	0	1	1	4	2	2	2	0	0	0	0	1	0	1	4	1	1	5
34(F)A	Upper	2	1	0	0	5	1	0	2	2	3	1	2	4	2	0	2	3	2	2	4	0	0	0	1	1	0	0	4	1	1	5
34(F)A	Lower	5	2	0	0	4	0	0	2	2	3	1	1	3	1	0	2	3	2	2	3	0	0	0	1	1	0	1	4	1	1	5
34A	All	5	2	0	0	1	0	0	2	2	3	1	1	3	1	0	1	3	2	2	3	0	0	0	0	1	1	1	4	1	1	5
34B	All	5	3	0	0	1	0	0	2	3	3	1	2	3	1	0	1	3	2	2	3	0	0	0	1	1	1	1	4	1	1	5
36A	All	3	1	0	0	3	2	0	2	2	3	1	1	4	2	0	1	3	4	4	4	0	0	1	0	1	3	4	4	1	1	5
36B	All	3	1	0	0	3	1	0	2	3	3	1	1	4	1	0	1	3	3	5	4	0	0	0	0	1	3	4	4	1	1	5
36C	All	3	1	0	0	4	1	0	2	3	3	1	1	4	1	0	2	3	3	5	4	0	0	0	0	0	2	3	4	1	1	5
36D	All	2	1	0	0	4	2	0	2	3	3	1	1	3	1	0	1	3	2	3	5	0	0	0	0	1	1	2	4	1	1	5
36E	All	2	1	0	0	2	2	0	2	3	3	2	0	1	0	0	1	1	1	2	2	0	0	0	0	0	0	0	4	1	1	5
38A	All	5	2	0	0	2	1	0	2	3	3	1	1	3	2	0	1	3	2	3	3	0	0	0	1	1	3	3	4	1	1	5
38B	All	5	3	0	0	2	1	1	2	3	3	1	1	3	2	0	1	3	3	4	3	0	0	0	1	1	1	2	4	1	1	5
38C	All	5	3	0	0	2	1	1	2	3	3	1	1	3	1	0	1	3	2	4	3	0	0	0	1	1	2	3	4	1	1	5
38D	All	5	3	0	0	2	1	1	2	3	3	1	0	3	0	0	1	3	3	3	3	0	0	0	0	0	2	3	4	1	1	5
38E	All	5	3	0	0	2	1	1	2	3	3	1	0	2	1	0	1	3	3	4	3	0	0	0	1	1	2	2	4	1	1	5
42A	All	6	4	2	0	2	0	1	2	3	3	1	1	1	0	0	1	2	0	0	2	0	1	1	2	3	2	1	15	1	3	2
42B	All	6	4	2	1	2	0	1	2	3	3	1	1	0	1	0	1	3	2	0	1	0	1	2	2	1	2	1	15	1	3	2
42C	All	6	4	2	0	1	0	1	2	3	3	1	1	1	0	1	0	3	2	0	1	0	0	0	2	1	2	1	15	1	3	2
43A	All	3	2	0	0	2	1	1	2	3	3	1	1	3	1	0	1	3	3	4	3	0	0	0	1	1	2	2	5	1	1	5

Appendix 5 - Badentarbat Level 1 data

SECTION	SUBSCTN	QUARTZ	FELDSPAR	SANDSTNE	SILTSTNE	PHYTOLTH	DIATOMS	CACO3	MNRLTYPE	MNRLCOLR	LIMPIDTY	FUNGAL	LIGNTISS	PRNCHTIS	ORGANRES	BIGCHRCL	FUNGLSML	AMORPBLK	A_YLW.OR	A_RD.BRN	CELLRESD	SLTCLYCT	CLAYCTGS	LPDCLYCT	A_C.NODL	A_C.CTGS	MAMEXCR	SPHREXCR	MICROSTR	BASCDIST	BFABRIC	RELDISTR
43B	All	3	2	0	0	1	1	0	2	3	3	1	1	2	1	0	1	4	3	3	2	0	0	0	1	1	0	1	12	1	1	5
43C	All	4	2	0	0	1	1	0	2	3	3	1	1	2	0	0	1	4	3	2	2	0	0	0	1	1	1	2	12	1	1	5
43D	All	4	3	0	0	1	1	0	2	3	3	0	1	1	1	0	1	4	2	3	2	0	0	0	1	1	0	0	4	1	1	5
44A	All	6	4	3	0	1	0	1	2	3	3	1	0	1	1	1	0	3	2	2	1	1	0	0	2	2	2	3	15	1	3	2
44B	All	6	4	3	1	2	0	1	2	3	3	1	0	1	1	1	0	3	1	2	1	0	0	0	3	2	2	3	15	1	3	2
44C	All	6	4	4	0	2	0	1	2	3	3	1	0	1	0	1	0	3	1	2	1	2	0	0	3	3	3	2	15	1	3	2
45A	All	6	4	3	0	2	0	1	2	3	3	1	2	2	2	0	1	3	2	1	2	0	0	0	2	2	4	3	15	1	3	2
45B	All	6	4	2	0	2	0	1	2	3	3	1	1	2	2	1	1	4	2	2	2	0	0	0	3	2	3	3	15	1	3	2
45C	All	6	4	1	0	1	0	1	2	3	3	1	1	3	2	2	1	4	2	2	2	0	0	0	3	3	3	2	15	1	3	2
45D	All	6	4	1	0	1	0	2	2	3	3	1	1	2	1	0	1	3	2	1	2	0	0	0	2	2	2	1	15	1	3	5
46A	All	5	4	1	0	2	0	1	2	3	3	2	1	3	2	1	1	2	1	2	2	0	0	0	1	2	2	0	4	1	1	5
46B	All	5	3	1	0	2	0	0	2	3	3	1	1	3	2	1	0	2	1	3	2	0	0	0	2	2	1	0	4	1	1	5
46C	Upper	6	3	1	0	2	1	1	2	3	3	1	0	2	1	0	1	2	1	1	3	0	0	0	2	2	0	1	4	1	1	5
46C	Lower	6	2	3	2	1	1	0	2	3	3	1	0	2	1	0	0	1	0	0	2	0	0	0	2	2	0	1	15	1	1	4
46D	Lower	6	3	1	1	1	1	2	2	3	3	1	0	2	0	1	1	3	2	3	1	0	0	0	2	1	2	3	15	1	1	4
46D	Upper	6	3	1	2	1	1	2	2	3	3	0	0	2	0	1	1	1	1	2	2	0	0	0	2	2	1	1	15	1	3	4
46E	Lower	5	2	0	2	2	2	1	2	3	3	1	0	3	1	1	1	2	1	1	3	0	0	0	0	1	1	2	4	1	1	5
46E	Top left	6	3	0	1	1	1	2	2	3	3	1	0	2	0	0	1	1	1	0	2	0	0	0	1	1	1	2	15	1	1	4
47A	All	6	2	0	2	2	0	1	2	3	3	2	0	2	1	1	1	1	2	1	2	0	0	0	3	2	4	3	15	1	3	4
47B	All	5	4	1	2	1	0	1	2	2	3	1	1	1	0	1	1	1	1	2	1	0	0	0	2	1	4	3	15	1	3	4
47C	All	5	4	1	3	1	0	1	2	2	3	1	0	0	0	1	1	1	1	1	1	1	0	0	2	1	3	2	15	1	3	4
47D	All	5	4	1	2	1	0	1	2	2	3	1	0	1	1	1	0	2	0	1	1	0	0	0	2	1	3	2	15	1	3	4
49A	All	3	1	1	1	2	1	1	2	3	3	2	1	5	2	1	2	3	2	3	4	0	0	0	1	0	3	2	4	1	1	5
49B	Upper	5	3	1	2	2	0	1	2	3	3	2	1	3	2	2	0	3	1	2	2	0	0	0	1	0	1	2	4	1	1	5
49B	Lower	2	1	0	0	1	0	0	2	3	3	1	1	2	2	1	0	3	1	1	1	0	0	0	1	1	1	0	4	1	1	5
49C	Upper	6	3	0	1	1	0	1	2	3	3	1	1	2	1	2	1	3	0	1	2	0	0	0	1	0	2	1	4	1	1	5
49C	Lower	7	4	1	1	1	0	1	2	3	3	1	0	1	1	0	1	2	1	0	1	0	0	0	1	0	2	2	14	1	3	4
50A	All	2	1	1	0	2	1	0	2	2	3	2	0	4	3	1	2	2	2	1	3	0	0	0	0	0	2	1	4	1	1	5
50B	All	2	1	0	1	1	1	0	2	2	3	2	2	4	2	1	2	3	1	0	3	0	0	0	1	0	0	1	4	1	1	5
50C	All	2	1	0	0	1	1	0	2	2	3	2	2	3	2	1	1	4	2	0	2	0	0	0	1	0	0	0	4	1	1	5
50D	Upper	3	1	1	0	1	1	0	2	3	3	1	1	3	2	0	2	3	1	0	3	0	0	0	0	0	0	0	4	1	1	5

Appendix 5 - Badentarbat Level 1 data

SECTION	SUBSCTN	QUARTZ	FELDSPAR	SANDSTNE	SILTSTNE	PHYTOLTH	DIATOMS	CACO3	MNRLTYPE	MNRLCOLR	LIMPIDTY	FUNGAL	LIGNTISS	PRNCHTIS	ORGANRES	BIGCHRCL	FUNGLSML	AMORPBLK	A_YLW.OR	A_RD.BRN	CELLRESD	SLTCLYCT	CLAYCTGS	LPDCLYCT	A_C.NODL	A_C.CTGS	MAMEXCR	SPHREXCR	MICROSTR	BASCDIST	BFABRIC	RELDISTR
50D	Lower	4	2	1	1	1	1	0	2	3	3	1	0	3	1	1	1	2	0	0	2	0	0	0	0	0	1	2	4	1	1	5
51(F)A	All	1	1	0	0	1	0	0	2	2	3	1	0	5	1	0	2	1	1	0	4	0	0	0	0	0	0	0	4	1	1	5
51(F)B	All	2	1	0	0	1	0	0	2	2	3	2	1	2	0	1	1	3	2	0	3	0	0	0	0	0	1	1	4	1	1	5
51A	All	4	2	1	2	1	0	1	2	3	3	2	0	2	1	0	2	4	2	2	2	0	0	0	0	0	3	1	4	1	1	5
51B	All	5	3	1	2	1	0	1	2	3	3	1	0	2	1	1	1	4	2	3	2	0	0	0	1	0	0	0	4	1	1	5
51C	All	2	1	0	0	1	0	0	2	3	3	2	0	3	1	1	3	3	2	2	3	0	0	0	0	0	3	1	4	1	1	5
51D	All	1	0	0	0	1	0	0	0	0	0	2	2	5	1	2	2	4	3	2	3	0	0	0	0	0	2	3	4	1	1	5
51E	Upper	2	2	1	2	1	0	0	2	2	3	2	1	3	0	1	1	3	1	1	3	0	0	0	0	0	1	2	4	1	1	5
51E	Lower	1	1	1	0	0	0	1	2	2	3	2	0	4	0	1	1	3	1	1	4	0	0	0	0	0	0	0	4	1	1	5
51F	All	1	1	1	0	1	1	0	2	2	3	2	2	4	0	1	1	4	2	1	4	0	0	0	0	0	0	0	4	1	1	5
52(F)A	All	2	1	0	0	1	0	0	2	2	3	1	1	2	1	1	2	3	1	3	2	0	0	0	0	0	1	2	4	1	1	5
52(F)B	Upper	5	2	1	1	1	1	2	2	3	3	1	1	2	0	1	1	2	3	2	2	0	0	0	0	0	0	0	4	1	3	5
52(F)B	Lower	4	2	0	0	1	1	3	2	5	3	0	0	2	1	0	1	2	1	2	2	0	0	0	1	0	0	0	4	1	3	5
52A	All	2	1	0	0	1	0	0	2	2	3	0	0	2	1	1	1	2	1	3	2	0	0	0	1	1	1	1	4	1	1	5
52B	All	2	1	0	0	1	0	1	2	2	3	1	0	2	1	0	1	2	1	3	2	0	0	0	1	0	2	2	4	1	1	5
52C	All	3	1	0	0	1	0	0	2	2	3	1	1	2	0	1	1	3	1	1	2	0	0	0	0	0	1	1	4	1	1	5
52D	All	3	2	1	1	1	1	1	2	2	3	1	1	1	1	1	1	3	1	1	1	0	0	0	1	1	1	0	4	1	1	5
52E	Lower	5	2	0	0	1	0	0	2	3	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	5	1	3	5
52E	Middle	7	3	1	1	1	0	1	2	3	3	0	0	1	0	0	0	1	0	0	1	0	0	0	1	0	0	0	4	1	1	5
52E	Upper	6	3	0	0	1	0	1	2	2	3	0	0	1	0	0	0	2	2	1	1	0	0	0	1	0	0	0	4	1	3	5
53A(1)	All	3	2	0	1	1	1	0	2	3	3	1	1	3	1	0	1	1	1	3	1	0	0	0	0	1	0	0	4	1	1	5
53B	All	6	3	1	1	1	0	1	2	3	3	1	1	1	1	0	0	2	1	3	1	0	0	0	0	1	0	0	4	1	1	5
53C	Middle	2	1	1	0	0	0	0	2	3	3	1	1	1	0	1	0	1	1	3	1	0	0	0	0	1	0	0	4	1	1	5
53C	Lower	6	3	1	1	1	0	1	2	3	3	0	1	1	1	1	0	1	1	1	1	0	0	0	1	1	1	1	15	1	1	4
53D	All	7	3	2	1	0	0	1	2	2	3	0	0	1	0	0	1	1	2	0	1	0	0	0	1	1	1	0	15	1	3	5
54A	All	5	4	1	1	3	1	0	2	2	3	1	1	1	1	1	1	2	1	1	1	0	0	0	1	1	1	1	15	1	3	5
54B	All	5	4	1	1	1	0	1	2	2	3	1	0	1	1	1	1	4	2	1	1	0	0	0	1	1	2	1	15	1	3	5
54C	All	5	4	1	1	1	1	1	2	2	3	1	0	1	0	1	1	3	2	2	1	0	0	0	1	1	2	1	15	1	3	5
54D	All	6	4	1	1	1	1	1	2	3	3	1	0	1	1	1	1	3	1	3	1	0	0	0	1	1	2	1	15	1	3	5

Appendix 5 - Badentarbat Level 1 data

Appendix 6

Appendix 6 - Boyken Level 2 data

SECTION	SUBSCTN	GRIDSQUAR	QRTZPERC	QRTZBASC	QRTZREFR	QRTZSHPE	SANDPERC	SANDBASC	SANDREFR	CELLPERC	CELLBASC	MAMLPERC	MAMLBASC	SPHRPERC	SPHRBASC	MICROSTR	RELDDIST
1/56A	Top	1	40	1	1	4	10	1	1	5	1	15	2	0	0	7	6
1/56A	Top	3	40	1	1	4	15	1	1	5	1	10	2	0	0	4	6
1/56A	Top	5	15	1	1	4	25	1	1	0	0	5	2	0	0	7	6
1/56A	Top	7	40	1	1	4	10	1	1	5	1	25	1	0	0	7	6
1/56A	Top	9	20	1	1	4	10	1	1	5	1	25	1	0	0	7	6
1/56A	Top	11	40	1	1	4	10	1	1	5	1	10	1	0	0	7	6
1/56A	Top	13	40	1	1	4	20	1	1	0	0	20	1	0	0	7	6
1/56A	Top	15	40	1	1	4	25	1	1	5	1	15	1	0	0	4	6
1/56A	Top	17	35	1	1	4	30	1	1	0	0	15	1	0	0	4	6
1/56A	Top	19	20	1	1	4	40	1	1	5	1	20	1	0	0	7	6
1/56A	Top	21	30	1	1	4	50	1	1	0	0	25	1	5	2	7	6
1/56A	Top	23	35	1	1	4	20	1	1	5	1	10	2	10	2	7	6
1/56A	Top	25	35	1	1	4	40	1	1	5	1	0	0	0	0	4	6
1/56A	Top	27	35	1	1	4	30	1	1	5	1	10	2	0	0	4	6
1/56A	Top	29	20	1	1	4	70	1	1	0	0	10	1	10	2	7	2
1/56A	Top	31	15	1	1	4	60	1	1	0	0	15	1	5	2	9	2
1/56A	Top	33	20	1	1	4	60	1	1	5	1	15	1	0	0	7	6
1/56A	Top	41	20	1	1	4	40	1	1	5	1	15	1	0	0	9	6
1/56A	Top	43	20	1	1	4	50	1	1	5	1	10	1	0	0	9	6
1/56A	Top	(1/2)45	5	1	1	4	85	1	4	0	0	0	0	0	0	7	6
1/56A	Btmlft	35	35	1	1	4	15	1	1	5	1	0	0	0	0	8	6
1/56A	Btmlft	37	35	1	1	4	15	1	1	0	0	0	0	0	0	8	6
1/56A	Btmlft	39	25	1	1	4	60	1	1	0	0	0	0	0	0	8	6
1/56A	Btmlft	(1/2)45	10	1	1	4	55	1	4	0	0	5	2	0	0	9	2
1/56A	Btmlft	47	5	1	1	4	85	1	3	0	0	0	0	0	0	8	6
1/56B	All	1	0	0	0	0	75	1	1	0	0	0	0	0	0	0	0
1/56B	All	3	15	1	1	4	40	1	1	5	1	5	2	0	0	9	2
1/56B	All	5	0	0	0	0	5	2	1	0	0	0	0	0	0	1	1
1/56B	All	7	20	1	1	4	80	1	1	5	1	10	2	0	0	9	4
1/56B	All	9	15	1	1	4	85	1	1	0	0	0	0	0	0	9	4
1/56B	All	11	0	0	0	0	80	1	1	0	0	0	0	0	0	0	0
1/56B	All	13	0	0	0	0	100	1	1	0	0	0	0	0	0	0	0
1/56B	All	15	20	1	1	4	75	1	1	0	0	5	2	0	0	9	2
1/56B	All	17	15	1	1	4	80	1	1	0	0	5	2	5	2	9	2
1/56B	All	19	10	1	1	4	80	1	1	5	2	5	2	5	2	9	2
1/56B	All	21	35	1	1	4	45	1	1	5	1	10	2	0	0	4	5
1/56B	All	23	5	1	1	4	50	1	1	0	0	0	0	0	0	4	5
1/56B	All	25	20	1	1	4	65	1	1	0	0	10	2	0	0	9	5
1/56B	All	27	25	1	1	4	55	1	1	0	0	5	2	0	0	9	5
1/56B	All	29	10	1	1	4	70	1	1	0	0	5	2	0	0	9	2
1/56B	All	31	30	1	1	4	60	1	1	0	0	10	1	5	2	9	2
1/56B	All	33	30	1	1	4	50	1	1	0	0	5	2	0	0	9	2
1/56B	All	35	20	1	1	4	45	1	1	0	0	0	0	0	0	9	2
1/56B	All	37	30	1	1	4	50	1	1	0	0	5	2	0	0	9	2
1/56B	All	39	35	1	1	4	50	1	1	0	0	10	1	0	0	9	2
1/56B	All	41	5	2	1	4	10	2	1	0	0	0	0	0	0	0	0
1/56B	All	43	0	0	0	0	35	2	1	0	0	0	0	0	0	0	0
1/56B	All	45	25	1	1	4	25	1	1	5	1	10	1	0	0	9	2
1/56C	Top	1	40	1	1	4	5	1	1	15	1	5	2	0	0	4	6
1/56C	Top	3	30	1	1	4	5	1	1	20	1	5	2	0	0	8	6
1/56C	Top	5	40	1	1	4	5	1	1	20	1	0	0	0	0	8	6
1/56C	Top	7	40	1	1	4	10	1	1	15	1	5	2	0	0	8	6
1/56C	Top	9	35	1	1	4	5	1	1	15	1	0	0	0	0	8	6

Appendix 6 - Boyken Level 2 data

SECTION	SUBSCTN	GRIDSQUAR	QRTZPERC	QRTZBASC	QRTZREFR	QRTZSHPE	SANDPERC	SANDBASC	SANDREFR	CELLPERC	CELLBASC	MAMLPERC	MAMLBASC	SPHRPERC	SPHRBASC	MICROSTR	RELDDIST
1/56C	Top	11	40	1	1	4	5	1	1	15	1	5	2	0	0	8	6
1/56C	Top	13	40	1	1	4	5	1	1	10	1	10	2	0	0	8	6
1/56C	Top	15	40	1	1	4	10	1	1	10	1	10	2	0	0	8	6
1/56C	Top	17	40	1	1	4	10	1	1	10	1	5	2	0	0	8	6
1/56C	Top	(1/2)19	20	1	1	4	5	1	1	5	1	0	0	0	0	8	6
1/56C	Top	21	40	1	1	4	10	1	1	5	1	10	2	0	0	8	6
1/56C	Bottom	(1/2)19	20	1	1	4	55	1	3	5	1	0	0	0	0	4	6
1/56C	Bottom	23	20	1	1	4	35	1	1	5	1	5	2	0	0	8	6
1/56C	Bottom	25	25	1	1	4	70	1	4	5	1	0	0	0	0	8	6
1/56C	Bottom	27	20	1	1	4	60	1	4	5	1	5	2	0	0	7	6
1/56C	Bottom	29	25	1	1	4	40	1	1	5	1	20	1	10	2	8	6
1/56C	Bottom	31	20	1	1	4	50	1	1	5	1	0	0	0	0	8	6
1/56C	Bottom	33	25	1	1	4	10	1	1	5	1	0	0	0	0	8	6
1/56C	Bottom	35	20	1	1	4	50	1	1	5	1	5	2	0	0	8	6
1/56C	Bottom	37	25	1	1	4	35	1	1	5	1	10	2	0	0	8	6
1/56D	Top	1	10	1	1	4	15	1	1	0	0	0	0	0	0	8	6
1/56D	Top	3	20	1	1	4	45	1	1	0	0	5	2	5	2	8	6
1/56D	Top	5	30	1	1	4	20	1	1	0	0	0	0	0	0	8	6
1/56D	Top	7	35	1	1	4	15	1	1	5	1	10	2	0	0	8	6
1/56D	Top	9	25	1	1	4	40	1	1	5	1	0	0	0	0	8	6
1/56D	Top	11	30	1	1	4	10	1	1	5	1	0	0	0	0	8	6
1/56D	Top	13	30	1	1	4	10	1	1	5	1	15	2	0	0	4	6
1/56D	Top	15	20	1	1	4	55	1	1	5	1	10	2	0	0	8	6
1/56D	Top	17	25	1	1	4	25	1	1	5	1	5	2	0	0	8	6
1/56D	Top	19	35	1	1	4	10	1	1	5	1	15	2	5	2	4	6
1/56D	Bottom	21	20	1	1	4	5	1	1	5	1	0	0	0	0	4	6
1/56D	Bottom	23	35	1	1	4	10	1	1	5	1	5	2	0	0	8	6
1/56D	Bottom	25	25	1	1	4	10	1	1	5	1	10	2	5	2	8	6
1/56D	Bottom	27	40	1	1	4	5	1	1	0	0	0	0	0	0	4	6
1/56D	Bottom	29	35	1	1	4	5	1	1	5	1	0	0	5	2	8	6
1/56D	Bottom	31	15	1	1	4	5	1	1	5	1	5	2	0	0	8	6
1/56D	Bottom	33	40	1	1	4	5	1	1	5	1	5	2	0	0	8	6
1/56D	Bottom	35	35	1	1	4	5	1	1	5	1	0	0	0	0	8	6
1/56D	Bottom	37	35	1	1	4	5	1	1	5	1	5	2	0	0	8	6
1/56D	Bottom	39	35	1	1	4	5	1	1	5	1	10	2	0	0	8	6
1/56E	All	1	25	1	1	4	10	1	1	5	1	15	2	10	2	8	6
1/56E	All	3	35	1	1	4	5	1	1	5	1	10	2	15	2	8	6
1/56E	All	5	15	1	1	4	55	1	1	5	1	15	2	0	0	8	6
1/56E	All	7	20	1	1	4	50	1	1	5	1	10	2	5	2	7	6
1/56E	All	9	35	1	1	4	10	1	1	5	1	20	2	5	2	7	6
1/56E	All	11	30	1	1	4	20	1	1	5	1	20	1	5	2	7	6
1/56E	All	13	30	1	1	4	5	1	1	5	1	10	2	0	0	8	6
1/56E	All	15	30	1	1	4	20	1	1	5	1	25	1	5	2	7	6
1/56E	All	17	30	1	1	4	30	1	1	5	1	15	1	0	0	7	6
1/56E	All	19	30	1	1	4	30	1	1	5	1	0	0	5	2	8	6
1/56E	All	21	35	1	1	4	10	1	1	5	1	25	1	10	2	7	6
1/56E	All	23	20	1	1	4	40	1	1	5	1	10	2	0	0	8	6
1/56E	All	25	25	1	1	4	30	1	1	5	1	10	2	5	2	7	6
1/56E	All	27	25	1	1	4	35	1	1	5	1	10	1	5	2	7	6
1/56E	All	29	25	1	1	4	35	1	1	5	1	5	2	0	0	7	6
1/56E	All	31	30	1	1	4	10	1	1	5	1	10	1	0	0	7	6
1/56E	All	33	35	1	1	4	10	1	1	5	1	10	2	5	2	7	6
1/56E	All	35	25	1	1	4	35	1	1	5	1	10	2	0	0	8	6

Appendix 6 - Boyken Level 2 data

SECTION	SUBSCTN	GRIDSQUAR	QRTZPERC	QRTZBASC	QRTZREFR	QRTZSHPE	SANDPERC	SANDBASC	SANDREFR	CELLPERC	CELLBASC	MAMLPERC	MAMLBASC	SPHRPERC	SPHRBASC	MICROSTR	RELDDIST
1/56E	All	37	35	1	1	4	5	1	1	5	1	10	2	0	0	8	6
1/56E	All	39	30	1	1	4	15	1	1	5	1	20	1	0	0	7	6
1/56E	All	41	30	1	1	4	15	1	1	5	1	15	1	5	2	7	6
5/52A	All	1	5	1	1	4	0	0	0	5	2	0	0	0	0	7	6
5/52A	All	3	25	1	1	4	5	1	1	10	1	15	1	0	0	7	6
5/52A	All	5	25	1	1	4	0	0	0	5	1	5	1	0	0	7	6
5/52A	All	7	25	1	1	4	30	1	4	5	1	10	1	0	0	7	6
5/52A	All	9	30	1	1	4	5	1	1	5	1	10	1	0	0	7	6
5/52A	All	11	20	1	1	4	0	0	0	5	1	5	1	0	0	7	6
5/52A	All	13	30	1	1	4	0	0	0	5	1	10	1	0	0	7	6
5/52A	All	15	35	1	1	4	5	1	1	5	1	10	1	5	1	7	6
5/52A	All	17	30	1	1	4	10	1	4	10	1	5	2	0	0	7	6
5/52A	All	19	35	1	1	4	0	0	0	5	1	10	1	0	0	7	6
5/52A	All	21	35	1	1	4	5	1	1	5	1	5	2	0	0	8	6
5/52A	All	23	30	1	1	4	25	1	4	5	1	0	0	0	0	4	6
5/52A	All	25	35	1	1	4	15	1	4	5	1	5	2	0	0	7	6
5/52A	All	27	30	1	1	4	10	1	1	5	1	5	1	0	0	7	6
5/52A	All	29	35	1	1	4	5	1	1	5	1	10	2	0	0	7	6
5/52A	All	31	25	1	1	4	5	1	4	0	0	0	0	0	0	7	6
5/52A	All	33	35	1	1	4	5	1	1	5	1	15	1	0	0	7	6
5/52A	All	35	35	1	1	4	10	1	4	5	1	5	1	0	0	7	6
5/52B	All	1	35	1	1	4	5	1	4	5	1	10	2	0	0	4	6
5/52B	All	3	35	1	1	4	5	1	4	0	0	5	1	0	0	4	6
5/52B	All	5	30	1	1	4	5	1	4	5	1	5	1	0	0	4	6
5/52B	All	7	35	1	1	4	5	1	1	5	1	10	1	0	0	4	6
5/52B	All	9	35	1	1	4	5	1	1	5	1	10	1	0	0	4	6
5/52B	All	11	35	1	1	4	5	1	1	5	1	10	2	0	0	7	6
5/52B	All	13	35	1	1	4	5	1	1	5	1	15	2	0	0	7	6
5/52B	All	15	35	1	1	4	5	1	4	5	1	15	2	0	0	7	6
5/52B	All	17	35	1	1	4	30	1	4	5	1	10	2	5	2	4	6
5/52B	All	19	35	1	1	4	5	1	4	5	1	20	2	5	2	4	6
5/52B	All	21	30	1	1	4	5	1	1	5	1	15	2	0	0	4	6
5/52B	All	23	20	1	1	4	60	1	4	5	1	5	2	0	0	7	6
5/52B	All	25	35	1	1	4	25	1	1	5	1	5	2	0	0	7	6
5/52B	All	27	30	1	1	4	40	1	1	5	1	10	2	0	0	4	6
5/52B	All	29	30	1	1	4	5	1	1	5	1	5	2	0	0	7	6
5/52B	All	31	35	1	1	4	10	1	1	5	1	0	0	0	0	7	6
5/52B	All	33	35	1	1	4	10	1	1	5	1	0	0	0	0	4	6
5/52B	All	35	30	1	1	4	10	1	1	5	1	0	0	0	0	7	6
5/52C	All	1	35	1	1	4	5	1	3	5	1	0	0	0	0	8	6
5/52C	All	3	35	1	1	4	5	1	4	10	1	0	0	0	0	8	6
5/52C	All	5	35	1	1	4	0	0	0	10	1	5	1	0	0	7	6
5/52C	All	7	35	1	1	4	10	1	4	10	1	10	2	10	2	7	6
5/52C	All	9	35	1	1	4	5	1	1	10	1	15	1	0	0	4	6
5/52C	All	11	35	1	1	4	5	1	4	10	1	0	0	5	2	7	6
5/52C	All	13	35	1	1	4	0	0	0	10	1	10	1	0	0	7	6
5/52C	All	15	35	1	1	4	5	1	1	10	1	10	2	0	0	7	6
5/52C	All	17	35	1	1	4	5	1	1	10	1	10	2	0	0	4	6
5/52C	All	19	35	1	1	4	0	0	0	10	1	5	2	0	0	8	6
5/52C	All	21	35	1	1	4	5	1	4	10	1	5	2	0	0	8	6
5/52C	All	23	35	1	1	4	5	1	1	5	1	0	0	0	0	8	6
5/52C	All	25	35	1	1	4	0	0	0	5	1	5	2	0	0	8	6
5/52C	All	27	35	1	1	4	5	1	3	5	1	5	1	0	0	7	6

Appendix 6 - Boyken Level 2 data

SECTION	SUBSCTN	GRIDSQUAR	QRTZPERC	QRTZBASC	QRTZREFR	QRTZSHPE	SANDPERC	SANDBASC	SANDREFR	CELLPERC	CELLBASC	MAMLPERC	MAMLBASC	SPHRPERC	SPHRBASC	MICROSTR	RELDDIST
5/52C	All	29	35	1	1	4	0	0	0	15	1	5	2	0	0	7	6
5/52C	All	31	25	1	1	4	30	1	4	5	1	5	2	0	0	8	6
5/52C	All	33	25	1	1	4	35	1	3	5	1	0	0	0	0	7	6
5/52C	All	35	35	1	1	4	5	1	1	5	1	5	2	0	0	8	6
5/52C	All	37	35	1	1	4	5	1	1	5	1	5	2	0	0	4	6
5/52C	All	39	35	1	1	4	10	1	1	5	1	0	0	0	0	8	6
5/52C	All	41	35	1	1	4	0	0	0	5	1	5	2	0	0	8	6
5/52C	All	43	35	1	1	4	5	1	2	5	1	0	0	0	0	8	6
5/52C	All	45	35	1	1	4	5	1	4	5	1	0	0	0	0	8	6
5/52C	All	47	35	1	1	4	5	1	4	5	1	5	2	0	0	8	6
5/52D	All	1	35	1	1	4	10	1	3	5	1	5	2	0	0	8	6
5/52D	All	3	35	1	1	4	35	1	3	5	1	10	2	0	0	7	6
5/52D	All	5	35	1	1	4	30	1	4	5	1	0	0	0	0	8	6
5/52D	All	7	35	1	1	4	5	1	1	5	1	0	0	0	0	7	6
5/52D	All	9	35	1	1	4	5	1	1	5	1	5	2	0	0	8	6
5/52D	All	11	35	1	1	4	5	1	4	5	1	5	2	0	0	8	6
5/52D	All	13	35	1	1	4	5	1	1	5	1	0	0	0	0	8	6
5/52D	All	15	35	1	1	4	5	1	4	5	1	5	2	0	0	8	6
5/52D	All	17	35	1	1	4	0	0	0	5	1	5	2	0	0	4	6
5/52D	All	19	35	1	1	4	5	1	1	5	1	5	2	0	0	8	6
5/52D	All	21	35	1	1	4	5	1	1	5	1	5	2	0	0	8	6
5/52D	All	23	35	1	1	4	5	1	1	5	1	10	2	0	0	7	6
5/52D	All	25	35	1	1	4	5	1	4	5	1	5	1	0	0	8	6
5/52D	All	27	35	1	1	4	10	1	1	5	1	5	2	0	0	4	6
5/52D	All	29	35	1	1	4	10	1	1	5	1	5	1	5	2	7	6
5/52D	All	31	35	1	1	4	5	1	4	5	1	5	2	0	0	8	6
5/52D	All	33	20	1	1	4	5	1	2	10	1	5	2	0	0	7	6
5/52D	All	35	35	1	1	4	10	1	1	5	1	5	2	0	0	8	6
5/52D	All	37	15	1	1	4	80	1	4	5	1	0	0	0	0	7	6
5/52D	All	39	35	1	1	4	0	0	0	5	1	5	2	0	0	7	6
5/52D	All	41	35	1	1	4	0	0	0	5	1	5	2	0	0	8	6
11/36A	All	1	20	1	1	4	5	1	1	10	1	0	0	0	0	8	6
11/36A	All	3	20	1	1	4	0	0	0	10	1	0	0	0	0	8	6
11/36A	All	5	20	1	1	4	0	0	0	10	1	0	0	0	0	8	6
11/36A	All	7	20	1	1	4	5	1	1	10	1	0	0	0	0	8	6
11/36A	All	9	20	1	1	4	5	1	1	10	1	0	0	5	2	8	6
11/36A	All	11	20	1	1	4	5	1	1	10	1	0	0	0	0	7	6
11/36A	All	13	20	1	1	4	0	0	0	5	1	0	0	5	2	8	6
11/36A	All	15	20	1	1	4	5	1	1	5	1	0	0	5	2	8	6
11/36A	All	17	20	1	1	4	5	1	1	5	1	5	2	5	2	8	6
11/36A	All	19	20	1	1	4	5	1	1	5	1	0	0	5	2	8	6
11/36A	All	21	20	1	1	4	5	1	1	5	1	0	0	0	0	8	6
11/36A	All	23	20	1	1	4	10	1	1	5	1	5	2	5	2	8	6
11/36A	All	25	20	1	1	4	5	1	1	5	1	5	2	0	0	8	6
11/36A	All	27	20	1	1	4	10	1	1	5	1	10	2	0	0	8	6
11/36A	All	29	20	1	1	4	15	1	1	5	1	5	2	0	0	8	6
11/36A	All	31	20	1	1	4	5	1	1	5	1	10	2	0	0	8	6
11/36A	All	33	20	1	1	4	5	1	1	5	1	0	0	0	0	8	6
11/36A	All	35	20	1	1	4	5	1	1	5	1	10	2	5	2	8	6
11/36A	All	37	20	1	1	4	15	1	1	5	1	0	0	5	2	8	6
11/36A	All	39	20	1	1	4	5	1	1	5	1	10	2	5	2	8	6
11/36A	All	41	20	1	1	4	5	1	1	10	1	10	2	0	0	8	6
11/36B	All	1	25	1	1	4	30	1	3	5	1	0	0	0	0	8	6

Appendix 6 - Boyken Level 2 data

SECTION	SUBSCTN	GRIDSQUAR	QRTZPERC	QRTZBASC	QRTZREFR	QRTZSHPE	SANDPERC	SANDBASC	SANDREFR	CELLPERC	CELLBASC	MAMLPERC	MAMLBASC	SPHRPERC	SPHRBASC	MICROSTR	RELDDIST
11/36B	All	3	15	1	1	4	15	1	3	5	1	0	0	0	0	8	6
11/36B	All	5	20	1	1	4	40	1	4	5	1	10	2	0	0	8	6
11/36B	All	7	25	1	1	4	10	1	3	5	1	0	0	0	0	8	6
11/36B	All	9	0	0	0	0	95	1	0	0	0	5	2	0	0	0	0
11/36B	All	11	0	0	0	0	100	1	0	0	0	0	0	0	0	0	0
11/36B	All	13	20	1	1	4	50	1	1	5	1	5	2	5	2	8	6
11/36B	All	15	20	1	1	4	30	1	4	5	1	0	0	0	0	7	6
11/36B	All	17	30	1	1	4	15	1	3	5	1	0	0	5	2	8	6
11/36B	All	19	30	1	1	4	15	1	1	5	1	5	2	0	0	8	6
11/36B	All	21	30	1	1	4	25	1	4	5	1	5	2	0	0	8	6
11/36B	All	23	20	1	1	4	30	1	1	10	1	5	2	0	0	8	6
11/36B	All	25	5	1	1	4	95	1	1	5	2	5	2	0	0	7	6
11/36B	All	27	30	1	1	4	10	1	4	5	1	5	2	5	2	8	6
11/36B	All	29	25	1	1	4	35	1	1	5	1	0	0	0	0	8	6
11/36B	All	31	30	1	1	4	0	0	0	5	1	5	2	0	0	8	6
11/36B	All	33	30	1	1	4	10	1	1	5	1	0	0	0	0	8	6
11/36B	All	35	20	1	1	4	40	1	1	5	1	5	2	0	0	8	6
11/36B	All	37	25	1	1	4	15	1	2	5	1	10	2	5	2	8	6
11/36B	All	39	25	1	1	4	20	1	1	5	1	0	0	0	0	8	6
11/36B	All	41	25	1	1	4	25	1	4	5	1	0	0	0	0	8	6
11/36B	All	43	25	1	1	4	45	1	1	5	1	5	2	0	0	8	6
11/36C	All	1	30	1	1	4	40	1	1	0	0	0	0	0	0	4	6
11/36C	All	3	25	1	1	4	15	1	1	0	0	0	0	0	0	4	6
11/36C	All	5	20	1	1	4	65	1	1	5	2	0	0	0	0	4	6
11/36C	All	7	35	1	1	4	10	1	1	0	0	0	0	0	0	4	6
11/36C	All	9	0	0	0	0	100	1	1	0	0	0	0	0	0	0	0
11/36C	All	11	20	1	1	4	75	1	1	5	2	5	2	0	0	4	6
11/36C	All	13	30	1	1	4	40	1	1	5	2	10	2	0	0	4	6
11/36C	All	15	20	1	1	4	45	1	1	0	0	5	2	0	0	4	6
11/36C	All	17	35	1	1	4	20	1	1	0	0	0	0	0	0	4	6
11/36C	All	19	35	1	1	4	5	1	1	0	0	0	0	0	0	4	6
11/36C	All	21	35	1	1	4	5	1	1	5	2	0	0	0	0	4	6
11/36C	All	23	35	1	1	4	5	1	1	0	0	0	0	0	0	4	6
11/36C	All	25	30	1	1	4	35	1	1	0	0	0	0	0	0	4	6
11/36C	All	27	35	1	1	4	10	1	1	0	0	5	2	0	0	4	6
11/36C	All	29	35	1	1	4	5	1	1	5	2	5	2	0	0	4	6
11/36C	All	31	35	1	1	4	10	1	1	0	0	5	2	0	0	4	6
11/36C	All	33	35	1	1	4	25	1	1	0	0	5	2	0	0	4	6
11/36C	All	35	20	1	1	4	70	1	1	0	0	5	2	0	0	4	6
11/36C	All	37	20	1	1	4	70	1	1	0	0	0	0	0	0	4	6
13/22A	Top	1	20	1	1	4	20	1	1	5	1	10	2	0	0	7	6
13/22A	Top	3	15	1	1	4	65	1	1	5	1	5	2	0	0	8	6
13/22A	Top	5	15	1	1	4	60	1	1	10	1	15	2	0	0	8	6
13/22A	Top	7	30	1	1	4	20	1	1	5	1	15	1	0	0	7	6
13/22A	Top	9	25	1	1	4	35	1	1	5	1	10	2	5	2	7	6
13/22A	Top	11	35	1	1	4	10	1	1	5	1	5	2	0	0	8	6
13/22A	Top	13	35	1	1	4	10	1	1	5	1	10	2	0	0	8	6
13/22A	Top	15	35	1	1	4	5	1	1	10	1	10	1	5	2	7	6
13/22A	Top	17	40	1	1	4	5	1	1	5	1	5	1	5	2	8	6
13/22A	Top	19	35	1	1	4	10	1	1	5	1	5	1	10	2	8	6
13/22A	Top	21	30	1	1	4	20	1	1	5	1	10	2	0	0	8	6
13/22A	Top	23	35	1	1	4	15	1	1	5	1	10	2	0	0	8	6
13/22A	Top	25	25	1	1	4	30	1	1	5	1	10	1	0	0	8	6

Appendix 6 - Boyken Level 2 data

SECTION	SUBSCTN	GRIDSQUAR	QRTZPERC	QRTZBASC	QRTZREFR	QRTZSHPE	SANDPERC	SANDBASC	SANDREFR	CELLPERC	CELLBASC	MAMLPERC	MAMLBASC	SPHRPERC	SPHRBASC	MICROSTR	RELDDIST
13/22A	Top	(1/2)27	35	1	1	4	10	1	1	5	1	5	2	0	0	8	6
13/22A	Top	(1/2)29	30	1	1	4	20	1	1	5	1	10	1	0	0	8	6
13/22A	Bottom	(1/2)27	35	1	1	4	10	1	1	5	1	15	1	0	0	8	6
13/22A	Bottom	(1/2)29	35	1	1	4	10	1	1	5	1	10	1	0	0	8	6
13/22A	Bottom	31	35	1	1	4	15	1	1	5	1	10	1	0	0	7	6
13/22A	Bottom	33	25	1	1	4	35	1	1	5	1	15	1	0	0	8	6
13/22A	Bottom	35	20	1	1	4	55	1	1	5	1	5	2	0	0	8	6
13/22A	Bottom	37	35	1	1	4	15	1	1	5	1	5	2	0	0	8	6
13/22A	Bottom	39	25	1	1	4	35	1	1	5	1	10	1	0	0	7	6
13/22B	All	1	20	1	1	4	40	1	1	5	1	15	1	0	0	7	6
13/22B	All	3	35	1	1	4	15	1	1	5	1	25	1	0	0	8	6
13/22B	All	5	15	1	1	4	60	1	1	5	1	10	2	0	0	8	6
13/22B	All	7	20	1	1	4	45	1	1	5	1	25	1	5	2	8	6
13/22B	All	9	30	1	1	4	25	1	1	5	1	10	1	0	0	8	6
13/22B	All	11	20	1	1	4	40	1	1	5	1	10	1	0	0	8	6
13/22B	All	13	35	1	1	4	10	1	1	5	1	45	1	0	0	7	6
13/22B	All	15	35	1	1	4	15	1	1	5	1	20	1	0	0	8	6
13/22B	All	17	25	1	1	4	40	1	1	5	1	10	1	0	0	8	6
13/22B	All	19	30	1	1	4	30	1	1	5	1	10	1	0	0	7	6
13/22B	All	21	35	1	1	4	15	1	1	5	1	5	2	0	0	8	6
13/22B	All	23	20	1	1	4	25	1	1	5	1	5	2	0	0	8	6
13/22B	All	25	30	1	1	4	20	1	1	5	1	15	1	5	2	8	6
13/22B	All	27	20	1	1	4	40	1	1	5	1	10	1	0	0	8	6
13/22B	All	29	20	1	1	4	50	1	1	5	1	5	1	0	0	8	6
13/22B	All	31	25	1	1	4	30	1	1	5	1	0	0	0	0	8	6
13/22B	All	33	35	1	1	4	10	1	1	5	1	5	2	0	0	8	6
13/22B	All	35	35	1	1	4	10	1	1	5	1	10	1	0	0	8	6
13/22B	All	37	20	1	1	4	50	1	1	5	1	5	2	0	0	8	6
13/22B	All	39	25	1	1	4	20	1	1	5	1	0	0	0	0	8	6
22A	All	1	35	1	1	4	5	1	1	5	1	0	0	0	0	8	6
22A	All	3	35	1	1	4	5	1	1	5	1	0	0	0	0	8	6
22A	All	5	40	1	1	4	5	1	1	5	1	5	2	0	0	8	6
22A	All	7	40	1	1	4	0	0	0	5	1	5	2	0	0	8	6
22A	All	9	40	1	1	4	0	0	0	5	1	0	0	20	1	8	6
22A	All	11	35	1	1	4	0	0	0	5	1	5	1	5	2	8	6
22A	All	13	35	1	1	4	5	1	1	5	1	5	1	20	1	8	6
22A	All	15	40	1	1	4	0	0	0	5	1	10	1	0	0	8	6
22A	All	17	40	1	1	4	5	1	1	5	1	15	2	0	0	7	6
22A	All	19	40	1	1	4	0	0	0	5	1	0	0	10	2	8	6
22A	All	21	35	1	1	4	5	1	4	5	1	0	0	0	0	7	6
22A	All	23	40	1	1	4	5	1	1	5	1	10	1	10	2	8	6
22A	All	25	15	1	1	4	60	1	1	5	1	5	1	5	1	8	6
22A	All	27	25	1	1	4	35	1	1	5	1	0	0	20	1	8	6
22A	All	29	35	1	1	4	5	1	1	5	1	10	2	5	2	8	6
22A	All	31	10	1	1	4	40	1	1	5	1	5	2	5	2	8	6
22A	All	33	15	1	1	4	35	1	1	5	1	10	1	10	2	8	6
22B	All	1	30	1	1	4	20	1	1	0	0	10	2	0	0	8	6
22B	All	3	0	0	0	0	100	1	1	0	0	0	0	0	0	0	0
22B	All	5	20	1	1	4	30	1	1	5	1	20	1	0	0	4	6
22B	All	7	15	1	1	4	60	1	1	5	1	10	2	0	0	7	6
22B	All	9	25	1	1	4	35	1	1	5	1	25	1	0	0	8	6
22B	All	11	20	1	1	4	45	1	1	5	1	10	1	0	0	8	6
22B	All	13	20	1	1	4	45	1	1	5	1	15	1	0	0	7	6

Appendix 6 - Boyken Level 2 data

SECTION	SUBSCTN	GRIDSQUAR	QRTZPERC	QRTZBASC	QRTZREFR	QRTZSHPE	SANDPERC	SANDBASC	SANDREFR	CELLPERC	CELLBASC	MAMLPERC	MAMLBASC	SPHRPERC	SPHRBASC	MICROSTR	RELDDIST
22B	All	15	20	1	1	4	40	1	1	5	1	5	2	0	0	7	6
22B	All	17	20	1	1	4	50	1	1	5	1	20	2	0	0	7	6
22B	All	19	20	1	1	4	20	1	1	5	1	5	2	0	0	8	6
22B	All	21	10	1	1	4	75	1	1	5	1	5	1	0	0	7	6
22B	All	23	30	1	1	4	30	1	1	5	1	25	1	0	0	7	6
22B	All	25	30	1	1	4	20	1	1	5	1	5	1	0	0	7	6
22B	All	27	30	1	1	4	30	1	1	5	1	15	2	0	0	7	6
22B	All	29	15	1	1	4	10	1	1	0	0	5	1	0	0	7	6
22B	All	31	20	1	1	4	45	1	1	5	1	15	1	0	0	7	6
22B	All	33	20	1	1	4	50	1	1	5	1	10	1	0	0	7	6
22B	All	35	30	1	1	4	30	1	1	5	1	5	2	0	0	7	6
22C	All	1	25	1	1	4	40	1	1	0	0	10	2	0	0	8	6
22C	All	3	30	1	1	4	30	1	1	5	1	10	2	0	0	8	6
22C	All	5	20	1	1	4	45	1	1	5	1	10	1	0	0	7	6
22C	All	7	25	1	1	4	35	1	1	5	1	10	2	0	0	8	6
22C	All	9	25	1	1	4	35	1	1	5	1	5	2	0	0	8	6
22C	All	11	30	1	1	4	25	1	1	5	1	5	2	0	0	8	6
22C	All	13	15	1	1	4	60	1	1	5	1	5	2	0	0	8	6
22C	All	15	25	1	1	4	40	1	1	5	1	10	1	0	0	4	6
22C	All	17	20	1	1	4	45	1	1	5	1	10	2	0	0	8	6
22C	All	19	30	1	1	4	25	1	1	5	1	5	2	0	0	4	6
22C	All	21	20	1	1	4	50	1	1	5	1	20	2	0	0	4	6
22C	All	23	30	1	1	4	25	1	1	5	1	5	2	0	0	4	6
22C	All	25	15	1	1	4	60	1	1	5	1	10	2	0	0	4	6
22C	All	27	20	1	1	4	45	1	1	5	1	10	2	0	0	4	6
22C	All	29	20	1	1	4	55	1	1	5	1	15	1	0	0	4	6
22C	All	31	15	1	1	4	60	1	1	5	1	10	2	0	0	4	6
22C	All	33	30	1	1	4	30	1	1	5	1	15	1	0	0	4	6
22C	All	35	20	1	1	4	45	1	1	5	1	10	1	0	0	4	6
26/30A	All	1	35	1	1	4	10	1	1	15	1	5	2	5	2	8	6
26/30A	All	3	35	1	1	4	5	1	1	15	1	0	0	0	0	8	6
26/30A	All	5	40	1	1	4	5	1	1	15	1	0	0	0	0	8	6
26/30A	All	7	40	1	1	4	0	0	0	10	1	5	2	0	0	8	6
26/30A	All	9	40	1	1	4	5	1	1	15	1	5	2	0	0	8	6
26/30A	All	11	40	1	1	4	5	1	1	15	1	5	1	0	0	8	6
26/30A	All	13	40	1	1	4	5	1	1	10	1	5	2	5	2	8	6
26/30A	All	15	40	1	1	4	5	1	1	10	1	5	1	5	2	8	6
26/30A	All	17	15	1	1	4	60	1	1	10	1	5	2	0	0	8	6
26/30A	All	19	35	1	1	4	10	1	1	10	1	5	2	0	0	8	6
26/30A	All	21	20	1	1	4	15	1	1	5	1	5	2	0	0	8	6
26/30A	All	23	0	0	0	0	100	1	1	0	0	0	0	0	0	0	0
26/30A	All	25	35	1	1	4	10	1	1	10	1	10	1	0	0	8	6
26/30A	All	27	20	1	1	4	40	1	1	10	1	5	2	0	0	8	6
26/30A	All	29	10	1	1	4	65	1	1	5	1	0	0	0	0	8	6
26/30A	All	31	10	1	1	4	65	1	1	5	1	10	1	0	0	4	6
26/30A	All	33	40	1	1	4	5	1	1	10	1	5	2	0	0	8	6
26/30A	All	35	40	1	1	4	5	1	1	5	1	0	0	0	0	8	6
26/30A	All	37	35	1	1	4	5	1	1	5	1	5	2	0	0	8	6
26/30A	All	39	5	1	1	4	85	1	4	5	1	0	0	0	0	4	6
26/30B	All	1	20	1	1	4	5	1	4	5	1	0	0	0	0	4	6
26/30B	All	3	35	1	1	4	5	1	1	5	1	0	0	0	0	4	6
26/30B	All	5	40	1	1	4	5	1	1	5	1	0	0	0	0	4	6
26/30B	All	7	30	1	1	4	20	1	1	5	1	0	0	0	0	4	6

Appendix 6 - Boyken Level 2 data

SECTION	SUBSCTN	GRIDSQUAR	QRTZPERC	QRTZBASC	QRTZREFR	QRTZSHPE	SANDPERC	SANDBASC	SANDREFR	CELLPERC	CELLBASC	MAMLPERC	MAMLBASC	SPHRPERC	SPHRBASC	MICROSTR	RELDDIST
26/30B	All	9	30	1	1	4	20	1	1	5	1	0	0	0	0	4	6
26/30B	All	11	35	1	1	4	10	1	1	5	1	5	2	0	0	4	6
26/30B	All	13	20	1	1	4	50	1	1	5	1	0	0	0	0	4	6
26/30B	All	15	35	1	1	4	10	1	1	5	1	5	2	0	0	4	6
26/30B	All	17	10	1	1	4	75	1	1	5	1	5	2	0	0	4	6
26/30B	All	19	10	1	1	4	75	1	1	5	1	0	0	0	0	4	6
26/30B	All	21	15	1	1	4	55	1	1	5	1	0	0	0	0	4	6
26/30B	All	23	15	1	1	4	60	1	1	5	1	0	0	0	0	4	6
26/30B	All	25	35	1	1	4	10	1	1	5	1	0	0	0	0	4	6
26/30B	All	27	25	1	1	4	40	1	1	5	1	0	0	0	0	4	6
26/30B	All	29	20	1	1	4	45	1	1	5	1	0	0	0	0	4	6
30(1)A	All	1	35	1	1	4	5	1	1	5	1	0	0	5	2	8	6
30(1)A	All	3	35	1	1	4	0	0	0	5	1	0	0	0	0	8	6
30(1)A	All	5	35	1	1	4	0	0	0	5	1	5	2	0	0	8	6
30(1)A	All	7	30	1	1	4	25	1	1	5	1	0	0	5	2	8	6
30(1)A	All	9	30	1	1	4	5	1	1	5	1	5	2	0	0	8	6
30(1)A	All	11	30	1	1	4	5	1	1	5	1	0	0	5	2	8	6
30(1)A	All	13	35	1	1	4	5	1	1	5	1	5	2	5	2	8	6
30(1)A	All	15	35	1	1	4	5	1	1	5	1	0	0	0	0	8	6
30(1)A	All	17	35	1	1	4	10	1	1	5	1	5	2	0	0	8	6
30(1)A	All	19	35	1	1	4	5	1	1	10	2	5	2	0	0	8	6
30(1)A	All	21	30	1	1	4	15	1	1	5	1	0	0	5	2	8	6
30(1)A	All	23	35	1	1	4	5	1	1	5	1	5	2	5	2	8	6
30(1)A	All	25	35	1	1	4	5	1	1	5	1	5	2	0	0	8	6
30(1)A	All	27	35	1	1	4	5	1	1	5	1	0	0	0	0	8	6
30(1)A	All	29	35	1	1	4	5	1	1	5	1	5	2	0	0	8	6
30(1)A	All	31	20	1	1	4	30	1	1	5	1	0	0	0	0	7	6
30(1)A	All	33	30	1	1	4	10	1	1	5	1	5	2	0	0	8	6
30(1)A	All	35	35	1	1	4	5	1	1	5	1	5	2	5	2	8	6
30(1)B	All	1	15	1	1	4	50	1	1	0	0	0	0	0	0	7	6
30(1)B	All	3	40	1	1	4	5	1	1	5	1	15	1	5	2	7	6
30(1)B	All	5	35	1	1	4	5	1	1	5	1	5	2	0	0	4	6
30(1)B	All	7	35	1	1	4	10	1	1	5	1	5	2	0	0	4	6
30(1)B	All	9	40	1	1	4	5	1	1	5	1	15	2	5	2	8	6
30(1)B	All	11	30	1	1	4	25	1	1	5	1	15	2	0	0	8	6
30(1)B	All	13	30	1	1	4	25	1	1	5	1	10	2	0	0	4	6
30(1)B	All	15	15	1	1	4	5	1	1	5	1	5	1	0	0	7	6
30(1)B	All	17	25	1	1	4	30	1	1	5	1	5	1	5	2	7	6
30(1)B	All	19	30	1	1	4	15	1	1	5	1	10	2	0	0	7	6
30(1)B	All	21	30	1	1	4	5	1	1	5	1	5	2	5	2	7	6
30(1)B	All	23	5	1	1	4	25	1	3	0	0	0	0	0	0	7	6
30(1)B	All	25	30	1	1	4	20	1	1	5	1	5	2	0	0	7	6
30(1)B	All	27	10	1	1	4	75	1	1	5	1	0	0	0	0	7	6
30(1)B	All	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30(1)B	All	31	5	1	1	4	35	1	1	0	0	0	0	0	0	7	6
30(1)B	All	33	0	0	0	0	100	1	1	0	0	0	0	0	0	0	0
30(1)B	All	35	5	1	1	4	80	1	1	5	1	5	2	0	0	7	6
30(1)B	All	37	5	1	1	4	90	1	1	0	0	0	0	0	0	7	6
30(1)B	All	39	5	1	1	4	90	1	1	0	0	0	0	0	0	7	6

Appendix 6 - Badentarbat Level 2 data

SECTION	SUBSCTN	GRIDSQUAR	QRTZPERC	QRTZBASC	QRTZREFR	QRTZSHPE	SANDPERC	SANDBASC	SANDREFR	CELLPERC	CELLBASC	MAMLPERC	MAMLBASC	SPHRPERC	SPHRBASC	MICROSTR	RELDDIST
36A	All	1	5	1	1	4	0	0	0	15	1	20	1	0	0	4	6
36A	All	3	10	1	1	4	5	1	1	15	1	20	1	5	1	4	6
36A	All	5	10	1	1	4	0	0	0	15	1	25	1	0	0	4	6
36A	All	7	10	1	1	4	0	0	0	15	1	20	1	5	1	4	6
36A	All	9	10	1	1	4	0	0	0	20	1	20	1	5	1	4	6
36A	All	11	10	1	1	4	5	1	1	20	1	25	1	0	0	4	6
36A	All	13	10	1	1	4	0	0	0	20	1	20	1	5	1	4	6
36A	All	15	10	1	1	4	0	0	0	20	1	25	1	0	0	4	6
36A	All	17	10	1	1	4	0	0	0	15	1	20	1	5	2	4	6
36A	All	19	10	1	1	4	5	1	1	15	1	20	1	5	1	4	6
36A	All	21	10	1	1	4	0	0	0	15	1	15	1	10	2	4	6
36A	All	23	10	1	1	4	0	0	0	15	1	20	1	5	1	4	6
36A	All	25	15	1	1	4	5	1	1	15	1	20	1	5	1	4	6
36A	All	27	10	1	1	4	0	0	0	15	1	20	1	5	1	4	6
36A	All	29	5	1	1	4	0	0	0	15	1	20	1	5	1	4	6
36A	All	31	5	1	1	4	0	0	0	10	1	15	1	5	1	4	6
36A	All	33	10	1	1	4	0	0	0	15	1	15	1	5	1	4	6
36A	All	35	10	1	1	4	0	0	0	10	1	20	1	5	1	4	6
36B	All	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36B	All	3	10	1	1	4	0	0	0	10	1	20	1	10	1	4	6
36B	All	5	10	1	1	4	5	1	1	10	1	20	1	0	0	8	6
36B	All	7	10	1	1	4	0	0	0	10	1	20	1	5	2	4	6
36B	All	9	5	1	1	4	0	0	0	10	1	15	1	5	1	4	6
36B	All	11	5	1	1	4	0	0	0	10	1	15	1	5	1	4	6
36B	All	13	10	1	1	4	0	0	0	10	1	15	1	5	1	4	6
36B	All	15	10	1	1	4	0	0	0	10	1	15	1	5	1	4	6
36B	All	17	10	1	1	4	0	0	0	10	1	15	1	5	1	4	6
36B	All	19	10	1	1	4	0	0	0	10	1	10	1	5	1	4	6
36B	All	21	10	1	1	4	0	0	0	10	1	10	1	5	1	4	6
36B	All	23	10	1	1	4	0	0	0	10	1	10	1	5	1	4	6
36B	All	25	10	1	1	4	0	0	0	10	1	10	1	5	1	4	6
36B	All	27	10	1	1	4	0	0	0	10	1	10	1	0	0	4	6
36B	All	29	10	1	1	4	0	0	0	10	1	10	1	0	0	4	6
36B	All	31	10	1	1	4	0	0	0	10	1	5	1	5	1	4	6
36B	All	33	10	1	1	4	0	0	0	10	1	5	1	5	1	4	6
36B	All	35	10	1	1	4	0	0	0	10	1	5	1	5	1	4	6
36C	All	1	5	1	1	4	0	0	0	10	1	10	1	10	1	4	6
36C	All	3	5	1	1	4	0	0	0	10	1	5	1	0	0	4	6
36C	All	5	5	1	1	4	0	0	0	10	1	0	0	5	1	4	6
36C	All	7	5	1	1	4	0	0	0	10	1	10	1	0	0	4	6
36C	All	9	5	1	1	4	0	0	0	10	1	5	1	5	1	4	6
36C	All	11	5	1	1	4	0	0	0	15	1	5	1	0	0	5	6
36C	All	13	5	1	1	4	0	0	0	5	1	5	1	0	0	5	6
36C	All	15	5	1	1	4	0	0	0	10	1	10	1	0	0	4	6
36C	All	17	10	1	1	4	0	0	0	10	1	10	1	5	1	4	6
36C	All	19	5	1	1	4	0	0	0	10	1	15	1	5	2	4	6
36C	All	21	10	1	1	4	0	0	0	10	1	5	1	0	0	5	6
36C	All	23	5	1	1	4	0	0	0	10	1	5	1	0	0	5	6
36C	All	25	5	1	1	4	0	0	0	10	1	15	1	0	0	4	6
36C	All	27	5	1	1	4	5	1	1	10	1	10	1	5	1	4	6
36C	All	29	5	1	1	4	0	0	0	10	1	0	0	0	0	4	6
36C	All	31	5	1	1	4	0	0	0	10	1	5	1	0	0	5	6
36C	All	33	5	1	1	4	0	0	0	10	1	5	1	0	0	4	6

Appendix 6 - Badentarbat Level 2 data

SECTION	SUBSCTN	GRIDSQUAR	QRTZPERC	QRTZBASC	QRTZREFR	QRTZSHPE	SANDPERC	SANDBASC	SANDREFR	CELLPERC	CELLBASC	MAMLPERC	MAMLBASC	SPHRPERC	SPHRBASC	MICROSTR	RELDDIST
36C	All	35	5	1	1	4	0	0	0	15	1	5	2	5	1	4	6
36D	All	1	5	1	1	4	0	0	0	5	1	5	1	5	1	4	6
36D	All	3	5	1	1	4	0	0	0	10	1	5	1	0	0	5	6
36D	All	5	5	1	1	4	0	0	0	10	1	0	0	0	0	4	6
36D	All	7	5	1	1	4	0	0	0	10	1	5	1	0	0	4	6
36D	All	9	5	1	1	4	0	0	0	10	1	5	1	0	0	4	6
36D	All	11	5	1	1	4	0	0	0	5	1	0	0	0	0	4	6
36D	All	13	5	1	1	4	0	0	0	10	1	5	1	0	0	4	6
36D	All	15	5	1	1	4	0	0	0	5	1	0	0	0	0	4	6
36D	All	17	5	1	1	4	0	0	0	5	1	0	0	0	0	4	6
36D	All	19	5	1	1	4	0	0	0	5	1	0	0	0	0	4	6
36D	All	21	5	1	1	4	0	0	0	5	1	0	0	0	0	4	6
36D	All	23	5	1	1	4	0	0	0	5	1	0	0	0	0	4	6
36D	All	25	5	1	1	4	0	0	0	5	1	0	0	0	0	4	6
36D	All	27	5	1	1	4	0	0	0	10	1	5	2	0	0	4	6
36D	All	29	5	1	1	4	0	0	0	10	1	0	0	0	0	4	6
36D	All	31	5	1	1	4	0	0	0	5	1	0	0	0	0	4	6
36D	All	33	5	1	1	4	0	0	0	5	1	0	0	0	0	4	6
36D	All	35	5	1	1	4	0	0	0	10	1	0	0	0	0	4	6
36E	All	1	5	1	1	4	0	0	0	30	1	0	0	0	0	5	6
36E	All	3	5	1	1	4	0	0	0	20	1	0	0	0	0	5	6
36E	All	5	5	1	1	4	0	0	0	30	1	0	0	0	0	5	6
36E	All	7	5	1	1	4	0	0	0	20	1	0	0	0	0	5	6
36E	All	9	5	1	1	4	0	0	0	10	1	0	0	0	0	5	6
36E	All	11	5	1	1	4	0	0	0	10	1	5	2	0	0	5	6
36E	All	13	5	1	1	4	0	0	0	5	1	0	0	0	0	5	6
36E	All	15	5	1	1	4	0	0	0	5	1	0	0	0	0	5	6
36E	All	17	5	1	1	4	0	0	0	5	1	0	0	0	0	5	6
36E	All	19	5	1	1	4	0	0	0	5	1	0	0	0	0	5	6
36E	All	21	5	1	1	4	0	0	0	5	1	0	0	0	0	5	6
36E	All	23	5	1	1	4	0	0	0	5	1	0	0	0	0	5	6
36E	All	25	5	1	1	4	0	0	0	5	1	0	0	0	0	5	6
36E	All	27	5	1	1	4	0	0	0	5	1	0	0	0	0	5	6
36E	All	29	5	1	1	4	0	0	0	5	1	0	0	0	0	5	6
36E	All	31	5	1	1	4	0	0	0	10	1	0	0	0	0	5	6
36E	All	33	5	1	1	4	0	0	0	10	1	0	0	0	0	5	6
36E	All	35	5	1	1	4	0	0	0	5	1	0	0	0	0	5	6
42A	All	1	30	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42A	All	3	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42A	All	5	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42A	All	7	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42A	All	9	30	1	1	4	10	1	1	5	1	0	0	0	0	9	2
42A	All	11	30	1	1	4	15	1	1	5	1	0	0	0	0	9	2
42A	All	13	30	1	1	4	15	1	1	5	1	0	0	0	0	9	2
42A	All	15	30	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42A	All	17	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42A	All	19	30	1	1	4	15	1	1	5	1	0	0	0	0	9	2
42A	All	21	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42A	All	23	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42A	All	25	30	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42A	All	27	30	1	1	4	50	1	1	5	1	0	0	0	0	9	2
42A	All	29	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42A	All	31	35	1	1	4	10	1	1	5	1	0	0	0	0	9	2

Appendix 6 - Badentarbat Level 2 data

SECTION	SUBSCTN	GRIDSQUAR	QRTZPERC	QRTZBASC	QRTZREFR	QRTZSHPE	SANDPERC	SANDBASC	SANDREFR	CELLPERC	CELLBASC	MAMLPERC	MAMLBASC	SPHRPERC	SPHRBASC	MICROSTR	RELDDIST
42A	All	33	35	1	1	4	10	1	1	5	1	0	0	0	0	9	2
42A	All	35	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42B	All	33	35	1	1	4	10	1	1	5	1	0	0	0	0	9	2
42B	All	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42B	All	3	25	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42B	All	5	15	1	1	4	35	1	1	0	0	0	0	0	0	9	2
42B	All	7	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42B	All	9	20	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42B	All	11	25	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42B	All	13	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42B	All	15	30	1	1	4	10	1	5	1	0	0	0	0	0	9	2
42B	All	17	30	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42B	All	19	35	1	1	4	10	1	1	5	1	0	0	0	0	9	2
42B	All	21	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42B	All	23	40	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42B	All	25	35	1	1	4	10	1	1	5	1	0	0	0	0	9	2
42B	All	27	40	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42B	All	29	40	1	1	4	10	1	1	5	1	0	0	0	0	9	2
42B	All	31	40	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42B	All	35	35	1	1	4	10	1	1	5	1	0	0	0	0	9	2
42C	All	1	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42C	All	3	35	1	1	4	10	1	1	5	1	0	0	0	0	9	2
42C	All	5	35	1	1	4	10	1	1	5	1	0	0	0	0	9	2
42C	All	7	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42C	All	9	40	1	1	4	10	1	1	5	1	0	0	0	0	9	2
42C	All	11	40	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42C	All	13	30	1	1	4	10	1	1	0	0	0	0	0	0	7	5
42C	All	15	40	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42C	All	17	40	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42C	All	19	40	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42C	All	21	40	1	1	4	10	1	1	0	0	0	0	0	0	9	2
42C	All	23	40	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42C	All	25	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42C	All	27	40	1	1	4	5	1	1	0	0	0	0	0	0	9	2
42C	All	29	40	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42C	All	31	40	1	1	4	5	1	1	5	1	0	0	0	0	4	5
42C	All	33	40	1	1	4	5	1	1	5	1	0	0	0	0	9	2
42C	All	35	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
44A	All	1	25	1	1	4	10	1	4	5	1	0	0	0	0	9	2
44A	All	3	45	1	1	4	10	1	1	5	1	0	0	0	0	9	2
44A	All	5	35	1	1	4	15	1	1	5	1	0	0	5	2	9	2
44A	All	7	15	1	1	4	20	1	1	5	1	0	0	0	0	9	2
44A	All	9	30	1	1	4	10	1	1	5	1	0	0	0	0	9	2
44A	All	11	25	1	1	4	5	1	1	5	1	0	0	0	0	9	2
44A	All	13	35	1	1	4	20	1	1	5	1	0	0	0	0	9	2
44A	All	15	20	1	1	4	35	1	1	5	1	0	0	0	0	9	2
44A	All	17	30	1	1	4	25	1	1	5	1	0	0	0	0	9	2
44A	All	19	30	1	1	4	20	1	1	5	1	0	0	0	0	9	2
44A	All	21	15	1	1	4	5	1	1	5	1	0	0	0	0	9	2
44A	All	23	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
44A	All	25	30	1	1	4	15	1	1	5	1	0	0	0	0	9	2
44A	All	27	30	1	1	4	30	1	1	5	1	0	0	0	0	9	2
44A	All	29	30	1	1	4	15	1	1	5	1	0	0	0	0	9	2

Appendix 6 - Badentarbat Level 2 data

SECTION	SUBSCTN	GRIDSQUAR	QRTZPERC	QRTZBASC	QRTZREFR	QRTZSHPE	SANDPERC	SANDBASC	SANDREFR	CELLPERC	CELLBASC	MAMLPERC	MAMLBASC	SPHRPERC	SPHRBASC	MICROSTR	RELDDIST
44A	All	31	25	1	1	4	15	1	1	5	1	0	0	0	0	9	2
44A	All	33	35	1	1	4	15	1	1	5	1	0	0	0	0	9	2
44A	All	35	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
44B	All	1	15	1	1	4	45	1	1	5	1	0	0	0	0	9	2
44B	All	3	35	1	1	4	15	1	1	5	1	0	0	0	0	9	2
44B	All	5	25	1	1	4	25	1	1	5	1	0	0	0	0	9	2
44B	All	7	35	1	1	4	15	1	1	5	1	0	0	0	0	9	2
44B	All	9	35	1	1	4	10	1	1	5	1	0	0	0	0	9	2
44B	All	11	15	1	1	4	45	1	1	5	1	0	0	0	0	9	2
44B	All	13	30	1	1	4	30	1	1	5	1	0	0	0	0	9	2
44B	All	15	30	1	1	4	5	1	1	5	1	0	0	0	0	9	2
44B	All	17	35	1	1	4	20	1	1	5	1	0	0	0	0	9	2
44B	All	19	30	1	1	4	15	1	1	5	1	0	0	0	0	9	2
44B	All	21	30	1	1	4	20	1	1	5	1	0	0	0	0	9	2
44B	All	23	30	1	1	4	25	1	1	5	1	0	0	0	0	9	2
44B	All	25	30	1	1	4	5	1	1	5	1	0	0	0	0	9	2
44B	All	27	30	1	1	4	30	1	1	5	1	0	0	0	0	9	2
44B	All	29	40	1	1	4	5	1	1	5	1	0	0	0	0	9	2
44B	All	31	20	1	1	4	25	1	1	5	1	0	0	0	0	9	2
44B	All	33	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
44B	All	35	20	1	1	4	40	1	1	5	1	0	0	0	0	9	2
44C	All	1	25	1	1	4	15	1	1	5	1	0	0	0	0	9	2
44C	All	3	5	1	1	4	85	1	1	0	0	0	0	0	0	9	2
44C	All	5	5	1	1	4	50	1	1	0	0	0	0	0	0	7	5
44C	All	7	10	1	1	4	50	1	1	0	0	0	0	0	0	7	5
44C	All	9	10	1	1	4	20	1	1	0	0	0	0	0	0	7	5
44C	All	11	15	1	1	4	25	1	1	0	0	0	0	0	0	7	5
44C	All	13	20	1	1	4	5	1	1	0	0	0	0	0	0	7	5
44C	All	15	25	1	1	4	25	1	1	0	0	0	0	0	0	9	2
44C	All	17	35	1	1	4	5	1	1	0	0	0	0	0	0	9	2
44C	All	19	15	1	1	4	40	1	1	0	0	0	0	0	0	9	2
44C	All	21	15	1	1	4	50	1	1	0	0	0	0	0	0	9	2
44C	All	23	15	1	1	4	45	1	1	0	0	0	0	0	0	7	5
44C	All	25	15	1	1	4	40	1	1	0	0	0	0	0	0	7	5
44C	All	27	30	1	1	4	5	1	1	0	0	0	0	0	0	7	5
44C	All	29	0	0	0	0	100	1	1	0	0	0	0	0	0	0	0
44C	All	31	10	1	1	4	40	1	1	0	0	0	0	0	0	9	2
44C	All	33	20	1	1	4	25	1	1	0	0	0	0	0	0	9	2
44C	All	35	30	1	1	4	5	1	1	0	0	0	0	0	0	7	5
46A	All	1	5	1	1	4	0	0	0	5	1	0	0	0	0	4	6
46A	All	3	5	1	1	4	0	0	0	5	1	5	2	0	0	4	6
46A	All	5	10	1	1	4	5	1	1	5	1	5	2	0	0	4	6
46A	All	7	20	1	1	4	0	0	0	5	1	0	0	0	0	4	6
46A	All	9	10	1	1	4	5	1	1	5	1	0	0	0	0	4	6
46A	All	11	15	1	1	4	5	1	1	5	1	5	2	0	0	4	6
46A	All	13	30	1	1	4	15	1	1	5	1	0	0	0	0	4	5
46A	All	15	35	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46A	All	17	35	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46A	All	19	30	1	1	4	10	1	1	5	1	0	0	0	0	4	5
46A	All	21	20	1	1	4	0	0	0	5	1	0	0	0	0	4	5
46A	All	23	30	1	1	4	5	1	1	5	1	5	2	0	0	4	5
46A	All	25	35	1	1	4	5	1	1	5	1	5	2	0	0	4	5
46A	All	27	35	1	1	4	5	1	1	5	1	10	2	0	0	4	5

Appendix 6 - Badentarbat Level 2 data

SECTION	SUBSCTN	GRIDSQUAR	QRTZPERC	QRTZBASC	QRTZREFR	QRTZSHPE	SANDPERC	SANDBASC	SANDREFR	CELLPERC	CELLBASC	MAMLPERC	MAMLBASC	SPHRPERC	SPHRBASC	MICROSTR	RELDDIST
46A	All	29	35	1	1	4	10	1	1	5	1	15	2	0	0	4	5
46A	All	31	30	1	1	4	5	1	1	5	1	5	2	0	0	4	5
46A	All	33	30	1	1	4	15	1	1	5	1	5	2	0	0	9	2
46A	All	35	30	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46B	All	1	35	1	1	4	5	1	1	5	1	5	2	0	0	9	2
46B	All	3	35	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46B	All	5	25	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46B	All	7	30	1	1	4	5	1	1	5	1	0	0	0	0	9	2
46B	All	9	35	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46B	All	11	35	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46B	All	13	30	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46B	All	15	35	1	1	4	10	1	1	5	1	0	0	0	0	4	5
46B	All	17	30	1	1	4	10	1	1	5	1	0	0	0	0	4	5
46B	All	19	30	1	1	4	10	1	1	5	1	0	0	0	0	4	5
46B	All	21	25	1	1	4	10	1	1	5	1	0	0	0	0	4	5
46B	All	23	35	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46B	All	25	35	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46B	All	27	30	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46B	All	29	35	1	1	4	5	1	1	5	1	5	2	0	0	4	5
46B	All	31	10	1	1	4	10	1	1	5	1	0	0	0	0	9	2
46B	All	33	35	1	1	4	5	1	1	5	1	5	2	0	0	4	5
46B	All	35	15	1	1	4	0	0	0	5	1	0	0	0	0	4	5
46C	Top	1	35	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46C	Top	3	40	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46C	Top	5	40	1	1	4	5	1	1	5	1	0	0	0	0	3	5
46C	Top	7	25	1	1	4	5	1	1	10	1	5	2	0	0	4	5
46C	Top	9	25	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46C	Top	11	35	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46C	Top	13	25	1	1	4	5	1	1	10	1	0	0	0	0	4	5
46C	Top	15	30	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46C	Top	(1/2)17	35	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46C	Top	19	30	1	1	4	5	1	1	10	1	0	0	0	0	4	5
46C	Top	(1/2)21	35	1	1	4	5	1	1	10	1	0	0	0	0	4	5
46C	Bottom	23	40	1	1	2	15	1	1	5	1	0	0	0	0	9	2
46C	Bottom	25	45	1	1	4	25	1	1	5	1	0	0	0	0	9	2
46C	Bottom	(1/2)17	50	1	1	4	15	1	1	5	1	0	0	0	0	9	2
46C	Bottom	(1/2)21	60	1	1	2	0	0	0	5	1	0	0	0	0	9	2
46C	Bottom	27	45	1	1	4	10	1	1	5	1	0	0	0	0	9	2
46C	Bottom	29	45	1	1	4	15	1	1	5	1	5	2	0	0	9	2
46C	Bottom	31	60	1	1	4	10	1	1	5	1	0	0	0	0	9	2
46C	Bottom	33	55	1	1	2	10	1	1	5	1	0	0	0	0	9	2
46C	Bottom	35	20	1	1	4	35	1	1	5	1	0	0	0	0	9	2
46D	Top	1	25	1	1	4	20	1	1	10	1	0	0	0	0	9	2
46D	Top	3	35	1	1	4	15	1	1	5	1	0	0	0	0	9	2
46D	Top	5	40	1	1	4	30	1	1	5	1	0	0	0	0	9	2
46D	Top	7	40	1	1	4	10	1	1	5	1	0	0	0	0	9	2
46D	Top	9	40	1	1	4	5	1	1	10	1	0	0	0	0	9	2
46D	Top	11	45	1	1	4	10	1	1	5	1	0	0	0	0	9	2
46D	Top	13	50	1	1	4	5	1	1	5	1	0	0	0	0	9	2
46D	Top	15	40	1	1	4	15	1	1	5	1	0	0	0	0	9	2
46D	Top	17	40	1	1	4	10	1	1	5	1	0	0	0	0	9	2
46D	Top	19	45	1	1	4	5	1	1	5	1	0	0	0	0	9	2
46D	Top	21	50	1	1	4	5	1	1	5	1	0	0	0	0	9	2

Appendix 6 - Badentarbat Level 2 data

SECTION	SUBSCTN	GRIDSQUAR	QRTZPERC	QRTZBASC	QRTZREFR	QRTZSHPE	SANDPERC	SANDBASC	SANDREFR	CELLPERC	CELLBASC	MAMLPERC	MAMLBASC	SPHRPERC	SPHRBASC	MICROSTR	RELDDIST
46D	Bottom	23	40	1	1	4	5	1	1	5	1	0	0	0	0	9	2
46D	Bottom	25	45	1	1	4	5	1	1	5	1	0	0	0	0	9	2
46D	Bottom	27	35	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46D	Bottom	29	50	1	1	4	5	1	1	5	1	0	0	0	0	9	2
46D	Bottom	31	45	1	1	4	10	1	1	5	1	0	0	0	0	2	4
46D	Bottom	33	40	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46D	Bottom	35	45	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46E	Topleft	(1/2)3	30	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46E	Topleft	(1/2)5	25	1	1	4	5	1	1	5	1	0	0	0	0	4	5
46E	Topleft	9	40	1	1	4	10	1	1	5	1	0	0	0	0	9	2
46E	Topleft	(1/2)11	55	1	1	4	10	1	1	5	1	0	0	0	0	9	2
46E	Bottom	1	15	1	1	4	5	1	1	5	1	0	0	0	0	4	6
46E	Bottom	(1/2)3	15	1	1	4	0	0	0	5	1	0	0	0	0	4	6
46E	Bottom	(1/2)5	15	1	1	4	0	0	0	5	1	0	0	0	0	4	6
46E	Bottom	7	15	1	1	4	0	0	0	5	1	0	0	0	0	3	6
46E	Bottom	(1/2)11	25	1	1	4	5	1	1	5	1	0	0	0	0	3	6
46E	Bottom	13	20	1	1	4	5	1	1	5	1	0	0	0	0	4	6
46E	Bottom	15	15	1	1	4	0	0	0	5	1	0	0	0	0	3	6
46E	Bottom	17	20	1	1	4	0	0	0	10	1	0	0	0	0	3	6
46E	Bottom	19	20	1	1	4	5	1	1	10	1	0	0	0	0	3	6
46E	Bottom	21	20	1	1	4	0	0	0	10	1	0	0	0	0	3	6
46E	Bottom	23	20	1	1	4	0	0	0	10	1	0	0	0	0	3	6
46E	Bottom	25	20	1	1	4	0	0	0	10	1	5	1	0	0	3	6
46E	Bottom	27	25	1	1	4	0	0	0	10	1	5	1	0	0	3	6
46E	Bottom	29	20	1	1	4	0	0	0	10	1	0	0	5	1	3	6
46E	Bottom	31	20	1	1	4	0	0	0	10	1	5	2	0	0	4	6
46E	Bottom	33	25	1	1	4	0	0	0	10	1	5	1	0	0	4	6
46E	Bottom	35	20	1	1	4	0	0	0	10	1	5	1	0	0	4	6
49A	All	1	30	1	1	4	5	1	1	30	1	5	2	0	0	4	6
49A	All	3	10	1	1	4	0	0	0	30	1	5	2	0	0	7	6
49A	All	5	5	1	1	4	0	0	0	30	1	10	2	0	0	7	6
49A	All	7	30	1	1	4	5	1	1	30	1	0	0	0	0	4	6
49A	All	9	40	1	1	4	5	1	1	30	1	0	0	0	0	4	6
49A	All	11	30	1	1	4	5	1	1	20	1	0	0	0	0	4	6
49A	All	13	25	1	1	4	5	1	1	20	1	0	0	0	0	4	6
49A	All	15	30	1	1	4	5	1	1	20	1	0	0	0	0	4	6
49A	All	17	25	1	1	4	5	1	1	20	1	0	0	0	0	4	6
49A	All	19	25	1	1	4	5	1	1	20	1	0	0	0	0	4	6
49A	All	21	50	1	1	4	0	0	0	20	1	0	0	0	0	4	6
49A	All	23	30	1	1	4	0	0	0	20	1	0	0	0	0	4	6
49A	All	25	30	1	1	4	0	0	0	15	1	0	0	0	0	4	6
49A	All	27	55	1	1	4	0	0	0	10	1	0	0	0	0	7	6
49A	All	29	50	1	1	4	0	0	0	10	1	0	0	0	0	4	6
49A	All	31	55	1	1	4	5	1	1	5	1	0	0	0	0	4	5
49A	All	33	70	1	1	4	5	1	1	5	1	0	0	0	0	4	5
49A	All	35	55	1	1	4	5	1	1	5	1	0	0	0	0	4	5
49B	Top	1	55	1	1	4	5	1	1	5	1	0	0	0	0	9	2
49B	Top	3	65	1	1	4	5	1	1	5	1	0	0	0	0	4	5
49B	Top	5	70	1	1	4	5	1	1	5	1	0	0	0	0	9	2
49B	Top	7	50	1	1	4	5	1	1	5	1	0	0	0	0	4	5
49B	Top	9	50	1	1	4	5	1	1	5	1	0	0	0	0	4	5
49B	Top	11	40	1	1	4	5	1	1	5	1	0	0	0	0	4	5
49B	Top	13	55	1	1	4	0	0	0	5	1	0	0	0	0	6	5

Appendix 6 - Badentarbat Level 2 data

SECTION	SUBSCTN	GRIDSQUAR	QRTZPERC	QRTZBASC	QRTZREFR	QRTZSHPE	SANDPERC	SANDBASC	SANDREFR	CELLPERC	CELLBASC	MAMLPERC	MAMLBASC	SPHRPERC	SPHRBASC	MICROSTR	RELDDIST
49B	Top	15	60	1	1	4	0	0	0	5	1	0	0	0	0	6	5
49B	Top	17	40	1	1	4	0	0	0	5	1	0	0	0	0	4	5
49B	Bottom	19	5	1	1	4	0	0	0	5	1	0	0	0	0	3	6
49B	Bottom	21	5	1	1	4	0	0	0	5	1	0	0	0	0	3	6
49B	Bottom	23	5	1	1	4	0	0	0	5	1	0	0	0	0	3	6
49B	Bottom	25	5	1	1	4	0	0	0	5	1	0	0	0	0	2	6
49B	Bottom	27	5	1	1	4	0	0	0	5	1	0	0	0	0	3	6
49B	Bottom	29	5	1	1	4	0	0	0	5	1	5	2	0	0	3	6
49B	Bottom	31	5	1	1	4	0	0	0	5	1	0	0	0	0	3	6
49B	Bottom	33	5	1	1	4	0	0	0	5	1	5	2	0	0	3	6
49B	Bottom	35	5	1	1	4	0	0	0	5	1	0	0	0	0	3	6
49C	Top	1	80	1	1	4	5	1	1	5	1	5	2	0	0	3	5
49C	Top	3	80	1	1	4	5	1	1	5	1	0	0	0	0	9	2
49C	Top	5	80	1	1	4	0	0	0	5	1	0	0	0	0	3	5
49C	Top	7	85	1	1	4	0	0	0	5	1	0	0	0	0	3	5
49C	Top	9	80	1	1	4	5	1	1	5	1	0	0	0	0	3	5
49C	Top	(1/2)11	80	1	1	4	0	0	0	5	1	0	0	0	0	9	2
49C	Top	(1/2)13	80	1	1	4	0	0	0	5	1	0	0	0	0	9	2
49C	Bottom	15	85	1	1	4	0	0	0	5	2	5	2	0	0	9	2
49C	Bottom	(1/2)11	85	1	1	4	0	0	0	5	1	0	0	0	0	9	2
49C	Bottom	(1/2)13	85	1	1	4	0	0	0	5	1	0	0	5	2	9	2
49C	Bottom	17	85	1	1	4	5	1	1	5	2	5	2	0	0	9	2
49C	Bottom	19	90	1	1	4	0	0	0	0	0	5	2	0	0	9	2
49C	Bottom	21	90	1	1	4	5	1	1	0	0	0	0	0	0	9	2
49C	Bottom	23	90	1	1	4	0	0	0	0	0	5	2	0	0	9	2
49C	Bottom	25	80	1	1	4	0	0	0	0	0	5	2	0	0	9	2
49C	Bottom	27	85	1	1	4	0	0	0	0	0	5	2	0	0	9	2
49C	Bottom	29	85	1	1	4	0	0	0	5	1	5	2	0	0	9	2
49C	Bottom	31	70	1	1	4	5	1	1	5	1	5	2	0	0	3	5
49C	Bottom	33	90	1	1	4	5	1	1	0	0	0	0	0	0	9	2
49C	Bottom	35	85	1	1	4	0	0	0	0	0	5	2	0	0	9	2
54A	All	1	20	1	1	4	0	0	0	10	1	0	0	0	0	4	6
54A	All	3	20	1	1	4	0	0	0	10	1	0	0	0	0	4	6
54A	All	5	20	1	1	4	0	0	0	10	1	0	0	0	0	4	6
54A	All	7	25	1	1	4	5	1	1	10	1	0	0	0	0	4	6
54A	All	9	25	1	1	4	0	0	0	10	1	0	0	0	0	4	6
54A	All	11	5	1	1	4	0	0	0	10	1	0	0	0	0	4	6
54A	All	13	30	1	1	4	0	0	0	10	1	0	0	0	0	4	6
54A	All	15	25	1	1	4	0	0	0	10	1	5	2	0	0	4	6
54A	All	17	30	1	1	4	0	0	0	10	1	0	0	0	0	4	6
54A	All	19	15	1	1	4	0	0	0	10	1	0	0	0	0	4	6
54A	All	21	5	1	1	4	0	0	0	5	1	0	0	0	0	4	6
54A	All	23	30	1	1	4	15	1	1	5	1	0	0	0	0	4	6
54A	All	25	25	1	1	4	20	1	1	10	1	0	0	0	0	4	6
54A	All	27	20	1	1	4	40	1	1	5	1	0	0	0	0	4	6
54A	All	29	20	1	1	4	5	1	1	10	1	0	0	0	0	4	6
54A	All	31	15	1	1	4	5	1	1	5	1	0	0	0	0	4	6
54A	All	33	30	1	1	4	5	1	1	5	1	0	0	0	0	4	6
54A	All	35	25	1	1	4	30	1	1	5	1	0	0	0	0	4	6
54B	All	1	25	1	1	4	10	1	1	10	1	5	2	0	0	9	2
54B	All	3	30	1	1	4	5	1	1	10	1	10	2	0	0	4	6
54B	All	5	30	1	1	4	5	1	1	5	1	5	2	0	0	9	2
54B	All	7	35	1	1	4	5	1	1	10	1	0	0	0	0	4	6

Appendix 6 - Badentarbat Level 2 data

SECTION	SUBSCTN	GRIDSQUAR	QRTZPERC	QRTZBASC	QRTZREFR	QRTZSHPE	SANDPERC	SANDBASC	SANDREFR	CELLPERC	CELLBASC	MAMLPERC	MAMLBASC	SPHRPERC	SPHRBASC	MICROSTR	RELDDIST
54B	All	9	30	1	1	4	20	1	1	5	1	0	0	0	0	4	6
54B	All	11	30	1	1	4	5	1	1	5	1	5	2	0	0	4	6
54B	All	13	25	1	1	4	10	1	1	10	1	0	0	0	0	4	6
54B	All	15	30	1	1	4	5	1	1	10	1	5	2	0	0	4	6
54B	All	17	40	1	1	4	5	1	1	5	1	0	0	0	0	4	5
54B	All	19	35	1	1	4	5	1	1	5	1	0	0	0	0	4	5
54B	All	21	35	1	1	4	5	1	1	5	1	0	0	0	0	4	5
54B	All	23	40	1	1	4	5	1	1	5	1	0	0	0	0	4	5
54B	All	25	35	1	1	4	0	0	0	5	1	10	2	0	0	4	5
54B	All	27	35	1	1	4	5	1	1	5	1	0	0	0	0	4	5
54B	All	29	30	1	1	4	0	0	0	5	1	0	0	0	0	4	5
54B	All	31	5	1	1	4	60	1	2	5	1	5	2	0	0	4	6
54B	All	33	30	1	1	4	5	1	1	5	1	0	0	0	0	4	6
54B	All	35	30	1	1	4	5	1	1	5	1	0	0	0	0	9	2
54C	All	1	15	1	1	4	20	1	1	5	1	0	0	0	0	7	6
54C	All	3	20	1	1	4	5	1	1	5	1	10	2	0	0	7	6
54C	All	5	25	1	1	4	5	1	1	5	1	0	0	0	0	7	6
54C	All	7	25	1	1	4	5	1	1	5	1	0	0	0	0	9	2
54C	All	9	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
54C	All	11	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
54C	All	13	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
54C	All	15	30	1	1	4	15	1	1	5	1	5	2	0	0	9	2
54C	All	17	35	1	1	4	10	1	1	5	1	0	0	0	0	9	2
54C	All	19	35	1	1	2	5	1	1	5	1	0	0	0	0	9	2
54C	All	21	35	1	1	4	10	1	1	5	1	0	0	0	0	9	2
54C	All	23	40	1	1	4	5	1	1	5	1	0	0	0	0	9	2
54C	All	25	40	1	1	4	10	1	1	5	1	0	0	0	0	9	2
54C	All	27	40	1	1	4	0	0	0	5	1	0	0	0	0	9	2
54C	All	29	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
54C	All	31	30	1	1	4	10	1	1	5	1	0	0	0	0	9	2
54C	All	33	35	1	1	4	5	1	1	5	1	0	0	0	0	9	2
54C	All	35	30	1	1	4	5	1	1	5	1	0	0	0	0	9	2
54D	All	1	30	1	1	4	5	1	1	5	1	5	2	0	0	9	2
54D	All	3	40	1	1	4	5	1	1	5	1	5	2	0	0	9	2
54D	All	5	35	1	1	4	0	0	0	5	1	0	0	0	0	9	2
54D	All	7	30	1	1	4	15	1	1	5	1	0	0	0	0	7	5
54D	All	9	35	1	1	4	5	1	1	5	1	0	0	0	0	7	5
54D	All	11	30	1	1	4	10	1	1	5	1	0	0	0	0	9	2
54D	All	13	35	1	1	4	5	1	1	5	1	5	2	0	0	9	2
54D	All	15	10	1	1	4	30	1	1	5	1	0	0	0	0	7	6
54D	All	17	35	1	1	4	5	1	1	5	1	5	2	0	0	7	5
54D	All	19	25	1	1	4	5	1	1	5	1	0	0	0	0	7	5
54D	All	21	35	1	1	4	5	1	1	5	1	0	0	0	0	4	5
54D	All	23	20	1	1	4	5	1	1	5	1	5	2	0	0	7	5
54D	All	25	30	1	1	4	5	1	1	5	1	5	2	0	0	7	5
54D	All	27	35	1	1	4	5	1	1	5	1	10	2	0	0	9	2
54D	All	29	40	1	1	4	5	1	1	5	1	0	0	0	0	9	2
54D	All	31	40	1	1	4	5	1	1	5	1	0	0	0	0	9	2
54D	All	33	35	1	1	4	5	1	1	5	1	5	2	0	0	9	2
54D	All	35	35	1	1	4	5	1	1	5	1	5	2	0	0	9	2

Appendix 7

Appendix 7 - Level 1 data grouped by field class showing distribution content data per slide - Boyken.

ote: Only those parameters discussed in Section 7.1.2 are shown. The 3 parameters which show statistically significant differences (95% C.I.) between the field classes are shown first, followed by other non-significant parameters which are discussed in relation to differences between trenches.

Slides in each Field Class (Boyken)	Content of micromorphological parameters described at Level 1 (frequency class)														
	Siltstone		Cell residue		Mamillate excrement			Lignifie d tissue		Organ residue		Charcoal	Amorphous black fine OM	Amorphous yellow-orange fine OM	
Field Class 1	3	4	1	2	2	4	5	1	2	1	2	0	1	0	1
13/22A(U)		1	1			1			1		1	1	1		1
13/22A(L)		1	1				1		1		1	1	1		1
13/22B		1	1				1	1		1		1	1	1	
20/22A	1		1		1			1		1		1	1		1
20/22B	1		1		1				1	1		1	1		1
21/22A		1		1	1			1		1		1	1		1
21/22B	1		1		1			1		1		1	1		1

Slides in each Field Class (Boyken)	Content of micromorphological parameters described at Level 1 (frequency class)																										
	Siltstone				Cell residue		Mamillate excrement					Lignified tissue			Organ residue				Charcoal		Amorphous black fine OM				Amorphous yellow-orange fine OM		
Field Class 2	2	3	4	5	1	2	1	2	3	4	5	0	1	2	0	1	2	3	0	1	1	2	3	4	0	1	2
1/56A(U)				1		1					1		1			1				1				1		1	
1/56A(LL)			1		1		1					1			1				1					1		1	
1/56B				1	1					1		1			1					1			1			1	
1/56C(U)		1				1			1					1		1			1				1			1	
1/56C(L)	1					1				1			1				1			1		1			1		
1/56D(U)			1			1			1				1				1			1		1				1	
1/56D(L)		1				1			1				1				1			1			1				1
1/56E		1				1				1			1				1			1			1			1	
6/10A	1					1		1					1					1	1		1						1
6/10B		1			1				1				1			1				1	1					1	
6/10C		1			1				1				1			1			1		1				1		
6/10D			1		1				1				1		1					1	1				1		
8/38A			1		1				1			1			1				1		1				1		
27/38A		1				1		1					1			1			1			1				1	
27/38B	1					1			1				1		1				1			1			1		

	Content of micromorphological parameters described at Level 1 (frequency class)																							
Slides in each Field Class (Boyken)	Siltstone				Cell residue			Mamillate excrement				Lignified tissue			Organ residue				Charcoal		Amorphous black fine OM			Amorphous yellow-orange fine OM		
Field Class 3	1	2	3	4	0	1	2	1	2	3	4	0	1	2	0	1	2	3	0	1	1	2	3	0	1	2
5/52A	1					1				1			1					1		1		1		1		
5/52B	1					1				1			1				1			1			1	1		
5/52C	1					1				1				1		1			1			1			1	
5/52D	1						1		1					1			1		1		1				1	
11/36A		1					1			1			1		1				1		1				1	
11/36B		1					1			1		1			1				1		1			1		
11/36C			1			1				1		1			1				1		1			1		
19/47A(U)			1			1				1			1			1			1		1				1	
19/47A(L)		1					1			1			1			1			1		1				1	
19/47B				1			1			1			1		1				1		1					1
19/47C		1				1		1				1			1				1		1				1	
19/47D		1				1		1				1			1				1		1				1	
19/47E		1				1			1			1			1				1		1					1
19/47F			1		1			1				1			1				1		1					1
28/47A	1						1		1				1			1			1		1				1	
28/47B			1				1		1			1				1			1		1			1		
29/52A			1				1				1			1			1		1			1				1
29/52B			1				1				1		1				1		1				1		1	

	Content of micromorphological parameters described at Level 1 (frequency class)																
Slides in each Field Class (Boyken)	Siltstone			Cell residue		Mamillate excrement		Lignified tissue			Organ residue		Charcoal		Amorphous black fine OM		Amorphous yellow-orange fine OM	
Field Class 5	2	3	4	1	2	1	2	0	1	2	0	1	0	1	1	2	0	1
25/30A(U)	1				1		1			1	1		1		1			1
25/30A(L)		1			1	1		1				1		1	1		1	
25/30B		1		1		1		1			1		1		1		1	
25/30C			1	1			1	1				1	1		1		1	
26/30A	1				1		1	1				1		1		1		1
26/30B	1				1	1			1		1		1		1			1

	Content of micromorphological parameters described at Level 1 (frequency class)																							
Slides in each Field Class (Boyken)	Siltstone				Cell residue			Mamillate excrement			Lignified tissue			Organ residue			Charcoal		Amorphous black fine OM			Amorphous yellow-orange fine OM		
Field Class 7	1	2	3	4	1	2	3	2	3	4	0	1	2	0	1	2	0	1	1	2	3	0	1	2
22A		1					1		1			1			1		1		1			1		
22B				1			1		1			1			1		1		1			1		
22C				1		1			1			1			1			1	1			1		
23(1)A	1					1			1			1			1		1		1				1	
23(10B	1					1			1				1		1		1		1				1	
23(10C			1		1			1			1				1		1		1			1		
23(2)A		1				1		1				1			1		1		1				1	
23(2)B		1			1			1					1		1		1		1					1
30(1)A		1					1	1					1			1	1				1		1	
30(1)B			1			1				1		1				1	1			1		1		
30(2)A		1					1		1			1				1	1		1				1	
30(2)B			1				1		1			1		1			1			1			1	

Appendix 7 - Level 1 data grouped by Field class showing distribution of micromorphological parameters which showed statistically significant differences (95% C.I.) between field classes.

	Content of micromorphological parameters described at Level 1 (frequency class)																				
Slides in each Field Class (Badentarbat)	Feldspar				$CaCO_3$		Multi-cell fungal spores			Amorphous yellow-orange fine OM			Amorphous & cryptocrystalline coatings		Mamillate excrement				Spheroidal excrement		
Field Class 0	1	2	3	4	0	1	0	1	2	0	1	2	0	1	0	1	2	3	0	1	2
49A	1					1			1			1	1					1			1
49B(U)			1			1			1		1		1			1					1
49B(L)	1				1			1			1			1		1			1		
49C(U)			1			1		1		1			1				1			1	
49C(L)				1		1		1			1		1				1				1
50A	1				1				1			1	1				1			1	
50B	1				1				1		1		1		1					1	
50C	1				1				1			1	1		1				1		
50D(U)	1				1			1			1		1		1				1		
50D(L)		1			1			1		1			1			1					1
53A(1)		1			1			1			1			1	1				1		
53B			1			1		1			1			1	1				1		
53C(M)	1				1			1			1			1	1				1		
53C(L)			1			1	1				1			1		1				1	
53D			1			1	1					1		1		1			1		

Slides in each Field Class (Badentarbat)	Content of micromorphological parameters described at Level 1 (frequency class)																														
	Feldspar				CaCO$_3$		Multi-cell fungal spores			Amorphous yellow-orange fine OM						Amorphous & cryptocrystalline coatings				Mamillate excrement					Spheroidal excrement				
Field Class 1	1	2	3	4	0	1	0	1	2	0	1	2	3	4	5	0	1	2	3	0	1	2	3	4	0	1	2	3	4
32(F)A(UL)			1		1			1					1			1				1					1				
32(F)A(UR)			1		1			1							1	1				1					1				
32(F)A(LL)			1		1		1								1			1		1							1		
32(F)A(LR)			1		1			1						1		1				1					1				
32(F)B(U)			1		1			1							1	1				1						1			
32(F)B(L)			1		1		1					1							1	1						1			
32A		1			1			1					1			1						1						1	
32B		1			1			1				1				1					1						1		
32C			1		1				1					1		1				1					1				
32D			1		1				1					1			1			1						1			
32E			1		1			1					1			1				1					1				
32F(U)			1		1			1				1				1				1					1				
32F(L)			1		1			1				1					1			1						1			
34(F)A(U)	1				1			1				1					1			1					1				
34(F)A(L)		1			1			1				1					1			1						1			
34A		1			1			1				1					1				1					1			
34B			1		1			1				1					1				1					1			
36A	1				1			1						1			1						1						1
36B	1				1			1					1				1						1						1
36C	1				1			1					1			1						1						1	
36D	1				1			1				1					1				1						1		
36E	1				1				1		1					1				1					1				
43A		1				1		1					1				1					1					1		
43B		1			1			1					1				1			1						1			
43C		1			1			1					1				1				1						1		
43D			1		1		1					1					1			1					1				
44A				1		1		1				1						1				1						1	
44B				1		1		1			1							1				1						1	
44C				1		1		1			1								1				1				1		
47A		1				1			1			1						1						1				1	
47B				1		1		1			1						1							1				1	
47C				1		1		1			1						1						1				1		
47D				1		1		1		1							1						1				1		

Slides in each Field Class (Badentarbat)	Content of micromorphological parameters described at Level 1 (frequency class)										
	Feldspar	CaCO$_3$		Multi-cell fungal spores	Amorphous yellow-orange fine OM		Amorphous & cryptocrystalline coatings	Mamillate excrement		Spheroidal excrement
Field Class 2	4	0	1	1	1	2	1	1	2	1
54A	1	1		1	1		1	1		1
54B	1		1	1		1	1		1	1
54C	1		1	1		1	1		1	1
54D	1		1	1	1		1		1	1

Slides in each Field Class (Badentarbat)	Content of micromorphological parameters described at Level 1 (frequency class)																								
	Feldspar					CaCO$_3$			Multi-cell fungal spores			Amorphous yellow-orange fine OM				Amorphous & cryptocrystalline coatings			Mamillate excrement				Spheroidal excrement			
Field Class 3	0	1	2	3	4	0	1	2	0	1	2	0	1	2	3	0	1	2	0	1	2	3	0	1	2	3
46A					1		1				1		1					1			1		1			
46B				1		1				1			1					1		1			1			
46C(U)				1			1			1			1					1	1					1		
46C(L)			1			1				1		1						1	1					1		
46D(U)				1				1	1				1					1		1				1		
46D(L)				1				1		1				1			1				1					1
46E(UL)				1				1		1			1				1			1					1	
46E(L)			1				1			1			1				1			1					1	
51(F)A		1				1				1			1			1			1				1			
51(F)B		1				1					1			1		1				1				1		
51A			1				1				1			1		1						1		1		
51B				1			1			1				1		1			1				1			
51C		1				1					1			1		1						1		1		
51D	1					1					1				1	1					1					1
51E(U)			1			1					1		1			1				1					1	
51E(L)		1					1				1		1			1			1				1			
51F		1				1					1			1		1			1				1			

Slides in each Field Class (Badentarbat)	Content of micromorphological parameters described at Level 1 (frequency class)																					
	Feldspar			$CaCO_3$				Multi-cell fungal spores		Amorphous yellow-orange fine OM				Amorphous & cryptocrystalline coatings		Mamillate excrement			Spheroidal excrement			
Field Class 4	1	2	3	0	1	2	3	0	1	0	1	2	3	0	1	0	1	2	0	1	2	3
52(F)A	1			1					1		1			1			1				1	
52(F)B(U)		1				1			1				1	1		1			1			
52(F)B(L)		1					1	1			1			1		1			1			
52A	1			1				1			1				1		1			1		
52B	1				1				1		1			1				1			1	
52C	1			1					1		1			1			1			1		
52D		1			1				1		1				1		1		1			
52E(L)		1		1				1		1				1		1			1			
52E(M)			1		1			1		1				1		1			1			
52E(U)			1		1			1				1		1		1			1			

Slides in each Field Class (Badentarbat)	Content of micromorphological parameters described at Level 1 (frequency class)																				
	Feldspar			$CaCO_3$			Multi-cell fungal spores	Amorphous yellow-orange fine OM			Amorphous & cryptocrystalline coatings				Mamillate excrement				Spheroidal excrement		
Field Class 5	0	3	4	0	1	2	1	0	2	3	0	1	2	3	1	2	3	4	1	2	3
38A	1			1			1		1			1					1				1
38B		1			1		1			1		1			1					1	
38C		1			1		1		1			1				1					1
38D		1			1		1			1	1					1					1
38E		1			1		1			1		1				1				1	
42A			1		1		1	1						1		1			1		
42B			1		1		1		1			1				1			1		
42C			1		1		1		1			1				1			1		
45A			1		1		1		1				1					1			1
45B			1		1		1		1				1				1				1
45C			1		1		1		1					1			1			1	
45D			1			1	1		1				1			1			1		

Appendix 8

Appendix 8 - Level 2 data grouped by field class showing distribution of content recordings for the gridsquares from each slide representing each field class, Boyken.

Note: The number of gridsquares from each slide grouped in each field class is given in square brackets after the slide identification number. Only the micromorphological parameters which showed a statistically significant difference (95% C.I.) between two or more field classes are shown.

Slides in each field class	Sandstone content													Cell residue content		Mamillate excrement content						
Field Class 1	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**5**	**10**	**0**	**5**	**10**	**15**	**20**	**25**	**45**
13/22A(U) [15]	2	4	1	4		1	1					1	1	13	2		5	8	2			
13/22A(L) [7]		1	2				2				1		1	7			2	3	2			
13/22B [20]		3	3	2	2	2		4	1	2		1		20		2	5	7	2	1	2	1

Slides in each field class	Sandstone content																		Cell residue content					Mamillate excrement content					
Field Class 2	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**100**	**0**	**5**	**10**	**15**	**20**	**0**	**5**	**10**	**15**	**20**	**25**
1/56A(U) [21]		4	1	3	2	2		3		2		2		1			1		9	12				4	1	5	6	2	3
1/56A(LL) [5]			2								1	1					1		4	1				4	1				
1/56B [23]	1	1			1		1	1	2	4	2	1	1	1	2	4	1	1	18	5				9	8	6			
1/56C(U) [11]	7	4																		2	3	4	2	3	5	3			
1/56C(L) [9]		1				1	1	1		2	1	1		1						9				4	3	1		1	
1/56D(U) [10]		3	2	1	1			1	1		1								3	7				3	7				
1/56D(L) [10]	8	2																	1	9				4	4	2			
1/56E [21]	3	5	2			3	3	1		1	1									21				1	1	10	4	3	2

Slides in each field class	Sandstone content																		Cell residue content				Mamillate excrement content				
Field Class 3	0	5	10	15	20	25	30	35	40	45	50	60	65	70	75	80	95	100	0	5	10	15	0	5	10	15	20
11/36A [21]	3	14	2	2																14	7		12	4	5		
11/36B [22]	1		3	4	1	2	3	1	2	1	1						2	1	2	19	1		10	10	2		
11/36C [19]		4	3	1	1	1		1	2	1			1	2	1			1	14	5			11	7	1		
5/52A [18]	5	7	3	1		1	1												1	15	2		3	7	6	2	
5/52B [18]		11	3			1	1		1			1							1	17			3	5	6	3	1
5/52C [24]	6	14	2				1	1												13	10	1	8	11	4	1	
5/52D [21]	3	11	4				1	1								1				20	1		4	15	2		

Slides in each field class	Sandstone content														Cell residue content				Mamillate excrement content		
Field Class 5	0	5	10	15	20	40	45	50	55	60	65	75	85	100	0	5	10	15	0	5	10
26/30A [20]	1	10	3			1				1	2		1	1	1	6	8	5	6	12	2
26/30BB [15]		3	3		2	1	1	1	1	1		2			15				12	3	

Slides in each field class	Sandstone content																	Cell residue content			Mamillate excrement content					
Field Class 7	0	5	10	15	20	25	30	35	40	45	50	55	60	75	80	90	100	0	5	10	0	5	10	15	20	25
22A [17]	5	8						2	1				1						17		6	6	4	1		
22B [18]			1		3		4	1	1	3	2		1	1			1	3	15		1	6	4	3	2	2
22C [18]						3	2	2	2	4	1	1	3					1	17			5	10	2	1	
30(1)A [18]	2	11	2	1		1	1												17	1	8	10				
30(1)B [20]	1	5	1	1	1	3	1	1			1			1	1	2	1	7	13		8	7	2	3		

Appendix 8 - Level 2 data grouped by field class showing distribution of content recordings for the gridsquares from each slide representing each field class, Badentarbat.

Note: The number of gridsquares from each slide grouped in each field class is given in square brackets after the slide identification number. Only the micromorphological parameters which showed a statistically significant difference (95% C.I.) between two or more field classes are shown.

Slides in each field class	Quartz content													Sandstone content		Cell residue content						Mamillate excrement content			Spheroidal excrement content	
Field Class 0	**5**	**10**	**25**	**30**	**40**	**50**	**55**	**60**	**65**	**70**	**80**	**85**	**90**	**0**	**5**	**0**	**5**	**10**	**15**	**20**	**30**	**0**	**5**	**10**	**0**	**5**
49A [18]	1	1	3	6	1	2	3			1				7	11		3	2	1	7	5	15	2	1	18	
49B(U) [9]					2	2	2	1	1	1				3	6		9					9			9	
49B(L) [9]	9													9			9					7	2		9	
49C(U) [7]											6	1		4	3		7					6	1		7	
49C(L) [13]										1	1	7	4	9	4	7	6					4		9	12	1

Slides in each field class	Quartz content										Sandstone content											
Field Class 1	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**40**	**45**	**50**	**85**	**100**
36A [18]		3	14	1							14	4										
36B [18]		3	15								17	1										
36C [18]		16	2								17	1										
36D [18]		18									18											
36E [18]		18									18											
44A [18]				2	1	3	6	5		1		5	2	5	3	1		1	1			
44B [18]				2	2	1	7	5	1			4	1	3	2	3	2		1	2		
44C [18]	1	2	3	5	2	2	2	1				4		1	1	3		3	1	3	1	1

Slides in each field class	Cell residue content						Sandstone content						Spheroidal excrement content		
Field Class 1	**0**	**5**	**10**	**15**	**20**	**30**	**0**	**5**	**10**	**15**	**20**	**25**	**0**	**5**	**10**
36A [18]			2	12	4					3	12	3	4	13	1
36B [18]	1		17				1	3	6	5	3		4	13	1
36C [18]		1	15	2			2	9	5	2			11	6	1
36D [18]		9	8				12	6					17	1	
36E [18]		10	4		2	2	17	1					18		
44A [18]		18					18						17	1	
44B [18]		18					18						18		
44C [18]	17	1					18						18		

Slides in each field class	Quartz content								Sandstone content								Cell residue content		Mamillate excrement content			Spheroidal excrement content
Field Class 2	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**0**	**5**	**10**	**15**	**20**	**30**	**40**	**60**	**5**	**10**	**0**	**5**	**10**	**0**
54A [18]	2		2	5	5	4			10	4		1	1	1	1		6	12	17	1		18
54B [18]					2	9	5	2	2	12	2		1			1	13	5	11	5	2	18
54C [18]			1	1	2	3	8	3	1	11	4	1	1				18		16	1	1	18
54D [18]		1		1	1	4	8	3	1	14	1	1		1			18		9	8	1	18

Slides in each field class	Quartz content												Sandstone content								Cell residue content		Mamillate excrement content				Spheroidal excrement content	
Field Class 3	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**5**	**10**	**0**	**5**	**10**	**15**	**0**	**5**
46A [18]	2	2	1	2		6	5						4	10	2	2					18		9	7	1	1	18	
46B [18]		1	1		2	5	9						1	12	5						18		15	3			18	
46C(U) [11]					3	2	4	2						11							7	4	10	1			11	
46C(L) [9]				1				1	3	1	1	2	1		3	3		1		1	9		8	1			9	
46D(U) [11]					1		1	5	2	2				3	3	2	1		1		9	2	11				11	
46D(L) [7]							1	2	3	1				6	1						7		7				7	
46E(UL) [4]					1	1		1			1			2	2						4		4				4	
46E(L) [17]			5	9	3								13	4							7	10	12	5			16	1

Slides in each field class	Quartz content							Sandstone content						Cell residue content		Mamillate excrement content	Spheroidal excrement content
Field Class 5	**0**	**15**	**20**	**25**	**30**	**35**	**40**	**0**	**5**	**10**	**15**	**35**	**50**	**0**	**5**	**0**	**0**
42A [18]					8	10			11	3	3		11		18	18	18
42B [18]	1	1	1	2	2	7	4	1	10	6		1		2	16	18	18
42C [18]					1	6	11		13	5				3	15	18	18